Effect of P and Zn fertilisation on biomass yield and its uptake by maize lines (*Zea mays* L.)

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ABSTRACT

Three maize inbred lines (Os86-39, Os89-35 and Os87-24) were grown in pots with Eutric Cambisol using 9 fertilisation variants (control 10 kg/ha Zn – on soil surface; 5 kg/ha – foliar application; 61 kg/ha P; 61 kg/ha P and 10 kg/ha Zn – on soil surface; 61 kg/ha P and 5 kg/ha Zn – foliar application; 183 kg/ha P; 183 kg/ha P and 10 kg/ha Zn – on soil surface; 183 kg/ha P and 5 kg/ha Zn – foliar application). The effects of phosphorus and zinc fertilisation on the dry matter yield, plant height, stalk diameter as well as phosphorus and zinc concentrations in ear-leaves were investigated. Significant differences were found between the lines in all parameters investigated except for phosphorus concentration. Line Os87-24 was characterised by the best results in the total biomass production. Zinc fertilisation decreased while phosphorus fertilisation increased total plant dry matter mass. Phosphorus fertilisation increased its concentration in the ear-leaves. Zinc fertilisation, especially foliar, resulted in Zn concentration increase in the ear-leaf of the lines investigated.

Keywords: maize inbred lines; fertilisation; phosphorus; zinc; biomass yield; plant Zn; plant P

Mineral fertilisation is one of the most important yield factors. Genotypes of the same variety are characterised by various abilities to uptake the existing soil nutrients and to utilise the essential elements added by fertilisers under identical agro ecological conditions. Thus, arable crops yields and their quality can be improved by adequate soil and crop management practices or selection directed towards obtaining genotypes resistant to unfavorable production conditions. Approximately 60% of the world arable land is considered to be difficult for the plant production due to mineral stress caused by the deficiency, unavailability, or toxicity of some essential nutritive elements (Foy 1983). Of the microelements, Zn is thought to be the most widespread (Graham et al. 1992, Yilmaz et al. 1995, Cakmak et al. 1999). A large number of the former investigations (Mengel and Kirkby 1982) showed that maize together with bean, soybean, flax, hop, and vine is especially sensitive to zinc deficit. Zinc uptake can depend on different factors, for example the application of potassium humate. Pavliková et al. (1997) confirmed the positive effect of humate on the decrease of Zn content in barley and oats but in maize and poppy Zn content increased. Moreover, maize genotypes (inbred lines, hybrids) differ in their zinc requirements as well as in the uptake and translocation ability (Shukla and Ray 1976). Also, the maize inbred lines property of high or low zinc concentrations could be inherited in hybrids.

Total soil zinc content is usually present within the range of 10–300 mg/kg in various forms (Mengel and Kirkby 1982). Coks and Kamprath (1972) considered 1.4–3.0 mg/kg available Zn a critical soil limit. Optimum zinc concentration in the ear-leaves of maize amounts to 10–20 mg/kg in the silking stage (Bergmann 1992).

The most frequent causes affecting soil zinc availability are high soil pH values (Shuman 1980), carbonate content (Kamprath and Foy 1971, Karmian 1995), and organic matter, further soil texture and sorption capacity as well as the mainly studied zinc interraction with other elements such as iron, copper and manganese (Marschner 1986), and especially phosphorus (Loneragan et al. 1979, Trier and Bergmann 1974, Sankhyan and Sharma 1997, Deusoza et al. 1998). Phosphorus-induced zinc insufficiency occurs due to an increased phosphorus fertilisation on soils with high pH moderately supplied with zinc (Shuman 1980).

This investigation aimed to determine genetic differences between the three maize inbred lines in the plant height, stalk diameter, and dry matter mass of the overground plant parts, as well as phosphorus and zinc concentrations in the ear-leaves resulting from different fertilisation treatments with phosphorus and zinc.

MATERIAL AND METHODS

The investigation was conducted at the Faculty of Agriculture in Osijek (Croatia). The experiment was set up in a protection net where pots with sown maize were located according to three factorial plans (split-split-plot) in five replicates. Plastic pots of the capacity of 15 litres were filled with 35 kg soil whose chemical properties are shown in Table 1. The soil was taken from localities where zinc deficiency symptoms were observed in corn production during several years. The soil was mixed with sand in ratio 1:1. Five seeds were sown in each pot at 7 cm depth. During vegetation, the pots with corn plants were

Table 1. Soil chemical characteristics

pH (KCl)	7.00
Humus (%)	4.15
AL*-P (mg/100 g)	15.10
AL*-K (mg/100 g)	24.82
Zn-EDTA (ppm)	7.64

AL* – amonium-lactate method

exposed to atmospheric effects (rain, sun light, wind, etc.); soil moisture was maintained at 60% of field water capacity by irrigation (deionised water).

The elements of the experiment were as follows:

A. Three inbred lines of maize of the Agricultural institute in Osijek: 1. Line Os86-39, 2. Line Os89-35, 3. Line Os87-24.

B. Phosphorus and zinc fertilisation: 1. P_0Zn_0 – control, 2. P_0Zn_{10} – on soil surface, 3. P_0Zn_5 – foliar application, 4. $P_{61}Zn_0$, 5. $P_{61}Zn_{10}$ – on soil surface, 6. $P_{61}Zn_5$ – foliar application, 7. $P_{183}Zn_0$, 8. $P_{183}Zn_{10}$ – on soil surface, 9. $P_{183}Zn_5$ – foliar application.

Nitrogen was applied in the rate of 180 kg N/ha in the form of NH_4NO_3 (2.456 g NH_4NO_3 per pot or 0.884 g N per pot), potassium in the rate of 133 kg K/ha in the form of K_2SO_4 and KH_2PO_4 (P_1 = 0.611 g K_2SO_4 or 0.275 g K per pot + 1.317 g KH_2PO_4 or 0.653 g K per pot; P_0 and P_2 = 1.455 g K_2SO_4 or 0.653 g K per pot), phosphorus in doses of 140 and 420 kg P_2O_5/ha with a combination of KH_2PO_4 and NaH_2PO_4 (P_1 = 1.317 g KH_2PO_4 per pot or 0.299 g P per pot; P_2 = 4.529 g NaH_2PO_4 per pot or 0.899 g P per pot) whereas zinc in the rate of 10 kg Zn/ha on soil surface as $ZnSO_4.7\,H_2O$ (0.216 g $ZnSO_4.7\,H_2O$ or 0.136 g Zn per pot) and zinc foliar application in a dose of 5 kg Zn/ha as 0.5% solution of $ZnSO_4.7\,H_2O$ (0.108 g $ZnSO_4.7\,H_2O$ or 0.068 g Zn per pot).

Soil surface fertilisation was carried out in the 3–4 leaves phase and foliar application in 11–12 leaves phase. Plants isolation was done in 4–5 leaves phase so that only one plant was left in each pot. The plants were removed in the tasselling phase. The concentrations of P and Zn were determined in the ear-leaves (indicate supplied nutrients – according to Bergmann 1992). Wet-combustion procedure with sulphuric acid (Se was added as catalyst) was carried out according to Holz (1971). The content of Zn were determined in the diluted filtrate by atomic absorption spectrometer, and that of P by the vanadate molybdate ammonium method (Vukadinović and Bertić 1989).

Statistical data processing of the results obtained was performed by variance analysis according to split-split-plot method. The results were processed by modern statistical methods (ANOVA) using the computer program by StatSoft Inc. (2001) STATISTICA (data analysis software system), version 6.

Table 2. Influence of fertilisation treatments on plant height (cm), stalk diameter (cm) and total plant dry matter biomass (g/plant) – average values by three inbred lines

Fertilisation treatment	Plant height	Plant stalk diameter	Total plant biomass
	cm		g/plant
1. P_0Zn_0	114.2	1.78	36.33
2. P_0Zn_{10} -S	101.7	1.87	31.95
3. P_0Zn_5 -F	105.6	1.77	31.76
4. P_1Zn_0	115.1	1.84	37.49
5. P_1Zn_{10} -S	117.5	1.97	38.76
6. P_1Zn_5 -F	116.5	1.85	35.76
7. P_2Zn_0	124.5	1.95	40.03
8. P_2Zn_{10} -S	124.0	2.03	39.46
9. P_2Zn_5 -F	116.5	1.96	37.09
Average	115.13	1.88	36.51
LSD 0.05	7.348	0.048	3.025
LSD 0.01	9.672	0.063	3.982

S – on soil surface, F – foliar application

RESULTS AND DISCUSSION

Genetic specifity of maize mineral nutrition has been well-known for many years (Sayre 1947, Baker et al. 1967) but is still actual (Bukvić et al. 2000, Kovačević et al. 2001). Our investigation also showed differences between inbred lines in the element uptake ability (Tables 3 and 4) and biomass production (Table 2) on various phosphorus and zinc fertilisation treatments. Differences between all lines investigated (Os86-39, Os89-35, Os87-24) in the plants heights (112.96 cm, 91.93 cm, 140.51 cm, respectively), stalk diameters (2.03 cm, 1.57 cm, 2.06 cm, respectively) and total dry matter biomass (38.13 g per plant, 30.54 g per plant, 40.87 g per plant, respectively) were statistically very significant (Table 2). The best results were obtained with line Os87-24, then with Os86-39, while the Os89-35 had the lowest values. The inbred lines Os87-24 and Os86-39 were also tested under the field conditions (Rastija et al. 2002) and turned out to be among the best ones in grain yield. Phosphorus fertilisation treatments increased the plant height, plant stalk diameter, and total dry matter biomass of the lines investigated (Figures 1–3). The same effect of phosphorus fertilisation was observed by Abd Elnaim et al. (1984). On the contrary, zinc fertilisation, especially foliar zinc application, reduced the plant height (Figure 1) and dry matter biomass (Figure 3). Foliar zinc application often leads to opposite results. Josipović et al. (1997) obtained grain yield increase with three and its decrease with two of ten maize inbred lines investigated. Maize grain yields were not increased by a foliar zinc application in the investigations conducted by Kovačević et al. (1993). How-

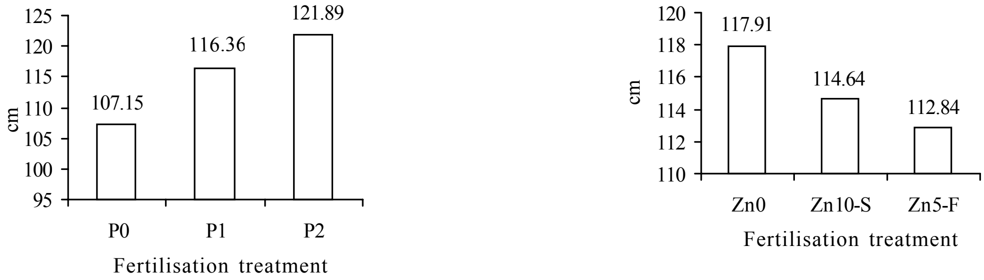

Figure 1. The influence of the phosphorus (P) and zinc (Zn) fertilisation treatment on the plant height (cm)

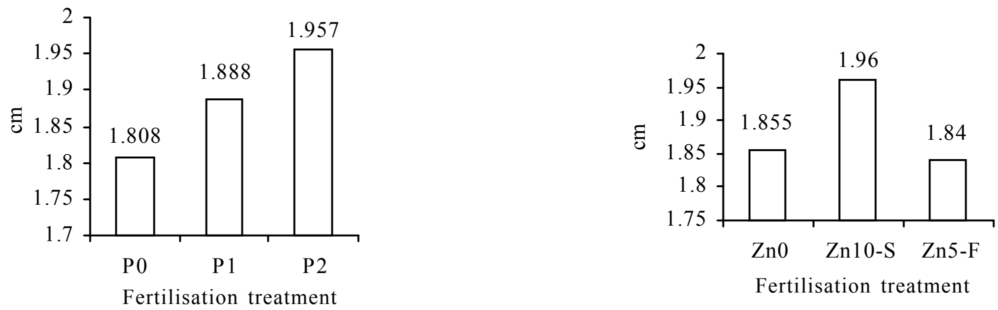

Figure 2. The influence of the phosphorus (P) and zinc (Zn) fertilisation treatment on the plant stalk diameter (cm)

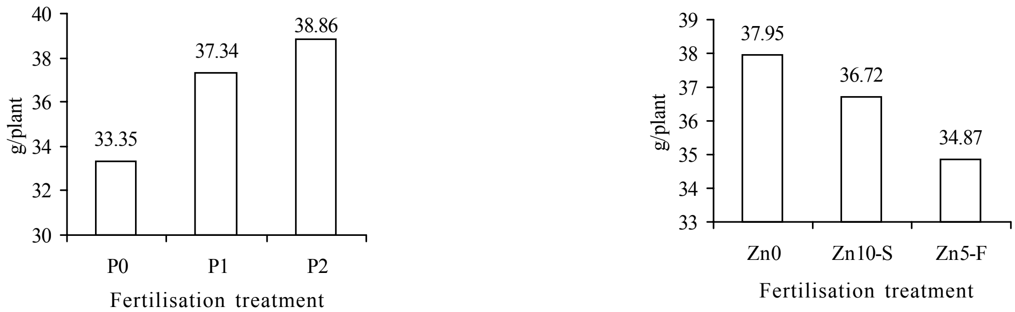

Figure 3. The influence of the phosphorus (P) and zinc (Zn) fertilisation treatment on the total plant dry matter biomass (g/plant)

Figure 4. The influence of the phosphorus (P) and zinc (Zn) fertilisation treatment on the zinc concentration of the ear-leaves (mg/kg)

ever, in the research carried out by Rastija et al. (2002), foliar spraying with 0.75% $ZnSO_4 \cdot 7\,H_2O$ solution resulted in a grain yield increase in all five inbreds investigated.

The results of the present study showed that the different biomass production under identical fertilisation treatment is a consequence of differences in the uptake and translocation abilities of phosphorus and zinc as well as their ratio in the ear-leaf.

It was found that the inbred line Os89-35 had good root zinc uptake and translocation ability (Table 4) because zinc concentration in the ear-leaf on the control treatment (P_0Zn_0) ranged within the optimal values from

Table 3. Phosphorus concentration of the ear-leaves (mg/kg) by inbred lines and fertilisation treatments

Fertilisation treatment	Inbred line (L)			
	OS 86-39	OS 89-35	OS 87-24	Average
1. P_0Zn_0	1925	2215	1930	2023
2. P_0Zn_{10} -S	2030	2220	2010	2087
3. P_0Zn_5 -F	2022	2337	1930	2096
4. P_1Zn_0	2007	1925	1930	1954
5. P_1Zn_{10} -S	2240	1732	2502	2158
6. P_1Zn_5 -F	2125	2217	2022	2121
7. P_2Zn_0	2432	2212	2130	2258
8. P_2Zn_{10} -S	2330	2315	2800	2481
9. P_2Zn_5 -F	2212	2410	2517	2380
Average	2147	2176	2196	2173

S – on soil surface, F – foliar application

LSD	L	P**	Zn	LP	LZn*	PZn	LPZn
0.05	ns	160.15	ns	ns	290.36	ns	ns
0.01	ns	210.81	ns	ns	407.08	ns	ns

Table 4. Zinc concentration of the ear-leaves (mg/kg) by inbred lines and fertilisation treatments

Fertilisation treatment	Inbred line (L)			
	OS 86-39	OS 89-35	OS 87-24	Average
1. P_0Zn_0	15.6	29.1	22.8	22.5
2. P_0Zn_{10} -S	18.8	23.9	23.3	22.0
3. P_0Zn_5 -F	55.2	235.5	33.3	108.0
4. P_1Zn_0	15.9	16.0	18.8	16.9
5. P_1Zn_{10} -S	20.7	163.5	23.2	69.1
6. P_1Zn_5 -F	36.5	239.2	34.6	103.4
7. P_2Zn_0	15.5	17.6	15.4	16.2
8. P_2Zn_{10} -S	15.1	18.1	23.4	18.9
9. P_2Zn_5 -F	34.4	408.0	37.2	159.9
Average	25.3	127.8	25.8	59.6

S – on soil surface, F – foliar application

LSD	L**	P**	Zn**	LP**	LZn**	PZn**	LPZn**
0.05	3.025	2.573	3.324	4.955	6.401	6.401	14.125
0.01	3.982	3.387	4.376	6.946	8.974	8.974	23.426

20 to 70 mg/kg (Bergmann 1992). Many authors consider the concentration of about 15 ppm zinc in the maize ear-leaf as a critical bottom limit (James and Christensen 1975, Carsky and Reid 1990). Therefore, zinc fertilisation, particularly foliar treatment, reduced dry matter biomass of the overground parts of plant. The foliar zinc application (Zn_5-F) at all levels of phosphorus fertilisation considerably increased zinc concentration in the ear-leaf. With this, the P/Zn ratio became much lower compared to optimum one being 65 (Blasl and Mayr 1978), or from 25 to 154, which are limiting values of P/Zn according to Prasad et al. (1971). The consequence of such an unfavourable ratio was a decrease of the total dry matter biomass of the overground parts in comparison to treatments without zinc (Zn_0) and soil zinc application (Zn_{10}-S). On the contrary, the same line responded to phosphorus treatments ($P_{1,2}Zn_0$) by an increase in dry matter biomass as phosphorus fertilisation reduced zinc concentration in the ear-leaf and in this way it increased P/Zn ratio ($P_0 = 76$, $P_1 = 118$, $P_2 = 125$) to optimal values. Consequently, regardless of the sufficient soil zinc content, phosphorus fertilisation inhibited its uptake (Warnock 1970, Takkar et al. 1976). Sankhyan et al. (1997) consider that phosphorus does not have an inhibitory effect on the root zinc uptake but obstructs its plant translocation.

The Os86-39 inbred line appeared to be the worst one regarding zinc uptake which indicates the importance of genetic specifity in zinc acquisition by inbreds (Elbendary et al. 1993). Zinc concentration in the ear-leaf was on a critical bottom limit ($Zn_0 = 15$ mg/kg). Phosphorus fertilisation ($P_{1,2}Zn_0$) negligibly increased phosphorus concentration in the ear-leaf but did not influence the already poor zinc uptake. Therefore, the phosphorus fertilisation treatments increased P/Zn ratio (from $P_0Zn_0 = 121$ to $P_1Zn_0 = 126$ and $P_2Zn_0 = 154$, respectively) whereby on the same treatments an increase of the total dry matter mass was found. Foliar zinc application (Zn_5-F) in combination with all phosphorus doses increased Zn concentration in the ear-leaf but reduced P/Zn ratio as well as dry matter biomass of the overground parts in comparison with others zinc fertilisation variants (Zn_0 and Zn_{10}-S). Surface soil zinc fertilisation (Zn_{10}-S) insignificantly increased its concentration in the leaves. In all phosphorus fertilisation variants, the total dry matter mass was reduced in comparison to the variant free of zinc (Zn_0) but it increased in the combination with phosphorus ($P_{1,2}Zn_{10}$-S). Regardless of the poorer zinc uptake and changes in the P/Zn ratio, the same one was within limiting values (36-155), in all fertilisation variants, so the average dry matter mass production of this line was higher compared to the preceding one. It could be supposed that unfavourable soil pH reaction caused the poor zinc uptake in our investigations (pH in KCl 7.00) as zinc deficiency occurs at pH 6.5–8.0 (Shuman 1980, Jen-Hshuan Chen and Barber 1990).

The line Os87-24 was characterised by the highest overground mass production and the least variability in the P/Zn ratio (57–136). Also, it showed a good zinc uptake ability in the control variant (P_0Zn_0). The highest dry matter mass was obtained on the phosphorus fertilisation treatments in combination with soil zinc application ($P_{1,2}Zn_{10}$-S) with P/Zn 108 and 120, respectively. Phosphorus fertilisation ($P_{1,2}Zn_0$) reduced zinc concentration (Table 4) and slightly increased phosphorus concentration in the ear-leaf (Table 3). At higher soil pH values, (> 6.5) phosphorus is transformed to poorly soluble forms (Ca-phosphates). It insignificantly affected phosphorus concentration but increased P/Zn ratio (from $P_0Zn_0 = 83$ to $P_1Zn_0 = 101$ and $P_2Zn_0 = 136$, respectively). Foliar zinc application (Zn_5-F) increased its concentration in the ear-leaf but to a lesser extent than in other lines tested. However, like in the other two investigated lines, the total overground mass was reduced compared to the treatments without zinc.

The results obtained showed an increase of the total overground biomass in the three maize inbred lines as a result of phosphorus fertilisation. However, under the conditions of an adequate soil zinc supply, foliar zinc treatment caused a reduction of the overground biomass to a larger or smaller extent in all lines investigated due to the increased zinc concentration and the unfavourable P/Zn ratio. So, foliar zinc application in maize growing could be recommended for alkaline soils (Arnon 1976) and soils with less expressive zinc deficiency (Randhawa et al. 1974). The soil surface zinc fertilisation is efficient only with soils having low contents of avaliable zinc. Fecenko and Ložek (1998) concluded that the highest zinc dose (6 kg/ha) resulted in a reduction of maize yields while 1.5 to 3 kg/ha is considered as optimum zinc dose for grain maize under the conditions of Zahorska Lowlands in the dependence on its content in soil. Also, it is necessary to take into consideration the choice of the maize genotypes with regard to their elements-uptake ability under certain agroecological growing conditions.

CONCLUSIONS

The results of the investigation of the effect of various phosphorus and zinc fertilisation variants on the dry matter mass, plant height, stalk diameter as well as P and Zn concentrations in ear-leaf in three inbred lines of maize grown in pots were as follows:

The inbred lines differed in the total dry matter mass, their plant height, stalk diameter, and zinc concentration in the ear-leaf; the highest total dry mass, plant height, and stalk diameter was obtained with line OS 87-24, and the lowest with line OS 89-35.

Phosphorus fertilisation increased the total dry matter mass, plant height and stalk diameter.

Soil surface zinc fertilisation with 10 kg/Zn/ha, especially foliar application with 5 kg Zn/ha in the form of 0.5% of Zn SO_4.7 H_2O solution, reduced the total dry matter mass and stalk diameter.

As for the ear-leaf zinc concentration, the lines responded diversely to various treatments but generally for all of them, foliar zinc application had the highest values.

An outstandingly high zinc concentration in the ear-leaf in line OS 89-35 as obtained in all foliar applications resulted in low P/Zn that brought about a reduced production of the organic matter.

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ABSTRAKT

Vliv hnojení fosforem a zinkem na výnos biomasy kukuřice a odběr P a Zn třemi hybridy

Tři hybridy kukuřice (Os86-39, Os86-35 a Os87-24) byly pěstovány v nádobovém pokuse s kambizemí při devíti variantách hnojení (kontrola; 10 kg/ha Zn na povrch půdy; 5 kg/ha Zn foliárně aplikovaného; 61 kg P/ha; 61 kg P/ha a 10 kg/ha Zn na povrch půdy; 61 kg P/ha a 5 kg/ha Zn foliárně aplikovaného; 183 kg P/ha; 183 kg P/ha a 10 kg/ha Zn na povrch půdy; 183 kg P/ha a 5 kg/ha Zn foliárně aplikovaného). Byl sledován vliv hnojení fosforem a zinkem na výnos sušiny, výšku rostlin, průměr stonku a obsah P a Zn v listenech palic. Byly zjištěny statisticky významné rozdíly mezi jednotlivými hybridy u všech ověřovaných parametrů s výjimkou obsahu fosforu. Hybrid Os87-24 prokázal nejlepší výsledky v tvorbě biomasy. Hnojení zinkem snížilo a hnojení fosforem zvýšilo tvorbu biomasy. Aplikace fosforu vedla k růstu jeho obsahu v listech. Hnojení zinkem, zejména foliární, také zvyšovalo obsah Zn v listenech palic u všech sledovaných hybridů.

Klíčová slova: hybridy kukuřice; hnojení; fosfor; zinek; výnos biomasy; rostlinný Zn; rostlinný P

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