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## Research Article

# Maize response to phosphorus and sulfur application on calcareous chernozem in Serbia

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## ABSTRACT

Field studies were conducted on carbonate chernozem in *Vojvodina Province* of Serbia during two seasons of maize growing to adjust nutrient management practices when fertilizers are broadcasted and incorporated into the soil before sowing. The experimental scheme included six fertilization treatments: $T_1$ (zero fertilizer control), $T_2$ ($N_{156}P_{64}K_{64}$, farmer fertilizer practice), $T_3$ ($N_{100}P_{60}K_{60}$), $T_4$ ($N_{100}P_{60}K_{60}S_{36}$), $T_5$ ($N_{100}P_{80}K_{60}$), and $T_6$ ($N_{100}P_{80}K_{60}S_{48}$). Nitrogen application practice was found to be excessive, while phosphorus application practice was found to be insufficient. Phosphorus application rate of 80 kg $P_2O_5$ $ha^{-1}$ was found to be rational when the soil test for phosphorus was very low or low. Sulfur (S) application improved grain yield in higher yield conditions, whereas soil containing 3.9–4.0% of organic matter (OM) could meet crop S requirements in lower yield conditions of 5 t $ha^{-1}$ and below. It is assumed that S application to maize in *the southern Pannonian Plain in Serbia* may be limited to 36 kg S $ha^{-1}$.
**Keywords:** maize, grain yield, phosphorus, sulfur.

## INTRODUCTION

Nutrient removal per 1 ton of maize grain averages 12 kg N, 6.3 kg $P_2O_5$, 4.5 kg $K_2O$, and 1.4 kg S (IPNI, 2016). More than half of total phosphorus (P) uptake by maize plants occurs after the tassel/first reproductive (VT/R1) stages, and S accumulation is greater during grain-filling stages, with more than half of sulphur (S) uptake occurring after the VT/R1 stages (Bender *et al*., 2013). Such dynamics of nutrient demand suggests that season-long supply of P and S is critical for maize nutrition.

Marginal purpling of maize leaves is a well-known symptom of P deficiency (Sharma and Kumar, 2011). However, P deficiency can slow plant growth and delay maturity without causing purpling; some maize hybrids show no signs of purpling even when severely deficient in P. Purpling may also be caused by a restriction of root growth, indicating that the plant is under stress, such as freezing stress (Bruulsema, 2016).

Phosphate sorption and precipitation are strongly favored in calcareous soils because of high concentrations of calcium carbonate ($CaCO_3$) increasing the soil's P buffer capacity, sorption strength, and precipitation reactions forming stable Ca phosphates (Brownrigg *et al*., 2022). It was hypothesized that after each P fertilizer application, the soil buffering capacity decreases, as does the soil's proclivity to continue reacting with P, resulting in more P in soil solution and, consequently, plants requiring less P (Barrow *et al*., 2018). Every phosphate fertilizer application thus increases the effectiveness of subsequent applications (Barrow *et al*., 2021). Understanding *phosphate* sorption and desorption in *soils* helps to rationalize P fertilizer use and avoid overfertilization, which causes eutrophication of surface waters. Maintaining or improving agricultural productivity while conserving and enriching the biodiversity is critical to the global provision of ecosystem services (Guignard *et al*., 2017).

For maize fields with very low soil test P values, it is typically recommended to broadcast a P rate before sowing and place the remainder of P fertilizer in bands at sowing. If the soil test P value is low or medium, P fertilizer can be applied via broadcasting or banding. If the P soil test value is high, banding is suggested (Kaiser *et al*., 2022), as broadcasting P fertilizer has a low chance of increasing maize yields when the soil test P value is high. Maize grain yield after broadcast and deep-band P fertilizer placement has been shown to be comparable across experimental years with strip-till operation, while the improved early growth and P uptake after deep-band placement may provide benefits at the field scale (Preston *et al*., 2019).

Sulfur nutrition is critical for plant growth and development, and this secondary macronutrient is increasingly being used in many crops. Plants absorb sulfate and convert it to essential amino acids, where S participates in a variety of metabolic functions, including protein synthesis (Norton *et al*., 2013). In young maize plants, sulfur deficiency may manifest as a general yellowing of the foliage (Sharma and Kumar, 2011). Because S is not easily translocated in the plant, S deficiency causes more yellowing of the younger leaves than N deficiency.

The frequency of maize responses to S fertilization can be quite high. Sulfur is best obtained from fertilizers containing sulfate ($SO_4^{2-}$) or thiosulfate ($S_2O_3^{2-}$). Broadcast application of 28 kg S $ha^{-1}$ or placement of 13.5 kg S $ha^{-1}$ in a band near the maize seed at sowing has proven to be satisfactory in most production scenarios (Rehm and Clapp, 2008). In S application rate studies conducted in Iowa, the U.S., 62% of the sites showed a significant yield increase due to applied S fertilizer: 72% of sites with loam, silt loam, fine sandy loam, loamy fine sand, and sandy loam textural classes; and 14% of sites with silty clay loam or clay loam textural classes (Sawyer *et al.*, 2011). The economic optimum S rate in these studies was 18 kg S/ha for fine-textured soils and 26 kg S/ha for coarse-textured soils. Maize yield increased with 11 kg S $ha^{-1}$ rate in two of ten locations in two states in the U.S., and yield was unrelated to both soil S and plant tissue S concentration (Kaur *et al*., 2019). It was assumed that S from subsoil plus mineralized S from soil organic matter could have met crop S demand at most locations. A controlled-climate chamber study suggests that S fertilizer application may benefit early season maize growth, but the response may be site-specific (Kovar, 2021).

An increase in S application to many crops coincides with a decrease in atmospheric S deposition as air quality improves. For example, an increase in S fertilizer use in the U.S. Midwest has outpaced the relative rate of change in other nutrient application, such as N, P, and K (Hinckley and Driscoll, 2022). It is therefore suggested that rational S fertilizer recommendations are urgently needed in order to maintain crop yields while minimizing the environmental consequences of excess S levels.

The ability of soil S tests to predict crop response to applied S has been inconsistent (Flis and Jones, 2020). Because S availability to plants is partially dependent on soil organic matter (OM) mineralization, the extractable $SO_4$-S concentration in top soil is unreliable for indicating potential S deficiency or the need for S application. Soil organic matter has a slightly better association with yield response, but does not clearly distinguish between responsive and non-responsive sites for the same reasons (Sawyer *et al.*, 2011). Sulfur mineralization assessment can be used to predict S availability to maize in the field (Carciochi *et al*., 2018). Sulfur applied together with P influences the behavior of the applied P in the soil. Eight weeks after MAP application in the seed-row together with $CaSO_4$, the proportion of phosphate adsorbed on the surface of soil minerals increased, while the proportion of brushite ($CaHPO_4 \cdot 2H_2O$) decreased in calcareous soil, compared to MAP alone (Kar *et al*., 2016). Sulfate S may contribute to increased P solubility in calcareous soils through complexation of $Ca^{2+}$ with $SO_4^{2-}$ (Brownrigg *et al*., 2022).

The objective of this study was to adjust nutrient management practices for maize on calcareous chernozem. Field experiments including six fertilization treatments were conducted based on the following assumptions: high P rates are required when available soil P levels are low; balanced P and S fertilization improves grain yield and economic return; crop response to S depends on yield potential.

## MATERIALS AND METHODS

### Experimental site

The experiment was conducted in an intensive cropping system in a farmer's field in Ruma municipality, *Vojvodina Province,* Serbia. The experimental site is located in Syrmia, in *the southern Pannonian Plain,* between the Danube and Sava rivers. It is a *temperate continental climate* region *where farmers primarily grow* field crops such as maize, oilseeds, sugar beet, and tobacco on chernozem soils formed on loess parent material.

### Climate and soil

The first experimental season in 2020 had favorable climatic conditions for maize. The period from November 2019 to October 2020 saw a 15% increase in precipitation over the long-term average, but there was a precipitation deficit in January, March, and April. Maize was sown in soil with low moisture reserves, and 94% of the plants emerged 16 days after sowing. Rainfall totaled 374 mm from sowing on April 14 to harvesting on November 5, 2020, which is sufficient for a good crop yield. The temperature conditions were favorable during the first vegetative season.

A severe lack of precipitation and higher temperatures characterized the second growing season. From ~~November 2019 to October 2020~~, precipitation was 45% lower than the long-term average. Only 197 mm of rain fell during the vegetative season, which lasted from April 15 to October 12, 2022.

**Table 1.** Initial soil characteristics (0 to 30 cm) at the experimental sites.

| Parameters | | 2020 | 2022 |
|---|---|---|---|
| OM (%) | | 3.88 | 4.02 |
| pH ($H_2O$) | | 8.10 | 7.52 |
| CEC ($mmol_c$ 100 $g^{-1}$) | | 31.2 | 29.6 |
| *$NH_4$-N* | mg $kg^{-1}$ | 7.1 | 3.6 |
| *$NO_3$-N* | | 10.2 | 6.2 |
| Olsen P | | 13.6 | 9.3 |
| Available K (AL method) | | 174 | 206 |
| Exchangeable Ca | | 422 | 568 |
| Exchangeable Mg | | 36.2 | 45.3 |
| Exchangeable Na | | 34.6 | 21.0 |
| Available S (*1 M KCl* extractable) | | 1.2 | 1.1 |

The soil has a diagnostic mollic horizon and is classified as chernozem according to WRB (2014). According to the national soil classification (Škorić *et al*., 1985), the soil is a medium deep carbonate chernozem formed on loess and loess-like sediments. The soil textural class is clay loam, with the following particle size distribution in 0–30 cm layer: 28% sand, 34% silt, and 38% clay. The soil had relatively low OM content (3.9–4.0%), a high cation exchange capacity (CEC) (30–31 $\text{mmol}_c$ 100 $g^{-1}$), and reaction ranging from slightly to moderately alkaline (pH=7.5–8.1) (Table 1). Mineral N and available P were both in the very low to low ranges; available K was in the medium to high ranges; and available S was low. The soil in the experimental site was not salinized, and the exchangeable sodium percentage (ESP) ranged from 0.3% to 0.5%.

**Experimental design and treatment**

The experimental scheme included six fertilization treatments (Table 2). Treatment $T_1$ was a zero fertilizer (control), and treatment $T_2$ ($N_{156}P_{64}K_{64}$) corresponded to farmer fertilization practice (FFP) in the region. In treatment $T_3$ ($N_{100}P_{60}K_{60}$), N rate was 36% lower than in $T_2$, assuming the farmer's practice overestimates N demand. Treatment $T_4$ ($N_{100}P_{60}K_{60}S_{36}$) had S rate of 36 kg S $ha^{-1}$ in a sulfate form, from a complex NPS fertilizer. In treatment $T_5$ ($N_{100}P_{80}K_{60}$), P rate was increased to 80 kg $P_2O_5$ $ha^{-1}$ considering low and very low levels of available soil P. Treatment $T_6$ ($N_{100}P_{80}K_{60}S_{48}$) also had a higher P rate of 80 kg $P_2O_5$ $ha^{-1}$ and S rate of 48 kg S $ha^{-1}$ from an NPS fertilizer. Urea was applied in all treatments to obtain the required N rate. Muriate of potash (MOP) was used as a K source in treatments 3–6. Mineral fertilizers were spring broadcasted prior to preplant cultivation.

Maize hybrid P0164 (FAO 420) was grown after sunflower during the first experimental season and after winter wheat during the second experimental season, with a seed rate of 75,000 seeds $ha^{-1}$. Soil tillage operations included autumn plowing at a depth of 30 cm, disk tillage at a depth of 15 cm in December, and pre-sowing cultivation at a depth of 10 cm. In both seasons, crop protection included pre-emergence (~~terbutilazin~~ + ~~metolahlor~~) and post-emergence herbicides (~~mezotrion~~ + ~~nikosulfuron~~).

Plot sizes ranged from 130 to 800 $m^2$ in the first and second seasons, respectively, according to a systematic experimental design with four replications. Tukey's Honest Significant Difference (HSD) test was used to assess the significance of differences between pairs of group means.

## RESULTS AND DISCUSSION

### Growth parameters

The number of plants emerged per hectare was measured at BBCH (plant phenological stage) 10 (Table 3). Fertilizer application had no significant effect on plant stand measured at this stage. All nutrient management systems increased plant height measured at BBCH 99 compared to a control treatment $T_1$, but there were no significant differences between fertilizer treatments.

**Table 2**. Experimental treatments.

| Treatment | | Fertilizer | Rate (kg $ha^{-1}$) |
|---|---|---|---|
| $T_1$ | Control | - | - |
| $T_2$ | $N_{156}P_{64}K_{64}$ (FFP*) | NPK 16-16-16 | 400 |
| | | Urea | 200 |
| $T_3$ | $N_{100}P_{60}K_{60}$ | Apaviva® NP 12-52 | 115 |
| | | Urea | 190 |
| | | MOP | 100 |
| $T_4$ | $N_{100}P_{60}K_{60}S_{36}$ | Apaviva® NP(S) 16-20(12) | 300 |
| | | Urea | 110 |
| | | MOP | 100 |
| $T_5$ | $N_{100}P_{80}K_{60}$ | Apaviva® NP 12-52 | 153 |
| | | Urea | 180 |
| | | MOP | 100 |
| $T_6$ | $N_{100}P_{80}K_{60}S_{48}$ | Apaviva® NP(S) 16-20(12) | 400 |
| | | Urea | 80 |
| | | MOP | 100 |

*Farmer fertilization practice in Vojvodina region (Serbia).

### Yield components

Fertilizer management practices had no effect on ear quantity per hectare during both seasons (Table 4), as evidenced by the absence of an effect on plant population. Ear length (EL), an important component of grain yield, was only measured in the second season. Nutrient management systems studied in the last two treatments ($T_5$ and $T_6$) provided a significant increase in EL compared to $T_1$. In the first year, thousand kernel weight (TKW) was significantly improved in treatments $T_4$, $T_5$, and $T_6$ compared to $T_1$. Only the last treatment, $T_6$, showed a positive effect of fertilization on TKW in 2022.

### Grain yield and quality

Grain yield increased by 16% and 19% in the first and second seasons, respectively, when FFP was used in $T_2$ versus a zero-fertilizer treatment $T_1$ (Table 5). The N rate of 156 kg $ha^{-1}$ typically applied by farmers appears to be excessive under rainfed conditions, given that in both years, nearly the same yield was obtained in treatment $T_3$ with a much lower N rate of 100 kg $ha^{-1}$.

Treatment $T_5$ with the highest P rate of 80 kg $P_2O_5$ $ha^{-1}$ produced the highest grain yield of 11.03 t $ha^{-1}$ in 2020 and 5.10 t $ha^{-1}$ in 2022. Site-specific management for primary macronutrients increased grain productivity by 15% in the favorable first year and by up to 20% in the drought-affected second year, when compared to ~~$T_1$,~~ that corresponded to FFP. When comparing treatments $T_3$ and $T_5$, very low and low ranges of available soil P found in the study area explain a noticeable maize response to a higher P rate with grain yield increase by 15–18%.

Sulfur addition at a lower rate improved maize grain yield. When comparing treatments $T_3$ and $T_4$, S application at 36 kg S $ha^{-1}$ increased grain yield by 7% in the first season. However, the positive effect of S application on crop productivity was not significant in the second season, which was characterized by a lack of precipitation. Sulfur mineralization in carbonate chernozem containing 3.9-4.0% OM was presumably sufficient to meet maize S requirements, considering that grain yield was more than two times lower in a drier year (5 t $ha^{-1}$ and below).

**Table 3.** Effect of P and S application on maize growth parameters.

| Treatment | | Plant population at BBCH 10 | | Plant height (cm) | |
|---|---|---|---|---|---|
| | | 2020 | 2022 | 2020 | 2022 |
| $T_1$ | Control | 69,683 | 71,076 | 252.4 | 187.0 |
| $T_2$ | $N_{156}P_{64}K_{64}$ (FFP) | 69,825 | 71,221 | 273.0 | 195.5 |
| $T_3$ | $N_{100}P_{60}K_{60}$ | 69,801 | 71,197 | 270.0 | 196.5 |
| $T_4$ | $N_{100}P_{60}K_{60}S_{36}$ | 70,015 | 71,415 | 269.6 | 207.1 |
| $T_5$ | $N_{100}P_{80}K_{60}$ | 70,110 | 71,512 | 269.4 | 199.3 |
| $T_6$ | $N_{100}P_{80}K_{60}S_{48}$ | 70,500 | 71,909 | 267.7 | 203.1 |
| HSD (p=0.05) | | NS | NS | 5.4 | 13.2 |

**Table 4.** Effect of P and S application on maize yield components.

| Treatment | | Ear quantity per ha | | EL (cm) | TKW (g) | |
|---|---|---|---|---|---|---|
| | | 2020 | 2022 | 2022 | 2020 | 2022 |
| $T_1$ | Control | 67,592 | 64,125 | 14.5 | 305.0 | 214.6 |
| $T_2$ | $N_{156}P_{64}K_{64}$ (FFP) | 68,429 | 65,676 | 15.3 | 350.8 | 222.8 |
| $T_3$ | $N_{100}P_{60}K_{60}$ | 68,508 | 65,750 | 15.0 | 345.3 | 231.3 |
| $T_4$ | $N_{100}P_{60}K_{60}S_{36}$ | 68,615 | 66,675 | 16.6 | 371.0 | 241.6 |
| $T_5$ | $N_{100}P_{80}K_{60}$ | 68,475 | 67,995 | 16.7 | 365.3 | 249.9 |
| $T_6$ | $N_{100}P_{80}K_{60}S_{48}$ | 69,090 | 65,800 | 16.8 | 365.3 | 239.9 |
| HSD (p=0.05) | | NS | NS | 2.2 | 6.1 | 14.8 |

**Table 5.** Effect of P and S application on maize grain yield and quality.

| Treatment | | Grain yield, t $ha^{-1}$ | | Starch, % | | Protein, % | |
|---|---|---|---|---|---|---|---|
| | | 2020 | 2022 | 2020 | 2022 | 2020 | 2022 |
| $T_1$ | Control | 8.29 | 3.56 | 77.03 | 77.53 | 5.98 | 7.26 |
| $T_2$ | $N_{156}P_{64}K_{64}$ (FFP) | 9.63 | 4.25 | 75.62 | 74.75 | 6.93 | 7.83 |
| $T_3$ | $N_{100}P_{60}K_{60}$ | 9.60 | 4.33 | 75.91 | 75.34 | 7.46 | 7.44 |
| $T_4$ | $N_{100}P_{60}K_{60}S_{36}$ | 10.30 | 4.47 | 75.78 | 74.19 | 6.56 | 6.96 |
| $T_5$ | $N_{100}P_{80}K_{60}$ | 11.03 | 5.10 | 76.17 | 76.69 | 7.10 | 7.05 |
| $T_6$ | $N_{100}P_{80}K_{60}S_{48}$ | 10.72 | 4.72 | 75.22 | 76.81 | 7.23 | 6.94 |
| HSD (p=0.05) | | 0.38 | 0.19 | 1.32 | 1.03 | 1.40 | 0.83 |

Sulfur application at a higher rate of 48 kg S $ha^{-1}$ was ineffective during both seasons, and such a rate of S even reduced grain yield by 7% in the second year with a lack of precipitation. *Maize* is known to be moderately sensitive to *salt* stress (Farooq *et al.*, 2015), but we assume that factors other than salt stress were at work because the total amount of nutrients applied in treatments $T_2$ and $T_6$ was nearly similar. Thus, S fertilization of maize should not exceed 36 kg S $ha^{-1}$ in the study area. Kaur *et al*. (2019) also observed a significant decrease in maize grain yield when the S rate was increased from 33 to 44 kg S $ha^{-1}$ in four of ten locations in two states in the U.S.

There was no clear relationship between nutrient management and protein content in maize grain (Table 5). Optimal nutrition with macronutrients in treatment $T_5$ with a higher P rate of 80 kg $P_2O_5$ $ha^{-1}$ resulted in a higher starch content in grain during both seasons, when compared to treatment $T_2$ that corresponded to FFP.

## CONCLUSION

Optimized nutrient management improved maize productivity by 15–20% and increased starch content in grain at the experimental site in *Vojvodina Province* of Serbia. Phosphorus application rate of 80 kg $P_2O_5$ $ha^{-1}$ was found to be rational when the soil test P values were in the very low and low ranges. Sulfur application rate of 36 kg S $ha^{-1}$ improved grain yield in higher yield conditions, and it is assumed that S application to maize under these conditions can be limited to the above-mentioned rate. Carbonate chernozem containing 3.9–4.0% OM is assumed to meet crop S requirements in lower yield conditions of 5 t $ha^{-1}$ and below.

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