# The role of genotypes on phosphorus, zinc, manganese and iron status and their relations in leaves of maize on hydromorphic soil

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**ABSTRACT**

Hydromorphy is a major soil fertility constraint in Europe and North America causing specific nutritional imbalance in soils and crops. The objectives of this study were to examine the differences among maize hybrids in phosphorus (P), zinc (Zn), manganese (Mn) and iron (Fe) status in leaves, and to investigate the interrelationship among these micronutrients as well as the interrelationship between Zn and P on hydromorphic soil in Eastern Croatia. Twenty maize (*Zea mays* L.) hybrids were grown under field conditions of Eastern Croatia in a period of two years. Considerable differences in mean ear-leaf Zn, Mn and Fe contents at silking stage were found ranging from 16.3 to 30.0 mg/kg for Zn, from 28.5 to 62.2 mg/kg for Mn and from 137 to 222 mg/kg for Fe content. Mean ratios among nutrients were at acceptable levels: 146 (P:Zn), 7.6 (Fe:Zn) and 3.72 (Fe:Mn). Differences among the hybrids ranged from 95.1 to 210.4 (P:Zn), from 5.3 to 10.4 (Fe:Zn) and from 2.4 to 5.79 (Fe:Mn). Maize hybrids which have higher P:Zn is less acceptable for growing on soils which are either rich in P or moderate in available Zn. Highly significant correlation coefficients between years for mineral content (0.696 for Zn, 0.586 for Mn and 0.525 for Fe) indicated high repeatability estimates within genotypes across the seasons and importance of heredity for nutritional status.

**Keywords:** maize hybrids; phosphorus; zinc; manganese; iron; hydromorphic soil

Nutrient storage capacity of soils is governed by its texture, which represents a foremost consideration in soil quality for maize (Olson and Sander 1988). Hydromorphic soils are not widely recommended for high yielding maize production due to not completely controllable holding of nutrients and water causing specific nutritional imbalance in soil and plant (Petošić et al. 2003). However, hydromorphy represents the most frequent soil constraint in Europe and North America (FAO 2000). In conjunction with the soil test data, leaf tissue analysis can be a useful aid in evaluating the mineral nutrient status of the soil-plant system, especially in determining plant micronutrient status.

Certain levels of micronutrients such as zinc (Zn), manganese (Mn) and iron (Fe) are necessary to mediate the numerous biochemical reactions essential for growth and development of the maize plant. Maize is a zinc-intensive plant with a high zinc-demand that very positively responds to zinc dressing under low levels of available zinc in the soil (Bergmann 1988). The importance of Zn for maize growth was stated by James and Christensen (1975), Carsky and Reid (1990), Mengel and Kirkby (2001). Zinc uptake can be inhibited by a high iron and copper content of plants (Bergmann 1992) indicating the importance of interrelationships among nutrient contents in maize.

Warnock (1970) reported about micronutrient uptake and mobility within maize plants in relation to phosphorus-induced zinc deficiency. Dennis (1971) suggested that the ratio P:Zn of 100 and the Fe:Mn ratio of 2 (calculated from original values in mg/kg) at the silking stage can be stated as normal nutrient ratios in maize. P:Zn ratio has major influences on both zinc status and the total zinc content. According to Trier and Bergmann (1974), optimal values for P:Zn ratio in maize is between 200 and 50 and out of this range are indications of latent zinc deficiency (from 201 to 300), acute zinc deficiencies (> 300) and zinc excess (< 25). Blasl and Mayr (1978) reported optimum P:Zn ratio of about 65 and an acceptable range from 15 to 180. Takkar et al. (1976) found on soils with a poor zinc status that P:Zn ratio 100 to 150 in leaves of maize is associated with moderate zinc deficiency. Blasl and Mayr (1978) reported about the importance of Fe:Zn ratio suggesting an optimum of about 5 with limits of 3–15.

Kovačević et al. (1997) tested the ear-leaf nutritional status (mg/kg of Zn, Mn and Fe on dry matter basis) of four genetically diverged inbred

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Table 1. Means of chemical characteristics of the soil (0–30 cm of depth) according to two methods at the start of the experiment with corresponding standard deviations (all in mg/kg of soil)

| Method | P | K | Zn | Mn | Fe |
|---|---|---|---|---|---|
| EUF | 4.4 ± 0.4 | 48.5 ± 2.2 | 0.8 ± 0.1 | 2.8 ± 0.2 | 2.0 ± 0.2 |
| ICP ($NH_4$ acetate-EDTA) | 3.0 ± 0.2 | 4.8 ± 0.3 | 30.0 ± 4.3 | 240.0 ± 9.0 | 211.0 ± 13.0 |

lines of maize as parents and their 12 single-cross hybrids on acidic soil. Generally, under the same environmental conditions considerable differences in Zn, Mn and Fe status were found among the parents and it was reflected on their progeny.

Objectives of this study were to examine differences among maize hybrids in P, Zn, Mn and Fe status in leaves, and to investigate the interrelationship among these micronutrients as well as between Zn and phosphorus on a hydromorphic soil in Eastern Croatia.

## MATERIAL AND METHODS

**Soil characteristics.** An experimental plot is characterized as a pseudogley moderately supplied with P and K. Three soil samples (15 individual sampling in each sample) were taken by auger to 30 cm of depth at the start of the experiment. According to the soil texture, it is powder loam with share of soil fractions as follows: 4.8, 13.1, 62.5 and 19.6%, for large sand (2.0–0.2 mm diameter of soil particles), petty sand (0.2–0.05 mm), powder (0.05–0.002 mm) and clay (< 0.002 mm), respectively. $H_2O$ and KCl methods detected a soil pH of 6.45 and 5.17, repectively. Humus content was in average 1.26%. Available Zn, Mn and Fe status seemed to be mainly adequate for plant needs (Table 1).

**The field experiment.** Twenty maize (*Zea mays* L.) hybrids (as shown in Table 3) were grown under field conditions in four replications (randomised complete block design) in the western part of Brod-Posavina County, Eastern Croatia in 2000 and 2001 growing seasons. Maize genotypes represent current maize breeding material mainly of US Corn-Belt origin differing in FAO maturity groups 100–400. An experimental plot was one 10-m row of 7.0 $m^2$. Maize hybrids were planted at the beginning of May (distance in row 20 cm = theoretical plant density of 71 429 plants/ha) and harvested on the first decade of October.

**Sampling, chemical and statistical analysis.** The ear-leaf at beginning of the silking stage (the second decade of July) was taken for chemical analysis (about 25 leaves in mean sample) from each plot. The total amounts of Zn, Mn and Fe in maize leaves were determined using inductively coupled plasma (ICP) technique after their microwave digestion by concentrated $HNO_3 + H_2O_2$. The mobile fraction of these elements in the soil was also determined by ICP after their extraction by ammonium acetate-EDTA (pH 4.65) solution by Lakanen and Ervio (1971) method. A plant and soil analysis was made by a Jobin-Yvon Ultrace 238 ICP-OES spectrometer in the laboratory of the Research Institute for Soil Science and Agricultural Chemistry (RISSAC) Budapest, Hungary. Soil Zn, Mn and Fe status was additionally determined by the EUF-method (Nemeth 1978). Statistical analysis of the data (analysis of variance and correlations) was made according to Mead et al. (1996).

Table 2. Weather data [rainfall (mm) and mean air-temperature (°C)] for Slavonski Brod (Eastern Croatia) – Slavonski Brod Weather Bureau[1]

| Year | | May | June | July | August | September | Total (mm) | Mean (°C) |
|---|---|---|---|---|---|---|---|---|
| 2000 | mm | 27 | 25 | 87 | 10 | 47 | 196 | |
| | ºC | 17.3 | 21.6 | 21.2 | 23.0 | 16.1 | | 19.8 |
| 2001 | mm | 32 | 188 | 25 | 32 | 224 | 501 | |
| | ºC | 17.9 | 17.8 | 21.9 | 22.2 | 14.5 | | 18.9 |
| Long-term means 1981–1999 | mm | 68 | 85 | 75 | 69 | 71 | 368 | |
| | ºC | 16.3 | 19.4 | 21.5 | 20.8 | 16.6 | | 18.9 |

[1]approximate air-distance of the experimental field from Slavonski Brod toward west is about 25 km

Table 3. Grain yield, nutritional status and ratios of some elements in ear-leaves of 20 maize hybrids tested in two years with corresponding least significant differences (*LSD*), and correlation coefficients between the two years with respective significant levels

| The factor | | Grain yield (t/ha) | The ear-leaf (silking stage) properties on dry matter basis | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | P (%) | Zn (mg/kg) | Mn (mg/kg) | Fe (mg/kg) | ratio | | |
| | | | | | | | P:Zn | Fe:Zn | Fe:Mn |
| **Influences of growing season (the factor A)** | | | | | | | | | |
| A1 | 2000 | 9.07 | 0.320 | 19.4 | 43.3 | 184 | 129.8 | 7.4 | 4.58 |
| A2 | 2001 | 7.70 | 0.306 | 25.6 | 53.3 | 147 | 161.5 | 7.8 | 2.86 |
| *LSD* A 5% | | 0.59 | 0.011 | 1.1 | 2.9 | 19 | 6.6 | n.s. | 0.43 |
| *LSD* A 1% | | 1.08 | n.s. | 2.0 | 5.4 | 35 | 12.2 | | 0.78 |
| **Influences of maize hybrids (the factor B)** | | | | | | | | | |
| B1 | Alpos | 4.06 | 0.465 | 22.3 | 56.3 | 222 | 210.4 | 9.9 | 3.94 |
| B2 | OsSK2-191 | 5.94 | 0.357 | 21.1 | 40.5 | 199 | 170.6 | 9.5 | 4.96 |
| B3 | OsSK333 | 8.37 | 0.286 | 19.7 | 43.0 | 157 | 146.6 | 8.0 | 3.64 |
| B4 | OsSK373 | 9.15 | 0.285 | 20.8 | 61.3 | 158 | 137.8 | 7.6 | 2.58 |
| B5 | OsSK233 | 9.50 | 0.307 | 23.5 | 74.3 | 176 | 137.1 | 7.7 | 2.40 |
| B6 | OsSK351 | 9.60 | 0.303 | 22.4 | 56.4 | 164 | 136.7 | 7.4 | 2.92 |
| B7 | OsSK298 | 10.78 | 0.281 | 28.2 | 62.2 | 161 | 108.6 | 6.1 | 2.64 |
| B8 | OsSK378 | 11.69 | 0.269 | 26.4 | 56.0 | 151 | 95.1 | 5.3 | 2.70 |
| B9 | OsSK321 | 9.91 | 0.288 | 27.1 | 34.5 | 137 | 113.8 | 5.3 | 3.98 |
| B10 | OsSK234 | 8.03 | 0.285 | 24.2 | 42.9 | 173 | 120.6 | 7.1 | 4.02 |
| B11 | OsSK277 | 10.26 | 0.291 | 26.7 | 39.0 | 176 | 111.1 | 6.6 | 4.90 |
| B12 | Tvrtko 303 | 8.53 | 0.288 | 20.2 | 49.3 | 166 | 143.6 | 8.1 | 3.67 |
| B13 | RK1456 | 8.31 | 0.314 | 19.5 | 53.8 | 159 | 162.7 | 8.3 | 2.98 |
| B14 | OsSK395 | 9.07 | 0.314 | 16.3 | 48.1 | 171 | 192.4 | 10.4 | 3.86 |
| B15 | OsSK332 | 8.41 | 0.307 | 21.5 | 42.1 | 155 | 143.7 | 7.2 | 4.59 |
| B16 | OsSK382 | 8.18 | 0.279 | 16.6 | 47.8 | 156 | 174.2 | 9.6 | 3.50 |
| B17 | OsSK247 | 5.86 | 0.327 | 18.4 | 43.9 | 160 | 179.6 | 8.8 | 3.92 |
| B18 | Bc278 | 5.10 | 0.361 | 20.4 | 28.5 | 156 | 183.2 | 7.9 | 5.79 |
| B19 | Clarica | 6.51 | 0.344 | 30.0 | 46.1 | 158 | 115.4 | 5.3 | 3.49 |
| B20 | Podravec 36 | 8.70 | 0.312 | 24.5 | 40.6 | 158 | 130.3 | 6.5 | 4.05 |
| *LSD* B 5% | | 0.74 | 0.026 | 2.1 | 6.3 | 20 | 13.1 | 1.10 | 0.62 |
| *LSD* B 1% | | 0.97 | 0.034 | 2.8 | 8.3 | 26 | 17.3 | 1.44 | 0.81 |
| Trial mean | | 8.39 | 0.313 | 22.5 | 48.3 | 166 | 145.6 | 7.6 | 3.72 |
| **Correlation coefficients (20 pairs) between the two years of testing** | | | | | | | | | |
| 2000:2001 | | 0.587* | 0.816** | 0.696** | 0.586** | 0.525** | 0.844** | 0.771** | 0.475* |

**P* = 1%, ***P* = 5%

## RESULTS AND DISCUSSION

While mean air temperatures did not deviate notably from the long-term mean, rainfall differed considerably during the two seasons (Table 2). Low precipitation in a 5-month period and somewhat higher air-temperatures characterized the 2000-growing season. Excess of rainfall in June and September, their shortage in July and August, as well high temperatures in August, are main characteristics of weather during growing seasons of maize in 2001. These weather conditions had an effect on significant differences between the two seasons in analysis of variance for grain yield, and presumably for nutrient contents (Table 3). Thus, in the 2000 growing season there were higher Zn and Fe as well lower Mn concentrations in maize leaves in comparison with the 2001.

Highly significant differences among genotypes were found for all traits investigated. In our study, heredity seems to be more influencing factor of nutritional status in maize compared to environmental factors due to considerably greater genotypic differences. Under same environmental conditions nutritional status among hybrids was from 16.3 to 30.0 for Zn, from 28.5 to 62.2 for Mn and from 137 to 222 for Fe content in ear-leaf (all in mg/kg as 2-year means).

As in the cases of individual nutrient status, considerable differences were found in their relationships among tested hybrids (2-year means: from 95.1 to 210.4 for P:Zn, 5.3 to 10.4 for Fe:Zn and from 2.40 to 5.79 for Fe:Mn). The mean values of the nutritional relationships were supposed to be acceptable or optimal according to suggestions by Trier and Bergmann (1974), Takkar et al. (1976) and Blasl and Mayr (1978). The group of five hybrids (OsSK378, OsSK298, OsSK321, OsSK277 and Clarica) had in both years notably lower values of P:Zn (in average 109) compared to the second group of other five hybrids (Alpos, OsSK395, Bc278, Os247 and OsSk382 – in average 188). Similar tendencies in differences between these two groups of maize hybrids were found for other two tested relationships as follows: 5.7 and 9.5 (Fe:Zn), 3.54 and 4.20 (Fe:Mn) for the two hybrid groups, respectively.

Highly significant correlation coefficients were estimated for nutritional status as well as for nutritional ratios between the two growing seasons. It indicates high repeatability of the nutritional status within genotypes across the seasons, although there were considerable climatic differences between the two seasons.

Zinc, manganese and iron status in maize is under considerable influences of heredity because under similar environmental conditions considerable differences were found among tested hybrids. Since maize is a Zn-demanding plant, special attention could be given for possible problems with zinc balance in soil and plant. Therefore, maize hybrids characterizing with higher P:Zn is less acceptable for growing on soils which are either rich in P or moderate in available Zn. However, the other nutritional problems are possible in maize growing, for example Fe or Mn either deficiencies or their excess, and under these conditions could be important specifity of these relationships among the maize hybrids.

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**ABSTRAKT**

**Význam genotypu kukuřice při hodnocení obsahu fosforu, zinku, manganu a železa a jejich vzájemného poměru v listech rostlin pěstovaných na hydromorfní půdě**

Hydromorfie je vážným problémem půdní úrodnosti v Evropě, ale i v Severní Americe, neboť způsobuje nevyváženou zásobu živin v půdě a biomase. Cílem výzkumu bylo definovat rozdíly v obsahu fosforu (P), zinku (Zn), manganu (Mn) a železa (Fe) v listech hybridů kukuřice a sledovat vzájemné vztahy mezi stanovenými mikroelementy a vztahy mezi Zn a P na hydromorfní půdě ve východním Chorvatsku. Dvacet hybridů kukuřice bylo pěstováno v uvedené oblasti ve dvouletém polním pokusu. K identifikaci dědičnosti byly analyzovány listy, z jejichž úžlabí vyrůstá palice ve fázi metání samčího květenství. V listech byly stanoveny významné rozdíly v obsahu Zn, Mn a Fe v rozsahu 16,3–30,0 mg Zn/kg, 28,5–62,2 mg Mn/kg a 137–222 mg Fe/kg. Průměrné poměry mezi hodnocenými prvky se pohybovaly v běžných úrovních 146 (P : Zn), 7,6 (Fe : Zn) a 3,72 (Fe : Mn). Rozdíly mezi jednotlivými hybridy kolísaly od 95,1 do 210,4 (P : Zn), od 5,3 do 10,4 (Fe : Zn) a od 2,4 do 5,79 (Fe : Mn). Hybridy kukuřice, u nichž byl zjištěn vyšší poměr P : Zn, je méně vhodné pěstovat na půdách s vysokým obsahem přístupného P nebo se střední zásobou přístupného Zn. Vysoce průkazné korelační koeficienty mezi obsahy sledovaných prvků a pokusnými roky (0,696 pro Zn, 0,586 pro Mn a 0,525 pro Fe) svědčí o vysoké stabilitě hodnot mezi jednotlivými genotypy bez ohledu na pokusný rok a o významu dědičnosti pro nutriční hodnotu.

**Klíčová slova:** hybridy kukuřice; fosfor; zinek; mangan; železo; hydromorfní půda

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