Effect of mineral fertilization with N, P, K and Si in a field experiment with maize on Haplic Vertisol

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Citation
Nenova, L. (2023). Effect of mineral fertilization with N, P, K and Si in a field experiment with maize on Haplic Vertisol. *Bulgarian Journal of Crop Science, 60*(4) 34-40

Abstract
Balanced mineral fertilization is a precondition for the optimal development of agricultural crops with a minimal negative effect on the environment. The present study aimed to determine the effect of fertilization with nitrogen (N), phosphorus (P), potassium (K), and silicon (Si) on the yield and plant height of maize (*Zea mays* L.) in a field experiment on Haplic Vertisol. The height of plants was significantly influenced by the applied fertilization with the strongest data variation occurring in the 11-12th leaf phase when a total of seven homogeneous groups were formed. The greatest height of maize plants was observed in variants: V_4 ($N_{200}P_{160}K_{120}Si_{14}$), V_6 ($N_{200}P_{80}K_{240}Si_{28}$), and V_8 ($N_{200}P_{160}K_{240}Si_{14}$) where the leading role of nitrogen (with the higher norm N_{200}) was distinguished. The multifactorial analysis confirmed the impact of nitrogen, potassium, and silicon on the formed maize grain yield, with silicon contributing the most to the variance in the experiment – 24.18%, followed by potassium – 20.45% and nitrogen – 16.15%. The highest yields were reported in variants V_6 ($N_{200}P_{80}K_{240}Si_{28}$) and V_7 ($N_{100}P_{160}K_{240}Si_{28}$) – 11762.8 kg.ha^{-1} and 13042.3 kg.ha^{-1}, respectively, with twice more an increase compared to the control.

Key words: nitrogen; phosphorus; potassium and silicon fertilizers; maize; yield; height; Haplic Vertisol

INTRODUCTION

Maize (*Zea mays* L.) is one of the main cereal crops grown worldwide, with great economic importance. In Bulgaria, it occupies second place in terms of yields and planted areas after wheat. According to the statistics and analysis department of the Ministry of Agriculture, maize grain production in 2020 decreased by 25.6% compared to the previous year to 2,969,210 tons, due to the lower average yield obtained by 28.2% as a result of permanent drought in the main production areas.

Maize yields are influenced by several factors, such as cultivation technology, fertilization, soil and climatic conditions of the region, physiological requirements and characteristics of the cultivar, etc. (Aleksandrova & Donov, 2003; Crista et al., 2014). Focusing researchers' attention on soil fertility parameters when growing field crops - corn and winter wheat aims to clarify the optimal variants that achieve the best conditions, both for the development of the respective crops and for the preservation and reproduction of soil organic matter. The compensation of removed nutrients and the restoration of disturbed mineral balance in agroecosystems is generally achieved by fertilization. Correct determination of fertilization norms and optimal combination of fertilizer types, application methods, and timings ensure better development of agricultural crops with a minimal negative effect on the environment (Gaj et al., 2020). Many authors study the quantity, quality, and components of maize grain yield, the growth, development, and parameters of crops, the recycling of carbon, nitrogen, and phosphorus elements, nitrogen utilization efficiency from industrial and mineral fertilizers, etc. (Pooniya et al., 2015; Toncheva et al., 2015; Ivanov & Dimitrov, 2018; Wang & Ning, 2019). Detailed characteristic of different maize classes and hybrids is presented in the studies of (Szmigel et al., 2013;

Vulchinkov & Vuchnikova, 2013). The effectiveness of nutrients applied by fertilization depends not only on the amounts of individual elements but also on the complex interaction between them. Silicon is widespread in soils, but its use as a fertilizer is poorly studied in our country. Silicon application can contribute to increasing the quantity and quality of yields, as well as to increasing the resistance of maize to adverse climatic conditions, diseases, and enemies (Bocharnikova & Matichenkov, 2012; Xie et al., 2014; Mabagala et al., 2021).

The present study aimed to assess the influence of mineral fertilization with nitrogen (N), phosphorus (P), potassium (K), and silicon (Si) and their optimal rates on the yield and height of maize plants in a field experiment on Haplic Vertisol.

MATERIAL AND METHODS

A field experiment was carried out with maize as a test crop (*Zea mays* L.) – medium early hybrid – P-8834 from the 310 FAO group, at the experimental field of Bozhurishte, Sofia region. The soil in the studied area is identified as Haplic Vertisol, according to FAO, 2015 (IUSS Working Group WRB, 2015). The following mineral fertilizers were applied before sowing of the crop: nitrogen (N) in the form of ammonium nitrate, phosphorus (P) in the form of triple superphosphate, potassium (K) as potassium sulfate and silicon (Si), diatomaceous earth, which represents 89-95% silicon in amorphous form. The multifactorial design of the experiment allowed the assessment of the action and interaction of the four factors (N, P, K, and Si) varying on three levels (Sadovski et al., 2022). The experimental plot was 25 m^2 in size. Eight variants of fertilization and one control variant – without fertilization were tested in three repetitions (Table 1). Maize was grown under non-irrigated conditions, and all of the necessary agrotechnical measures for the crop were observed.

Table 1. Scheme of the field experiment with maize, Bozhurishte, 2020

Variants	Fertilization norms ($kg.ha^{-1}$) active substance			
	N	P	K	Si
V_1	100	80	120	14
V_2	200	80	120	28
V_3	100	160	120	28
V_4	200	160	120	14
V_5	100	80	240	14
V_6	200	80	240	28
V_7	100	160	240	28
V_8	200	160	240	14
V_9	0	0	0	0

The following methods for soil analysis were used: determination of humus - by oxidation, according to Tyurin's method (Kononova, 1963); pH – potentiometrically in H_2O and KCl (Arinushkina, 1962); total nitrogen (N) and mineral nitrogen (Nmin) - according to the methods of Bremner and Kiney (Bremner, 1965a; Bremner, 1965b); mobile forms of P and K (P_2O_5 and K_2O) – by the acetate-lactate method (Ivanov, 1984).

Plant height was measured at different growth stages of maize development (6-7th leaf, 11-12th leaf, and milk-dough stage). Plant samples for the determination of grain yield were taken at the full maturity phase of maize. The yield was recalculated to 14% grain moisture.

Statistical processing of the data was performed using One-way-ANOVA, Multifactor-ANOVA, and Correlation analysis from the statistical package Statgraphics 19. The method of least significant differences at $p \leq 0.05$ (95%) was used.

RESULTS AND DISCUSSION

The agrochemical characteristic of the soil from Bozhurishte experimental station (Haplic Vertisol) showed that in the arable horizon (0 – 30 cm) it was relatively well stocked with total nitrogen 0.139% (Table 2). However, the mineral nitrogen content (NH_4+NO_3) was not high – 12.67 $mg.kg^{-1}$. Regarding available phosphorus P_2O_5, the reserves of the soil were also low - from 0.20 to 0.34 mg.100 g^{-1}. The soil was well supplied with available potassium - up to 30.11 K_2O mg.100 g^{-1}. Soil reaction was slightly acidic to neutral, in the surface layer pH (H_2O) - 6.2, the humus content showed that the soil was average stocked with organic matter.

The height of maize plants (cm), measured in three growth stages of its development –6-7th leaf,

Table 2. Agrochemical characteristics of Haplic Vertisol, Bozhurishte

Haplic Vertisol, depth, cm	pH		∑ N-NH_4+NO_3	Total N	P_2O_5	K_2O	Humus
	H_2O	KCl	$mg.kg^{-1}$	%	$mg.100\ g^{-1}$		%
0-30	6.2	5.4	12.67	0.139	0.20	30.11	3.02
30-60	6.5	5.6	8.64	0.113	0.34	21.8	3.09

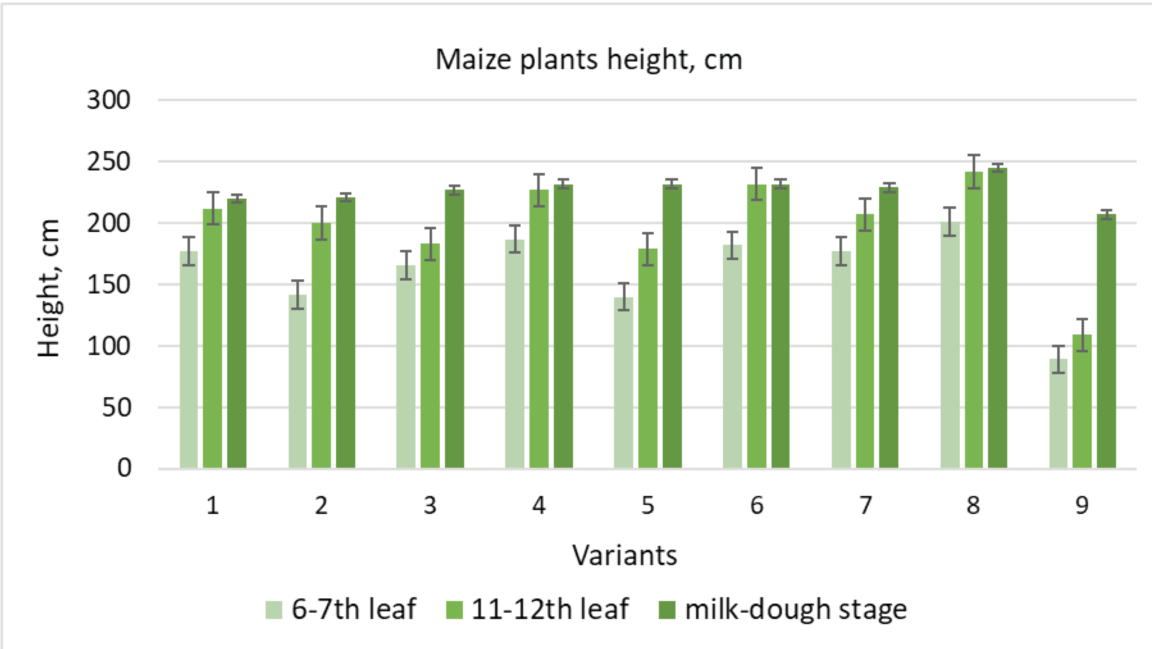

Figure 1. Plants height in three growth stages of maize (6-7th leaf, 11-12th leaf, and milk-dough phase)

11-12th leaf, and milk-dough maturity, showed a significant variation of the data depending on the variants in the experiment (Figure 1). The plants in variant V_8 ($N_{200}P_{160}K_{240}Si_{14}$) had the greatest height for the entire experimental period, and the plants in the control variant V_9 ($N_0P_0K_0Si_0$) had the lowest. Good results were obtained in variants V_4 ($N_{200}P_{160}K_{120}$-Si_{14}) and V_6 ($N_{200}P_{80}K_{240}Si_{28}$). What units the variants with the greatest height was the application of nitrogen in the N_{200} norm, which confirmed the leading role of this element in the formation of plant biomass.

Statistical processing of the data for maize height from the three sampling dates showed significant variability depending on the variants of fertilization, which was most pronounced in the 11-12th leaf phase, when seven homogeneous groups were formed, from "a" to "g" (Table 3). In this phase, the plants of variants V_4, V_6, and V_8 were more than twice as tall as in the control variant. As growth progressed, in the milk-dough maturity phase, the plants equalized in height, with only the control V_9 ($N_0P_0K_0Si_0$) and variant V_8 ($N_{200}P_{160}K_{240}Si_{14}$) being distinguished, with the smallest (207 cm) and the largest (245 cm) average height.

The changes in maize grain yield under the influence of applied fertilization are presented in Figure 2.

Maize grain yield varied between 5833.9 $kg.ha^{-1}$ in the control variant to 13042.3 $kg.ha^{-1}$ in variant V_7 ($N_{100}P_{160}K_{120}Si_{28}$). Obtained yields in the variants V_3, V_6, V_7, and V_8 could be characterized as high – over 10000 $kg.ha^{-1}$. For comparison, in the study by Gaj et al. (2020), the maximum yield obtained after fertilization with NPKMgS was also nearly 10000 $kg.ha^{-1}$. In the study of Basa et al. (2016) the highest yield

Table 3. One-way ANOVA of the data for maize height (cm) from Bozhurishte, 2020

Variants	Height, cm	Homogenous groups	Height, cm	Homogenous groups	Height, cm	Homogenous groups
	6-7th leaves		11-12th leaves		Milk-dough phase	
V_1 ($N_{100}P_{80}K_{120}Si_{14}$)	177	cd	212	def	220	b
V_2 ($N_{200}P_{80}K_{120}Si_{28}$)	142	b	200	bcd	221	b
V_3 ($N_{100}P_{160}K_{120}Si_{28}$)	166	bc	183	bc	227	b
V_4 ($N_{200}P_{160}K_{120}Si_{14}$)	187	cd	227	efg	232	b
V_5 ($N_{100}P_{80}K_{240}Si_{14}$)	140	b	179	b	232	b
V_6 ($N_{200}P_{80}K_{240}Si_{28}$)	182	cd	232	fg	232	b
V_7 ($N_{100}P_{160}K_{240}Si_{28}$)	177	cd	207	cde	229	b
V_8 ($N_{200}P_{160}K_{240}Si_{14}$)	201	d	242	g	245	c
V_9 ($N_0P_0K_0Si_0$)	89	a	109	a	207	a
p-value	0.0000		0.0000		0.0001	
LSD (95%)	29,2		24,8		12,5	

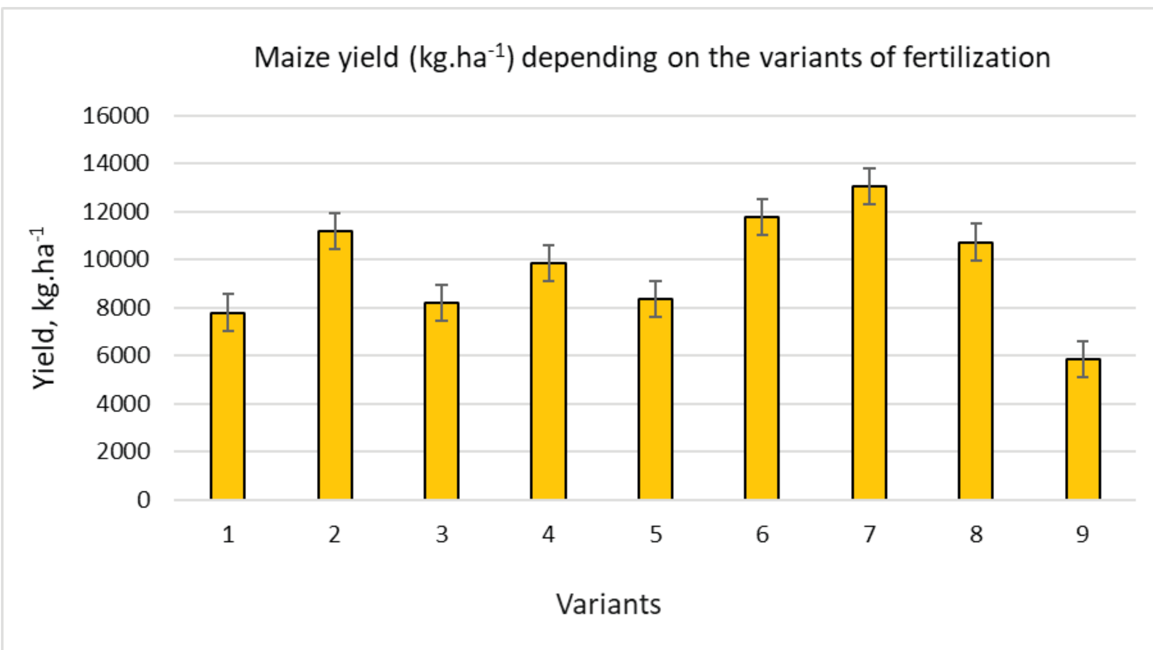

Figure 2. Maize grain yield (kg.ha^{-1}) in a field experiment on Haplic Vertisol, 2020

was 5798 kg.ha^{-1} depending on the precursor and the fertilization applied. Crista et al. (2014) obtained an optimum yield of 9034 kg.ha^{-1}, again at maximum fertilization rates. Statistical processing of the data for grain yield in the present study showed significant differences by variants (Table. 4).

The variants in the experiment were distributed in five homogenous classes from "a" to "e". The first homogenous group was formed by the control variant V_9 ($N_0P_0K_0Si_0$), which had a significantly lower yield compared to the all-other variants. The second homogenous group "b" consisted of the variants V_1 ($N_{100}P_{80}K_{120}Si_{14}$), V_3 ($N_{100}P_{160}K_{120}Si_{28}$), and V_5 ($N_{100}P_{80}K_{240}Si_{14}$), where the lower dose of nitrogen N_{100} was applied. With them, yields increased on average by 40% compared to the control. The variants in homogeneous class "e" - V_6 ($N_{200}P_{80}K_{240}Si_{28}$) and V_7 ($N_{100}P_{160}K_{240}Si_{28}$) were characterized by the highest values, where the obtained grain yield was over 100% higher than the control. Higher yields obtained in the variants with the application of Si_{28} could be explained by its role in overcoming water stress in maize (Xie et al., 2014). Increased photosynthetic activity and a decrease in plant evapotranspiration after silicon application in different doses were reported by the authors.

Table 4. One-way ANOVA of the data for maize yield (kg.ha^{-1}) from Bozhurishte, 2020

Variants	Yield, kg.ha^{-1}	Homogenous groups
V_1 ($N_{100}P_{80}K_{120}Si_{14}$)	7787.0	b
V_2 ($N_{200}P_{80}K_{120}Si_{28}$)	11178.3	cd
V_3 ($N_{100}P_{160}K_{120}Si_{28}$)	8195.3	b
V_4 ($N_{200}P_{160}K_{120}Si_{14}$)	9841.2	c
V_5 ($N_{100}P_{80}K_{240}Si_{14}$)	8359.9	b
V_6 ($N_{200}P_{80}K_{240}Si_{28}$)	11762.8	de
V_7 ($N_{100}P_{160}K_{240}Si_{28}$)	13042.3	e
V_8 ($N_{200}P_{160}K_{240}Si_{14}$)	10713.4	cd
V_9 ($N_0P_0K_0Si_0$)	5833.9	a
p-value	0.0000	
LSD (95%)	1396.8	

A significant positive correlation between grain yield and plant height in the 11th-12th leaf phase was found, which was expressed by correlation coefficient R = 0.715 ($p \leq 0.05$). In the other two phases of the experiment, (6-7th leaf and milk-dough stage) such dependence was not found. In the study by Gaj et al. (2020), a similar regression relationship between the nutritional status of maize in the 5-6th leaf phase and the obtained yield was reported. The authors found that the risk of low yields can be reduced using balanced mineral fertilization, which, in addition to NPK including Mg and S, further increased the obtained production.

Multifactor ANOVA analysis confirmed the influence of the investigated factors (fertilization with nitrogen, phosphorus, potassium, and silicon) and their interactions on the obtained yield (Table 5). A significant influence of nitrogen, potassium, and silicon separately and in combination was established ($p < 0.05$). The impact of silicon was found to be the greatest contribution in the reasons of variance – 24.18% were due to it. Potassium fertilization had a similar impact - 20.45%, while the influence of nitrogen in this soil was significant but lower - 16.15% of the variance was due to its application.

CONCLUSION

The influence of mineral fertilization with N, P, K and Si at different doses and combinations on

Table 5. Multifactor ANOVA of the data for maize yield from Bozhurishte, 2020

Source	SSQ	SSQ%	DF	MS	F	p
N	136990.7	**16.15**	3	45663.6	5.562	**0.0047**
P	26821.7	3.16	3	8940.6	1.089	0.3937
K	173449.3	**20.45**	3	57816.4	7.042	**0.0014**
Si	205076.5	**24.18**	3	68358.8	8.326	**0.0006**
N.P	205076.5	**24.18**	3	68358.8	8.326	**0.0006**
N.K	57616.2	6.79	3	19205.4	2.339	0.1035
N.Si	26821.7	3.16	3	8940.6	1.089	0.3937
Factors	831852.7	98.06	21	39612.0	4.825	0.0343
Error	16420.9	1.94	2	8210.5		
Sum	848273.6	100	23			

the productivity of maize (Zea mays L.) was tested in a field experiment on Haplic Vertisol. A significant effect of the applied fertilization on plant height (cm) and grain yield (kg.ha^{-1}) was established at high levels of confidence ($p<0.000$). The height of plants reflected the fertilization applied to the greatest extent in the 11-12th leaf phase of maize development when seven homogeneous groups were formed. The height in variants with the norm N_{200} – V_4 ($N_{200}P_{160}K_{120}Si_{14}$), V_6 ($N_{200}P_{80}K_{240}Si_{28}$), and V_8 ($N_{200}P_{160}K_{240}Si_{14}$) increased two-fold compared to the control. At the end of the growing season, the effect of fertilizers on the plant height decreased. The influence of nitrogen, potassium, and silicon on the formed yield was significant, with the greatest contribution for the variation - 24.18% of silicon, the influence of phosphorus application to the soil was not significant. Yields increased twice compared to the control in variants V_6 ($N_{200}P_{80}K_{240}Si_{28}$) and V_7 ($N_{100}P_{160}K_{240}Si_{28}$) - 11762.8 and 13042.3 kg.ha^{-1}, respectively, where the combinations of the applied fertilizers were the most favorable for the development of maize on the studied soil.

Acknowledgements

We express gratitude to Prof. Alexander Sadovski for his assistance in the statistical analysis of experimental data. The publication is a result of the work on Project KP-06 -H 36/15 of 17.12.2019 "Innovative method for optimal fertilization of agricultural crops", funded by the Research Fund, Bulgarian Ministry of Education and Science.

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