Effect of P, Zn and Cu Fertilization on Crops on a Calcareous Chernozem Soil

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Both the deficiency and excess of P, Zn and Cu elements are common in the soils of Hungary. Zn deficiency occurs on calcareous soils well fertilized with P under maize, while Cu deficiency is often detected in poor sandy soils and in organic soils. Zn and Cu excess can be found in city soils, in soils near highways and industrial areas (CSATHÓ, 1994, 1994a; LEHOCZKY et al., 1998; NÉMETH et al., 1993).

In this study the effect of P supply on yield and P/Zn ratios of crops will be shown in a long-term field experiment, presenting the phenomena of P-induced Zn deficiency on a calcareous chernozem. In an other field trial, the effect of Cu and Zn fertilization is studied on the same soil and on different crops.

Material and Methods

The experimental site (Research Station, Nagyhörcsök) is located in the Danube Valley on a calcareous loamy chernozem formed on loess, at a height of 140 m above sea level. The climate is continental, with mean annual temperature of 11 °C and 576 mm average annual precipitation. The main characteristics of the plough layer are: clay: 20–25%, silt: 50–55%, sand: 15–20%, humus: 3%, $CaCO_3$: 5%, total C: 2–2.3%, total N: 0.2%, pH(H_2O): 7.5–8, pH(KCl): 7–7.8, CEC: 30 mg/100 g soil. The mobile nutrient contents in soil are: AL (ammonium lactate-soluble)-P_2O_5: 60–80 mg/kg, AL-K_2O: 140–160 mg/kg, KCl-soluble Mg: 150-180 mg/kg, KCl+EDTA Mn: 80–150 mg/kg, Cu: 2–3 mg/kg, Zn: 1–2 mg/kg. The experimental soil is well supplied with Ca, Mg and Mn; moderately supplied with N and K; poorly supplied with P and Zn. The water table is found at a depth of 13–15 m and has no effect on soil processes or fertilizer efficiency.

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A field experiment was set up in 1973 and has been continued up till now. Yearly or every two years different crops were studied. Four levels of N, P and K in a full combination (4x4x4=64 treatments) with two replications resulted altogether 128 plots (36 m² each). The N fertilizer was given in doses of 0, 100, 200, 300 kg N/ha/year, split into two halves for autumn and spring application. The P and K fertilizers were applied and ploughed in to build up the desired PK levels of the plots in doses of 0, 500, 1000, 1500 kg/ha P_2O_5 and K_2O. The form of fertilizers was: Ca-ammonium-nitrate (25 % N), superphosphate (18 % P_2O_5) and KCl (40 % K_2O). Winter wheat was grown in the 1st and 2nd, while maize in the 2nd and 4th years with commonly used agrotechnics. The procedure, material and methods of the experiments have been described in previous papers (KÁDÁR et al., 1991; BÉNDEK & KÁDÁR, 1988).

Another field trial was launched in 1991 on the same soil. The 52 treatments were arranged in a split-plot design with 2 replications. The 13 microelements were added on 4 loading levels (0, 90, 270 and 810 kg/ha) as soluble salts to plots (20 m² each) once at initiation and were mixed into the plough layer. The elements applied were, among others, Cu in the form of $CuSO_4$ and Zn as $ZnSO_4$. To ensure a sufficient macronutrient supply in the whole experiment, 100–100–100 kg N, P_2O_5 and K_2O have been given per ha per year. Maize was grown in the first experimental year with commonly used agrotechnics, followed by carrot, potato and green peas. The material and methods and the main conclusions of the trial were summarized earlier (KÁDÁR et al., 1994).

Results and Discussion

Table 1 shows the effect of P supply on the AL-P_2O_5 content in the plough layer of the soil in 1976 and on the grain yield and P/Zn ratios in winter wheat in 1975 as well as in maize in 1976 and 1977. The highest wheat yields were reached at about 120–150 mg/kg AL-P_2O_5, while maize grain yield dropped over this concentration, presenting a yield loss of 1–1.5 t/ha/year. On these P over-fertilized plots, 6-leaf stage maize shoot and the harvested straw had P/Zn ratios higher than 200, while that of grain was 150–200.

Table 2 presents the phenomena of P-induced Zn deficiency as an effect of P supply/oversupply on the Zn content of crops. The Zn content in young shoots of winter wheat and maize decreased by about 30% on the elevated P levels as compared to the control, while there was a 35–40% decrease in maize grain and 50–70% in the harvested straw. The induced Zn deficiency seemed to increase with time. The higher maize yield resulted in lower Zn content in 1977 (mainly in the straw). As the Zn supply of the soil is limited, the Zn pool of straw was mined more deeply during the grain filling processes and the Zn migrated to the grain.

Table 1
Effect of P supply on yield and the P/Zn ratio of crops
(Calcareous chernozem, Nagyhörcsök)

Plant/ Plant parts	AL-soluble P_2O_5, mg/kg in soil, 1976				$LSD_{5\%}$	Mean
	65	123	90	290	22	167
Grain yield, t/ha						
W. wheat (1975)	4.0	5.1	5.3	5.4	0.2	5.0
Maize (1976)	4.7	5.6	4.9	4.2	0.3	4.9
Maize (1977)	9.0	9.2	8.8	8.3	0.4	8.8
P/Zn ratio, winter wheat (1975)						
Shoot[1]	95	172	186	210	44	165
Grain[2]	93	184	200	212	40	172
Straw[2]	33	78	114	150	28	94
P/Zn ratio, maize (1976)						
Shoot[1]	103	224	232	286	48	211
Grain[2]	85	183	191	210	36	167
Straw[2]	22	114	200	330	34	166
P/Zn ratio, maize (1977)						
Shoot[1]	144	248	284	328	40	251
Grain[2]	78	152	180	200	28	152
Straw[2]	46	200	300	367	30	228

P_2O_5 fertilization in 1973: 0, 500, 1000, 1500 kg/ha/10 years
[1]: wheat: end of tillering, maize: 6-leaf stage; [2]: harvest time

Table 2
Effect of P supply on the Zn content of crops, mg/kg air dry matter
(Calcareous chernozem, Nagyhörcsök)

Plant/ Plant parts	AL-soluble P_2O_5, mg/kg in soil, 1976				$LSD_{5\%}$	Mean
	65	123	90	290	22	167
Winter wheat in 1975 (5 t/ha grain yield)						
Shoot[1]	29	22	22	21	2	24
Grain[2]	30	19	18	17	2	21
Straw[2]	12	9	7	6	2	9
Maize in 1976 (5 t/ha grain yield)						
Shoot[1]	30	21	22	21	3	24
Grain[2]	34	23	23	21	3	25
Straw[2]	36	14	13	10	4	19
Maize in 1977 (9 t/ha grain yield)						
Shoot[1]	27	21	19	18	2	2
Grain[2]	32	21	20	20	2	23
Straw[2]	13	5	5	6	2	7

[1]: wheat: end of tillering, maize: 6-leaf stage; [2]: harvest time

The Cu uptake of crops was stimulated by both N and P fertilization on this soil well supplied with Cu. As a function of NxP fertilization, in the case of maize in 1977 a Cu content increase of 30% was found in leaves before flowering, 260% in grain, and 400% in straw, as compared to the control. According to literature, the optimal plant nutrient level in leaf below the ear at tasseling/before flowering is about 5–20 mg/kg dry matter (BERGMANN & NEUBERT, 1976). The Cu status of maize might be lifted markedly with NxP fertilization when the soil Cu supply is not limited (Table 3).

Table 3
Effect of NxP fertilization on the Cu content of maize, mg/kg air dry matter
(Calcareous chernozem, Nagyhörcsök, 1977)

N levels	P_0	P_1	P_2	P_3	$LSD_{5\%}$	Mean
			Leaves before flowering (8 July)			
N_0	13	15	16	18		15
N_1	15	17	16	17	2	16
N_2	15	14	17	17		16
N_3	16	17	17	17		17
Mean	15	16	16	17	1	16
			Straw at harvest time (21 October)			
N_0	3	4	3	5		4
N_1	6	7	8	9	4	7
N_2	7	9	11	9		9
N_3	9	11	11	12		11
Mean	6	8	8	9	2	8
			Grain at harvest time (21 October)			
N_0	2.8	4.1	5.5	4.8		4.3
N_1	5.9	5.9	7.0	7.6	1.2	6.6
N_2	6.6	7.6	6.6	8.3		7.3
N_3	7.6	5.8	5.8	7.3		6.6
Mean	5.8	5.9	6.2	7.0	0.6	6.2

Treatments:
N_0 = 0, N_1 = 100, N_2 = 200, N_3 = 300 kg N/ha/year
P_0 = 0, P_1 = 500, P_2 = 1000, P_3 = 1500 kg P_2O_5/ha/10 years

With the application of 0, 90, 270 and 810 kg/ha Cu in the form of $CuSO_4$ and Zn as $ZnSO_4$ in spring 1991, the "total" Cu and Zn contents of soil increased by one order of magnitude, while "mobile" Cu and Zn contents rose up by two orders of magnitude in the plough layer in 1994. The "total" content represents the cc. HNO_3+H_2O_2 extraction, while the "mobile" content shows the NH_4-acetat+EDTA extraction according to LAKANEN and ERVIÖ (1971). The data of soil analysis are presented in Table 4.

Table 4
Effect of Cu and Zn loads on the soil's Cu and Zn content in the plough layer
(Calcareous chernozem, Nagyhörcsök)

Fraction determined	Cu and Zn loads, kg/ha in 1991				$LSD_{5\%}$	Mean
	0	90	270	810		
Cu found in soil in 1994, mg/kg						
Total	17	43	85	230	14	94
Mobile	4	23	65	192	12	71
Zn found in soil in 1994, mg/kg						
Total	44	71	118	274	19	127
Mobile	1	19	44	147	11	53

Total: cc. HNO_3+H_2O_2 extraction; Mobile: NH_4 acetate+EDTA extraction

Table 5
Effect of Zn loads on the Zn content of crops, mg/kg air dry matter
(Calcareous chernozem, Nagyhörcsök)

Date of sampling,	plant part	Loads in spring 1991, kg/ha				$LSD_{5\%}$	Mean
		0	90	270	810		
1991: Experiment with maize (Zea mays L.)							
8 July	Root[1]	24	36	70	131	13	65
8 July	Shoot[1]	19	51	76	126	23	68
8 Aug	Leaves[3]	18	35	43	65	10	40
25 Nov	Straw[5]	7	31	47	54	23	35
25 Nov	Grain[5]	8	25	28	41	9	26
1992: Experiment with carrot (Daucus carota L.)							
29 June	Top[2]	29	49	88	150	20	79
7 Oct	Top[5]	15	27	30	83	15	39
7 Oct	Root[5]	18	20	23	34	5	24
1993: Experiment with potato (Solanum tuberosum L.)							
14 June	Leaves[3]	14	22	28	31	10	24
12 July	Leaves[4]	9	16	19	28	5	18
7 Sept	Tubes[5]	15	20	20	26	5	20
1994: Experiment with green peas (Pisum sativum L.)							
26 May	Top[3]	20	36	42	56	9	39
14 June	Straw[5]	5	19	35	57	5	29
14 June	Pods[5]	6	21	43	41	14	28
14 June	Grain[5]	21	45	49	59	7	44
18 July	Straw[6]	5	13	22	46	4	22
18 July	Grain[6]	19	46	51	55	5	43

[1] = 6-leaf stage; [2] = before rootbuilding; [3] = before flowering; [4] = after flowering; [5] = at harvest time; [6] = dry peas at harvest time

No significant changes were found in the harvested yield neither as a function of Cu loads nor Zn loads in this soil. In Table 5 the effect of Zn loads is shown on the Zn content of different crops and plant parts. Young vegetative organs like root, shoot, leaves showed a higher Zn accumulation than the harvestable yield. The harvested average yields were as follows: 8–9 t/ha maize grain in 1991, 16–18 t/ha carrot root in 1992, 12–14 t/ha potato tuber in 1993, 2.5–3.0 t/ha peas grain in 1994. To obtain a harvested maize straw and grain yield in 1991 with a Zn content of about 25–30 mg/kg dry matter or more, it was necessary to apply 90–270 kg/ha Zn as $ZnSO_4$ in this soil well supplied with P.

The effect of Cu loads on crops' Cu content is presented in Table 6. According to these data, Cu is not mobile in the soil–plant system. The Cu content of the harvested crop parts cannot be markedly raised by using $CuSO_4$ fertilizer, even with rates as high as 270 or 810 kg/ha. A dramatic increase in Cu content was detected only in young maize root and potato leaves on this soil. When

Table 6

Effect of Cu loads on the Cu content of crops, mg/kg air dry matter
(Calcareous chernozem, Nagyhörcsök)

Sampling date, plant parts		Loading in spring 1991, kg/ha				$LSD_{5\%}$	Mean
		0	90	270	810		
1991: Experiment with maize (Zea mays L.)							
8 July	Root[1]	8.9	13.1	25.5	42.5	9.2	22.5
8 July	Shoot[1]	17.8	20.2	20.8	21.8	4.0	20.2
8 Aug	Leaves[3]	11.6	13.6	13.2	13.0	1.4	12.8
25 Nov	Straw[5]	8.3	10.7	11.3	10.8	2.0	10.0
25 Nov	Grain[5]	1.5	1.4	1.5	1.8	0.5	1.5
1992: Experiment with carrot (Daucus carota L.)							
29 June	Top[2]	7.5	10.2	8.5	10.6	5.2	9.2
7 Oct	Top[5]	5.1	7.1	8.0	17.4	2.0	9.4
7 Oct	Root[5]	7.9	10.4	10.4	12.3	3.7	10.2
1993: Experiment with potato (Solanum tuberosum L.)							
14 June	Leaves[3]	8.0	15.0	19.0	23.0	2.9	16.2
12 July	Leaves[4]	6.7	12.9	17.5	19.1	3.0	14.0
7 Sept	Tubes[5]	5.0	6.6	7.3	7.7	1.3	6.6
1994: Experiment with green peas (Pisum sativum L.)							
26 May	Top[3]	6.0	8.3	8.7	9.0	2.0	8.0
14 June	Straw[5]	4.2	6.2	6.8	6.8	1.0	6.0
14 June	Pods[5]	4.9	6.9	6.8	6.6	1.7	6.3
14 June	Grain[5]	6.7	9.1	8.1	9.0	1.2	8.2
18 July	Straw[6]	3.4	5.5	7.8	7.3	1.0	6.0
18 July	Grain[6]	7.6	9.3	10.1	9.5	1.1	9.1

[1] = 6-leaf stage; [2] = before rootbuilding; [3] = before flowering; [4] = after flowering; [5] = at harvest time; [6] = dry peas at harvest time

maize straw is also used for animal feeding and a higher Cu content is desirable, N and P fertilization might effectively enhance the concentration of this important essential element in animal diet.

Summary

Both deficiency and excess of P, Zn and Cu are common in soils and crops of Hungary. The excess and deficiency of P occurring in agricultural soils and crops is a consequence of previous fertilization practice. Zn deficiency occurs mainly on calcareous soils well fertilized with P under maize, while Cu deficiency is often detected on poor sandy soils and on organic soils under other crops. Zn and Cu excess has been measured in city soils, in soils near highways and industrial areas.

In the present paper the effect of P supply is shown on yield and P/Zn ratios of crops, presenting the phenomena of the P-induced Zn deficiency on a calcareous loamy chernozem soil. In an other long-term field trial on the same soil, the effect of Cu and Zn loads was studied on soil and crop. The main conclusions drawn from these long-term field experiments are as follows:

1. An excess of available P in the plough layer of this soil might be detected by the ammonium lactate (AL) method when the soil analysis shows concentrations higher than 150–200 mg/kg P_2O_5. The P/Zn ratios of 6-leaf stage shoots and harvested straw of maize grown on these plots might be higher than 200, while that of grain 150–200.

2. In the frame of a fertilization program, P-induced Zn deficiency can be counterbalanced effectively on such calcareous chernozem soils with the application of P and Zn fertilizers in a ratio around 10:1.

3. The Cu content of crops could not be markedly raised by using $CuSO_4$ fertilizer, even with rates as high as 270 or 810 kg/ha Cu. However, as an effect of increased NxP fertilization, the Cu content of maize grain doubled, or that of maize straw was 4-times higher. This is an important tool for the Cu enrichment of animal diet, when maize straw is also used for animal feeding.

4. The soil and plant analysis data are proper means of controlling soil fertility and crop nutritional status when the soil and plant data are previously calibrated in long-term field experiments.

Key words: phosphorus, zinc, copper, fertilization, chernozem soil

References

BÉNDEK, GY. & KÁDÁR, I., 1988. Influence of soil nutrient levels on harvest yield and malting quality of brewing barley. J. Inst. Brew. **96.** 375–378.

BERGMANN, W. & NEUBERT, P., 1976. Pflanzendiagnose und Pflanzenanalyse. VEB Gustav Fischer Verlag. Jena.

CSATHÓ, P., 1994. Heavy metals and other toxic elements in soil–plant system. (In Hungarian) Agrokémia és Talajtan. **43.** 371–398.

CSATHÓ, P., 1994a. The heavy-metal contamination of the environment and agricultural production. Thematic literature review. (In Hungarian) RISSAC. Budapest.

KÁDÁR, I, CSATHÓ, P. & SARKADI, J., 1991. Potassium fertilization in Hungary: Responses in maize and in other crops. Acta Agronomica Hung. **40.** 295–317.

KÁDÁR, I., KONCZ, J. & FEKETE, S., 1994. Effect of some trace elements on soil, crop and animals. In: Proc. 6th Int. Trace Element Symp. (Ed: PAIS, I.) 1–8. Budapest.

LAKANEN, E. & ERVIÖ, R., 1971. A comparison of eight extractants for the determination of plant available micronutrients in soil. Acta Agr. Fenn. **123.** 223–232.

LEHOCZKY, É. et al., 1998. Effect of liming on the heavy metal uptake of lettuce. Agrokémia és Talajtan. **47.** 229–234.

NÉMETH, T. et al., 1993. Fate and plant uptake of some heavy metals in soil–plant systems studied on soil monoliths. Agrokémia és Talajtan. **42.** 195–206.