# Phosphorus fertilization impacts on maize yield and nutritional status with emphasis on P and Zn in leaves and grain

Vlado Kovacevic[A], Zdenko Loncaric[A], Imre Kadar[B], Dragutin Petosic[C] and Luka Andric[D]

[A]Faculty of Agriculture, University J. J. Strossmayer in Osijek, Croatia, Email vkovacevic@pfos.hr
[B]Research Institute for Soil Science and Agrochemistry of HASA, Hermann Otto u.15, HU-10125 Budapest, Hungary
[C]Faculty of Agriculture, University of Zagreb, Svetosimunska cesta 25, Zagreb, Croatia
[D]Agricultural Institute, Juzno predgradje 17, Osijek, Croatia

**Abstract**
Four field experiments with increasing rates of P fertilization (kg $P_2O_5$/ha: up to 2000, 1000, 1500, and 1500, for the exp. A, B, C and D, respectively) were started between spring of 2002 and 2004. The experiments were performed in four replicates (basic plot, depending on the trial, from 32 to 92 $m^2$). Monoammonium phoshate (MAP: 12% N + 52% $P_2O_5$ ) in experiments A-C and triplephoshate enriched with sulphur and zinc (45% $P_2O_5$ + 1,2% S + 0,06% Zn) in experiment D were used as P fertilizers. In general, P fertilization (the exp. A) had moderate yield effects probably due to acid soil reaction. Only application of the highest P rate had residual influences on maize yields for the 2003 growing season (7.74 and 8.38 t/ha, for the control and the highest rate of P, respectively). In the experiment B, fertilization resulted in significant yield increases up to 16%. In the exp. C maize yields were similar for applied P treatments. However, maize responded drastically to P fertilizations by yield increasing up to 32% , 17%, and 40%, for 2004, 2005, and 2006, respectively (the exp. D). An acceptable range of P:Zn ratio from 15 to 180 was mainly found in our study. For example, leaf P:Zn ranged from 38 to 80 (the exp. A), from 77 to 100 (the exp. B), from 35 to 69 (the exp. C) and from 73 to 168 (the exp.D). Grain P:Zn ratios were higher than leaf P:Zn (from 151 to 194 and from 124 to 168, for the exp. B and D, respectively). Phosphorus fertilization mainly increased P:Zn.

**Key Words**
Maize, phosphorus fertilization, yield, leaf and grain P and Zn status.

## Introduction
Some soils in Croatia have limited fertility, mainly because of less favorable physical and chemical properties. Acid reaction and nutritional unbalances, mainly low levels of plant available phosphorus (P), as well as unfavorable physical properties are limiting factor of some soils fertility in Croatia (Petosic *et al.* 2003). Soil improvement by ameliorative treatments (for example P fertilization) could overcome soil fertility limitations and result in field crop yield increase under these conditions. Aim of this study was to survey our recent investigations (Banaj *et al.* 2006; Komljenovic *et al.* 2006, 2008; Kovacevic *et al.* 2008; Loncaric *et al.* 2005) of maize response to P fertilization with emphasis on P and Zn status in plants.

## Methods
*The field experiments*
Four field experiments were started in spring from 2002 to 2004 by using different rates of P fertilizers in Brod-Posavina County (locality Zivike: experiment A), Bjelovar-Bilogora County (locality Maslenjaca: experiment B), Pozega-Slavonian County (locality Badljevina: experiment C) in Croatia and in Potkozarje area (locality Medjuvodje, northern Bosnia: experiment D). In two experiments (B and C) P fertilizers were applied alone or combined with potassium (KCl form). Maize was sown from the end of April/beginning May and harvested manually (4 rows from each basic plot) in October. The results of these experiments in details are shown in previous studies (Banaj *et al.* 2006; Komljenovic *et al.* 2006, 2008; Kovacevic *et al.* 2008; Loncaric *et al.* 2005). Monoammonium phosphate (MAP: 12% N + 52% $P_2O_5$ ) in experiments A-C and triplephosphate enriched with sulphur and zinc (45% $P_2O_5$ + 1,2% S + 0,06% Zn) in experiment D were used for P fertilization. This P was in additions to ordinary fertilization at start of the individual experiments, while in the next years residual effects were tested and the experiments were fertilized in range of ordinary fertilization only. The experiments were conducted in four replicates. Sizes of basic plots were, depending on the trial, from 32 to 92 $m^2$. reatments of individual experiments were as follows: experiment A (kg $P_2O_5$/ha): a) control = 125, b) 625, c) 1125 and d) 2125; experiment B (kg $P_2O_5$/ha and/or kg $K_2O$/ha): a) control = 125, b) 625 P, c) 825 P, d) 625 K, e) 625 P + 625 K; experiment C (kg $P_2O_5$/ha and/or kg $K_2O$/ha): a) control = 150 P, b) 650 P, c) 1150 P, d) 650 K, e) 650 P + 600 K, f) 1150 P + 1100 K; experiment D (kg $P_2O_5$/ha ): a) control = 80, b) 580, c) 1080, d) 1580.

*Sampling and chemical analysis*

The soils were sampled at the start of the experiments. The ear-leaf at flowering and grain at maturity were sampled for chemical analysis. The total amounts of P and Zn in maize leaves and grain were determined using ICP after microwave digestion by conc. $HNO_3$+$H_2O_2$. Soil pH was determined electrometrically in a soil suspension in water and in a solution of 1 mol/ L KCl (ISO, 1994). Soil organic matter was determined by sulfochromic oxidation (ISO, 1998). The soil samples were analyzed by AL-procedure (Egner *et al.* 1960) and extraction with $NH_4$-Acetate+EDTA solution (pH 4.65) according to Lakanen-Erviö (1971). Analyses of Ca, Mg and Zn in soil extracts and plant samples were performed with a Jobin-Yvon Ultrace 238 ICP-OES spectrometer in the laboratory of the RISSAC, Budapest, Hungary.

*Soil properties*

The experiments were conducted under different soil conditions. Very acid reaction and low levels of available Ca were main characteristics of the soils of experiments A and C. Poor levels of available P were found in soils A and D and very poor levels in soils B and C. Available Zn status was mainly satisfied with the exception of the soil of experiment D (Table 1).

**Table 1. Soil properties (0-30 cm depth) at starting (just before fertilization) of the experiments.**

| Soil pH, available P and K (AL-method); Ca, Mg and Zn (Ammonium Acetate – EDTA: pH 4.65); humus | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | | mg/100 g | | mg/kg | | | % | pH | | mg/100 g | | mg/kg | | | % |
| $H_2O$ | KCl | $P_2O_5$ | $K_2O$ | Ca | Mg | Zn | Humus | $H_2O$ | KCl | $P_2O_5$ | $K_2O$ | Ca | Mg | Zn | Humus |
| *Experiment A:* Brod-Posavina County (Croatia) | | | | | | | | *Experiment B*: Bjelovar-Bilogora County (Croatia) | | | | | | | |
| 5.67 | 4.26 | 6.8 | 15.6 | 2475 | 240 | 2.4 | 1.87 | 6.90 | 6.48 | 7.6 | 9.8 | 3591 | 336 | 4.5 | 0.93 |
| *Experiment C*: Pozega-Slavonian County (Croatia) | | | | | | | | *Experiment D*: the northern Bosnia (B&H) | | | | | | | |
| 6.12 | 4.30 | 4.5 | 6.3 | 670 | 148 | 4.6 | 2.10 | 7.65 | 6.90 | 11.3 | 17.4 | 28880 | 176 | 1.0 | 4.08 |

## Results

In our study, considerable differences in maize yields were found between tested years, mainly due to weather conditions (precipitation and temperature regimes, especially in July and August. The 2003 and 2007 growing seasons were less favorable because of drought and high air-temperatures (Tables 2-5). Nutritional status of maize (leaf and grain P and Zn) was dependent on P fertilization but it was in the normal range. In general, P fertilization (exp. A) had a moderate effect on yield probably due to acid soil reaction (Banaj *et al.* 2006) . Only application of the highest P rate had residual influences on maize yield for the 2003 growing season: 7.74 and 8.38 t/ha, for the control and the highest rate of P, respectively (Table 2). Influences of P fertilization were reflected in the Zn status of maize leaves (growing season 2002: 78 and 40 mg Zn/ kg, for the control and 2000 kg $P_2O_5$/ha, respectively).

**Table 2. Influences of P fertilization (experiment A) on maize yields (Banaj *et al.* 2006).**

| Fertilization impacts on yield and maize nutritional status (dry matter of ear-leaf at flowering – July 2002) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Spring of 2003 | The growing season | | | % | mg/kg | Precipitation (mm) and mean air-temp. ($^oC$): | | | | | |
| Fertilization | 2002 | 2003 | 2004 | 2002 (Leaf) | | Slav. Brod (LTM = long-term means: 1971-1990) | | | | | |
| ($P_2O_5$ kg /ha) | Grain yield (t/ha) | | | P | Zn | Month | | 2002 | 2003 | 2004 | LTM |
| 125 | 12.3 | 7.74 | 9.69 | 0.30 | 77.9 | July | mm | 78 | 61 | 47 | 87 |
| 625 | 12.0 | 7.96 | 9.73 | 0.31 | 66.6 | | $^oC$ | 22.4 | 22.6 | 21.3 | 20.6 |
| 1125 | 12.5 | 8.03 | 9.55 | 0.30 | 44.5 | Aug. | mm | 122 | 51 | 36 | 71 |
| 2125 | 12.3 | 8.38 | 9.78 | 0.32 | 39.9 | | $^oC$ | 20.7 | 23.8 | 20.9 | 19.9 |
| LSD (P 0.05) | n.s. | 0.47 | n.s. | 0.01 | 4.5 | Sum | mm | 200 | 112 | 83 | 158 |
| LSD (P 0.01) | | n.s. | | 0.02 | 6.8 | Mean | $^oC$ | 21.6 | 23.2 | 21.1 | 20.3 |

In experiment B, fertilization resulted in significant yield increases of 14% (2003: PK- treatment), 7% (2004: K-treatment), and 16% (2005 and 2006: PK and P-3, respectively) compared to the control. Also, significant effects of applied fertilization were found only on P concentrations in maize leaves in both tested growing seasons, while leaf Zn was significantly reduced due to applied P only in the 2004 growing season (Table 3). In exp. C (Table 4) maize yield was similar for all applied treatments. However, leaf P increased and leaf Zn decreased (2-year means: 0.29% P and 0.33% P, 63.4 mg Zn/kg and 53.2 mg Zn/kg, for the control and 1150 kg $P_2O_5$/ha, respectively) due to P fertilization. Maize responded to P fertilizations by yield increasing up to 32% , 17%, and 40%, for 2004, 2005, and 2006, respectively (Table 5). In the first year of testing, P fertilization resulted in leaf Zn decreases. However, in the third year of testing both leaf and grain Zn had increased due to P fertilization. Mobilization Zn added as triple superphosphate enriched with Zn could be a possible explanation of this phenomenon.

**Table 3. Response of maize to fertilization (Kovacevic *et al.* 2008) –experiment B.**

| Fertilization in spring of 2003 (kg/ha) | | Grain yield and maize P and Zn status in leaf (ear-leaf at flowering) and grain at maturity | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | The growing season | | | | Percent (P) and mg/kg (Zn) on dry matter basis | | | | | | | |
| | | 2003 | 2004 | 2005 | 2006 | 2004 growing season | | | | 2005 growing season | | | |
| | | Grain yield of maize | | | | Leaf | | Grain | | Leaf | | Grain | |
| $P_2O_5$ | $K_2O$ | t/ha | | | | P | Zn | P | Zn | P | Zn | P | Zn |
| 125 | 125 | 7.37 | 13.3 | 10.7 | 8.7 | 0.36 | 46.9 | 0.28 | 18.5 | 0.33 | 38.6 | 0.28 | 15.4 |
| 625 | 125 | 7.57 | 13.7 | 11.1 | 9.64 | 0.35 | 42.4 | 0.29 | 16.5 | 0.4 | 42.3 | 0.31 | 16 |
| 825 | 125 | 8.07 | 13.8 | 12.2 | 10.1 | 0.39 | 39 | 0.31 | 17 | 0.36 | 39.1 | 0.29 | 18.8 |
| 125 | 625 | 7.21 | 14.3 | 12.1 | 9.57 | 0.36 | 61.9 | 0.28 | 18.4 | 0.36 | 44.2 | 0.27 | 18.6 |
| 625 | 625 | 8.46 | 14.1 | 12.5 | 9.55 | 0.37 | 45.6 | 0.31 | 19 | 0.37 | 43.7 | 0.3 | 18.2 |
| LSD | (P 0.05) | 0.46 | 0.5 | 0.8 | 0.77 | 0.02 | 7.9 | 0.02 | ns | 0.03 | ns | 0.06 | 0.8 |
| July | mm | 38 | 65 | 106 | 19 | 86 | | | | | | | |
| | °C | 22.2 | 20.4 | 20.8 | 22.5 | 20.6 | Precipitation (mm) and mean air-temp. (°C) in | | | | | | |
| August | mm | 46 | 63 | 166 | 160 | 91 | Daruvar (underlined = 30-y means: 1961-1990) | | | | | | |
| | °C | 23.7 | 20.2 | 18.5 | 18.6 | 19.7 | | | | | | | |

**Table 4. Influences of fertilization (experiment C) on maize properties (Loncaric *et al.* 2005)**

| Fertilization (spring 2003) effects on grain yield of maize, P and Zn nutritional status | | | | | | | |
|---|---|---|---|---|---|---|---|
| Fertilization | | The growing season*: yield and leaf (ear-leaf at flowering) nutritional status | | | | | |
| in spring of 2003 | | 2003 | 2004 | 2003 Leaf status | | 2004 Leaf status | |
| (kg/ha) | | Grain yield | | Percent (P) and mg/kg (Zn) on dry matter basis | | | |
| $P_2O_5$ | $K_2O$ | t/ha | | P | Zn | P | Zn |
| 150 | 100 | 9.77 | 11.95 | 0.24 | 68.5 | 0.34 | 58.3 |
| 650 | 100 | 10.12 | 11.85 | | | | |
| 1150 | 100 | 9.92 | 11.91 | 0.29 | 54.1 | 0.36 | 52.3 |
| 650 | 600 | 10.07 | 12.31 | | | | |
| 1150 | 1100 | 10.71 | 12.23 | 0.29 | 57.5 | 0.35 | 46.2 |
| LSD (P 0.05) | | ns | ns | 0.02 | 6.4 | ns | 5.9 |

* Weather data in July and August of 2003 and 2004 (Daruvar Weather Bureau: Table 2)

**Table 5. P fertilization (experiment D) impacts on maize in Bosnia (Komljenovic *et al.* 2006, 2008).**

| Phosphorus fertilization (spring 2004) effects on grain yield of maize, P and Zn nutritional status | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fertilization | Yield | | | | Leaf and grain status (on dry matter basis) | | | | | | | |
| $P_2O_5$ | (t /ha) | | | | 2004 growing season | | | | 2006 growing season | | | |
| kg /ha | The growing season | | | | Leaf | | Grain | | Leaf | | Grain | |
| | 2004 | 2005 | 2006 | 2007 | P | Zn | P | Zn | P | Zn | P | Zn |
| 80 | 7.90 | 7.27 | 7.34 | 3.33 | 0.33 | 45.2 | 0.27 | 21.8 | 0.33 | 37.3 | 0.27 | 20.0 |
| 580 | 9.18 | 8.53 | 9.73 | 3.33 | 0.30 | 37.3 | 0.30 | 21.3 | 0.35 | 37.0 | 0.29 | 20.5 |
| 1080 | 9.85 | 8.38 | 10.3 | 3.44 | 0.32 | 28.2 | 0.30 | 19.9 | 0.35 | 35.3 | 0.28 | 20.1 |
| 1580 | 10.4 | 8.42 | 9.81 | 3.55 | 0.31 | 23.7 | 0.32 | 19.0 | 0.37 | 40.3 | 0.29 | 25.0 |
| LSD (P 0.05) | 0.37 | 0.29 | 0.37 | ns | ns | 9.4 | 0.02 | n.s. | 0.02 | ns | ns | 2.8 |
| July mm | 45 | 104 | 73 | 26 | 77 | | | | | | | |
| °C | 21.3 | 21.7 | 23.3 | 23.5 | 20.8 | Precipitation (mm) and mean air-temp. (°C) in | | | | | | |
| Aug. mm | 61 | 182 | 202 | 55 | 85 | Sisak (underlined = 30-y means: 1961-1990) | | | | | | |
| °C | 21.1 | 19.0 | 19.2 | 21.7 | 19.8 | | | | | | | |

For data interpretation an appraisal of the nutrient status of the ear-leaf of maize at the flowering stage according to Christensen was used (cit. Mengel and Kirkby, 2001) as follows (on dry matter basis): deficient (< 0.1 % P, <5 mg Zn/kg), low (0.1-0.2 % P and 15-20 mg Zn/kg), adequate (0.2-0.5 % P, 20-70 kg Zn/kg) and high (0.5-0.8% P, 70-150 kg Zn/kg). Amounts above 0.8% P are reported as excess. In our study, P and Zn in maize leaves were in the adequate ranges (Tables 2-5). Maize is a zinc-intensive plant with high zinc-demand. Antagonism between P and Zn is well known (Bergmann 1992; Mengel and Kirkby 2001). Blasl and Mayr (1978) reported an optimum P:Zn ratio of about 65 and acceptable range from 15 to 180. According Trier and Bergmann (1974), optimal values for the P:Zn ratio in maize are between 200 and 50 and values out of this range are indications of latent zinc deficiency (from 300 to 201), acute zinc deficiency (>300) and zinc excess (<25). Rahimi and Bussler (1975) give the following P:Zn ratios for old leaves of corn: optimal 54-122, zinc deficiency above 211 and phosphorus deficiency below 42. In our study, P:Zn ratios were in an acceptable range. For example, leaf P:Zn were in ranges from 38 to 80 (exp. A), from 77 to 100 (exp. B), from 35 to 69 (the exp. C) and from 73 to 168 (exp. D). Grain P:Zn were higher in comparison with leaf P:Zn (from 151 to 194 and from 124 to 168, for exp. B and D, respectively). Phosphorus fertilization mainly increased P:Zn. Similar observations regarding P effects on Zn status were found Bogdanovic *et al.* (1999, 2003) for a chernozem in Vojvodina (Serbia) .

**Conclusion**

The grain yield of maize was mainly moderately increased by ameliorative P fertilization, especially under acid soil conditions. Leaf and grain P and Zn, as well as P:Zn ratio were more influenced by fertilization than was yield, but these properties were in normal nutritional ranges.

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