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# Effect of different fertilizer rates on some quantitative parameters of maize in pot experiment with alluvial-meadow soil

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## Abstract

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The aim of the present study was to evaluate the effect of interaction between different rates of fertilizers: nitrogen, phosphorus, potassium and silicon on the vegetation of Maize (*Zea mays* L.), medium-early hybrid – Pioneer 8834 from FAO group 310. The experiment includes 16 variants of fertilization with 3 replications. The plant height on the 30th, 37th, and 47th day from the beginning of the vegetation and yield of fresh and dried biomass from the aboveground part and the roots of the crop at harvest were studied.

According to the results, the agronomic characteristics were affected significantly by treatments. The established trends on plant height during the vegetation period of maize correlate with the data for the yield of fresh biomass. To sum up, the leading role of nitrogen stands out in treatments with the high rate of nitrogen, low rate of phosphorus and silicon.

*Keywords:* fertilizer rates; nitrogen; phosphorus potassium and silicon; maize

## Introduction

Intensive agricultural activity is accompanied by a decrease in soil fertility, environmental pollution and a decrease of the production quality. Therefore, it is necessary to implement new, environmentally safe, and, highly effective methods of managing agricultural production.

The reduction of soil fertility and the agricultural production quality is associated to a significant extent, with the unbalanced nutrition of grown crops (Mineev, 1990; Aristarkhov, 2000; Kurganova, 2002; Bezuglov&Gogmachadze, 2008; Qiu et al., 2014; Davies et al., 2020). Liebig (1940) also recommended the restoration of the nutrients exported with the yields in the soil. In his work “Organic chemistry in its applications to agriculture and physiology” he emphasized the role of the four main macroelements – nitrogen, phosphorus, potassium, and silicon. The high prevalence of silicon – from 200 to 350 $g.kg^{-1}$ in clay soils and from 450-480 $g.kg^{-1}$ in sandy soils explains its significant role in soil formation and soil fertility formation processes (Kovda, 1985). Each year, 20 to 700 kg of Si/ha is exported from the soil with the plants (Bazilevich, 1971; Bocharnikova, 2012).

This magnitude is comparable to the exports of nitrogen, phosphorus, and potassium. Silicon is a structurally forming soil element and its constant export with plant production accelerates soil degradation (Matychenkov, 2008; Matychenkov, 2014). Research continues for achieving the optimal nutrient regime of plants by fertilizing with the main nutrients to compensate their exports with production (Zhang et al., 2007; Huang et al., 2010).

In our country, the use of silica fertilizers is poorly applied. Research on the interaction of silica with other mineral fertilizers in their combined application in the soil is small. Even less are studies on the application of fertilization rates, consistent with the physico-chemical properties of the soil type and the physiological requirements of different agricultural crops.

The main objective of the study is to clarify the role and importance of the main macroelements for plant nutrition and to determine the optimal dietary options of maize.

## Materials and Methods

A pot experiment with test culture Maize (*Zea mays* L.) – medium-early hybrid P 8834 of Pioneer's FAO Group 310 (FAOSTAT, 2019) is conducted in 3 kg containers. The soil for the experiment was supplied by the Experimental station of Tsalapitsa village from a non-fertilized field. 7 seeds per pot were sown. Twenty days after sowing, the sprouted seeds were reduced to 4 per pot. The soil used is Alluvial-meadow soil according to Bulgarian classification (Koinov, 1987) and it is defined as Eutric Fluvisol – FLeu according to FAO, 2015. It is characterized by a low content of total nitrogen and organic matter, with a slightly acidic to neutral reaction (pH) in the surface soil layer, with low sorption capacity in the arable horizon and average values in the below arable layer (Koleva et al., 2001).

The following methods of analysis are used: determination of Hummus – by oxidation during heating along with the Turin (Kononova, 1963), pH- potentiometrically in $H_2O$ and KCl (Arinushkina, 1962), total N – by Kjeldahl (PanReacAppliChem ), mineral N – Bremner and Kiney method (Bremner,1965a, Bremner,1965b), mobile forms of phosphorus and potassium ($P_2O_5$ and $K_2O$) – by the acetate method of Ivanov (Ivanov, 1986). The experiment includes 16 fertilization variants with 3 replications (Table 1).

The height of the plants (in cm) was determined on the 30$^{th}$, 37$^{th}$, and 47$^{th}$ days from the beginning of the experiment, and the values of fresh biomass from the above-ground and the roots of the plants (g/pot) were taken into account. For the Statistical processing of the data One-way-Anova method was used from the package Statgraphics 18 program. To identify the differences between the variants studied, the least significant differences (LSD) were used at $p \leq 0.05$ (95%). Regression analysis of the data were also performed.

**Table 1. Scheme of the experiment – active substance of fertilizers applied in mg/pot**

| Variants | Factors | | | |
|---|---|---|---|---|
| № | N | P | K | Si |
| 1 | 0 | 0 | 0 | 0 |
| 2 | 0 | 160 | 140 | 800 |
| 3 | 400 | 160 | 140 | 800 |
| 4 | 200 | 0 | 140 | 800 |
| 5 | 200 | 320 | 140 | 800 |
| 6 | 200 | 160 | 0 | 800 |
| 7 | 200 | 160 | 280 | 800 |
| 8 | 200 | 160 | 140 | 0 |
| 9 | 200 | 160 | 140 | 2000 |
| 10 | 200 | 160 | 140 | 800 |
| 11 | 300 | 240 | 70 | 400 |
| 12 | 300 | 80 | 210 | 400 |
| 13 | 300 | 80 | 70 | 1200 |
| 14 | 100 | 240 | 210 | 400 |
| 15 | 100 | 240 | 70 | 1200 |
| 16 | 100 | 80 | 210 | 1200 |

## Results and Discussion

Agrochemical characteristics of the experimental soil are presented in Table 2. Total nitrogen content of the arable horizon of the Alluvial-meadow soil is 0.052%, characterizing it as poorly supplied soil (Table 2). The mineral nitrogen content is also low – 11.52 – 12.67 mg N in 1000 g of soil. Mobile phosphorus is also low 3.5 to 8.09 mg $P_2O_5$ per 100 g of soil. The soil is poorly supplied with available potassium, too – 14.35 to 15.35 mg $K_2O$ per 100 g of soil.

The data for soil texture are presented in Table 3. A high content of stones (pebbles) and gravel – particles of a size exceeding 1mm were established – 49.6%. The sand content is also high, these are particles in size from 1 to 0.05 mm (50 + 15.9 = 65.9%). The amount of large, medium, and small silt is low and slightly exceeds 20%, the content of clay fraction is low – 13.2%.

Analysis of the results obtained shows that the soil has a high water permeability, does not increase its volume, and it is weakly plastic, but has capillarity and water capacity (according to the content of physical clay – 37.1% the soil is classified as sandy-clay).

**Table 2. Agrochemical characteristics of Alluvial-meadow soil**

| Soil depth | pH | | $\sum$ N-$NH_4$+$NO_3$ | Total N | $P_2O_5$ | $K_2O$ | Humus |
|---|---|---|---|---|---|---|---|
| | $H_2O$ | KCl | mg.kg$^{-1}$ | % | mg.100g$^{-1}$ | | % |
| 0 – 30 cm | 7.4 | 6.8 | 11.52 | 0.052 | 8.09 | 14.35 | 1.16 |
| 30 – 60 cm | 7.3 | 6.4 | 16.70 | 0.061 | 5.91 | 15.35 | 1.20 |

**Table 3. Soil texture of Alluvial-meadow soil, % of the weight of absolutely dry soil**

| Depth (0 – 30 cm) | Hygroscopic moisture, % | Sum > 1 | 1 - 0.25 | 0.25 - 0.05 | 0.05 - 0.01 | 0.01 - 0.005 | 0.005 - 0.001 | < 0.001 | Sum < 0.01 |
|---|---|---|---|---|---|---|---|---|---|
| Alluvial meadow | 1.92 | 49.6 | 50.0 | 15.9 | 10.2 | 6.5 | 4.2 | 13.2 | 23.9 |

During vegetation of maize, phenological observations were carried out. Corn sprouted only 7-8 days after sowing and after 3 weeks – at leaf stage V4-V5, there were noticeable differences between treatments.

The experimental data on plant growth and on the quantity of fresh biomass from above ground and plant roots at maize harvesting are presented at Figures 1 and 2. Observations during vegetation are confirmed by the measured heights of plants on the 30$^{th}$, 37$^{th}$, and 47$^{th}$ day after sowing, presented in Figure 1. One-way-Anova analysis on plant height on the 30th day was made and a significant difference between the variants was found ($p \leq 0.001$). The sixteen treatments are distributed in 6 homogeneous classes – A, B, C, D, E, and F (Table 4).

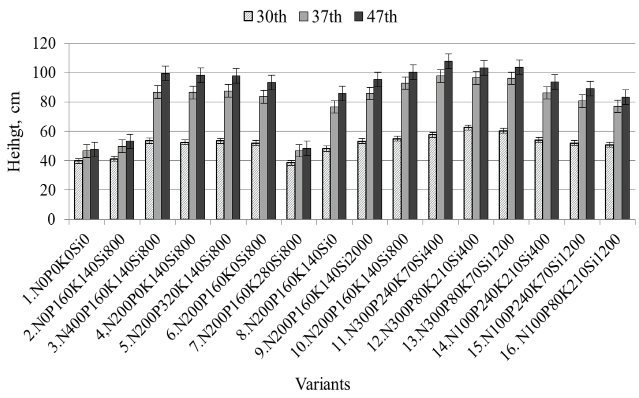


**Fig. 1. Maize height (cm) on the 30$^{th}$, 37$^{th}$ and 47$^{th}$ day after sowing**

The variants in separate homogenous groups have significant differences between them (LSD = 8.12 cm at 95.0% confidence level). The lowest are the values for plant height in variants 7 – 38.5 cm and the control variant 1 – 39.75 cm. They form a homogeneous class A and they are significantly different from those in the other variants. An interest is variant 7 ($N_{200}P_{160}K_{280}Si_{800}$) – with the highest rate of potassium applied. Contrary to expectations, the heights of the plants in it do not exceed those of the control. Fertilization with potassium fertilizers is known to improve the development and physiological characteristics of maize (Gaj, 2008; 2016). Many researchers (Hussain et al., 2015) found that potassium increases water use efficiency and reduces the ratio of root: stem (their dry weight). Vegetation experiments with maize and increasing rates of K prove that potassium in the

**Table 4. Multiple range tests for plant height (cm) on the 30$^{th}$ day after sowing, LSD = 8.12 at 95.0% confidence level**

| Variants | Average | Homogenous groups |
|---|---|---|
| 7 | 38.50 | A |
| 1 | 39.75 | A |
| 2 | 41.17 | A B |
| 16 | 41.54 | A B |
| 8 | 48.17 | B C |
| 15 | 52.00 | C D |
| 6 | 52.08 | C D |
| 4 | 52.42 | C D E |
| 9 | 53.33 | C D E |
| 5 | 53.50 | C D E |
| 3 | 53.58 | C D E |
| 14 | 54.08 | C D E |
| 10 | 54.92 | C D E F |
| 11 | 56.67 | D E F |
| 13 | 60.25 | E F |
| 12 | 62.50 | F |

rate up to 100 kg.ha$^{-1}$ increases the absorption of nutrients in the conditions of water deficiency. At the same time, in the variants with the higher rate of 130 kg.ha$^{-1}$, this ratio is the lowest. It is possible that in variant 7 it is precisely the high rate of K (280 mg/pot) that has no beneficial effect in the experiment with maize on the Alluvial-meadow soil.

The strongest is the growth in variant 12 ($N_{300}P_{80}K_{210}Si_{400}$) – 62.5 cm, which forms homogeneous group F. Close to the data of variant 12 are the values for the height of plants in variants 11 ($N_{300}P_{240}K_{70}Si_{400}$) and 13 ($N_{300}P_{80}K_{70}Si_{1200}$). They are in homogenous group DEF and EF. All other variants (8, 15, 6, 4, 9, 5, 3, 14, and 10) forms intermediate homogeneous groups AB, BC, CD, CDE, and CDEF and the differences between them are not statistically significant.

One-way-Anova analysis of the data for the height of maize plants in the other 2 periods (on the 37$^{th}$ and 47$^{th}$ day) was made and similar trends were observed. On the 37$^{th}$ day 7 homogeneous groups were formed (LSD = 6.73), the height of plants vary from 46.6 cm in the control variant 1 ($N_0P_0K_0Si_0$) to 97.7 cm in variant 11 ($N_{300}P_{240}K_{70}Si_{400}$). At the last period – on the 47$^{th}$ day, 8 homogeneous groups were formed (LSD = 9.61). Variants 11, 12 and 13, fertilized with $N_{300}$ are the highest – 107.9 cm, 103.2 cm and 103.5 cm, respectively.

The tendencies established from the statistical processing of the data on plant height during the period of maize vegetation correlate with the data for the yield of fresh biomass and roots of maize depending on the fertilization applied. At Figure 2 the data for the yield of fresh biomass and roots (g/pot) at harvest are presented.

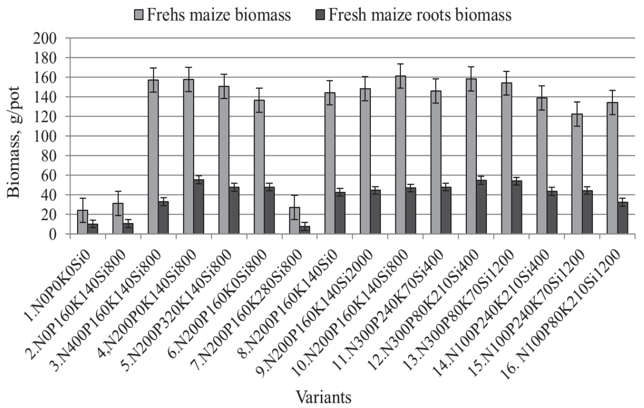


**Fig. 2. Yield of fresh plant biomass and roots of maize, g/pot**

During the statistical processing of the data for fresh maize biomass (g/pot), 4 homogeneous classes were formed, and the LSD between the different variants is 25.72 g (Table 5).

Variant 7 ($N_{200}P_{160}K_{280}Si_{800}$) – 27.0 g has close to the control values – 24.3 g, the tendency is similar as for the plant height. The highest yields are those from fresh aboveground biomass at variants 3, 4, 5, 10, 11, 12, and 13, in which the consistently increased nitrogen rates are combined with different P, K, and Si rates.

**Table 5. Multiple range test for plant weight (g/pot) by variants, LSD = 25.7 at 95.0% confidence level**

| Variants | Average | Homogenous groups |
|---|---|---|
| 1 | 24.3 | A |
| 7 | 27.0 | A |
| 2 | 31.3 | A |
| 15 | 122.7 | B |
| 16 | 134.3 | B C |
| 6 | 136.7 | B C D |
| 14 | 139.0 | B C D |
| 8 | 144.3 | B C D |
| 11 | 146.0 | B C D |
| 9 | 148.3 | B C D |
| 5 | 150.7 | C D |
| 13 | 154.0 | C D |
| 3 | 157.3 | C D |
| 4 | 158.0 | C D |
| 12 | 158.3 | C D |
| 10 | 161.3 | D |

It is confirmed that the influence of nitrogen is strongest on the studied indicators during the first stages of maize development – V6 and V8. As the nitrogen rate increases, on the $30^{th}$, $37^{th}$, and $47^{th}$ day from the beginning of the vegetation, the height of the plants and the yield of fresh biomass increase, too.

Thus, as a result of the One-way-Anova analysis of the values of plant height and quantity of biomass from the aboveground part of the plants, the leading role of nitrogen fertilization in the rate of 300 mg/pot was established on the 30th day from the beginning of the experiment (significant differences between the variants are at a high level of reliability $p \leq 0.001$).

A regression analysis of the obtained data for plant height on the $30^{th}$, $37^{th}$, and $47^{th}$ day were also performed. Below we present the regression analysis only for the $47^{th}$ day (Table 6).

**Table 6. Regression analysis of the data – height of the plant on the $47^{th}$ day**

| Terms | b | t | pt |
|---|---|---|---|
| $b_0$ | 79.107 | 6.876 | 0.0000 |
| N | -0.407 | -2.696 | 0.0134 |
| P | -0.514 | -2.703 | 0.0132 |
| K | -0.220 | -1.028 | 0.2318 |
| Si | -0.020 | -0.778 | 0.2906 |
| *sqr*N | 60.747 | 1.361 | 0.1564 |
| *sqr*P | 33.109 | 0.669 | 0.3149 |
| *sqr*K | -53.448 | -0.998 | 0.2389 |
| *sqr*Si | -16.549 | -0.835 | 0.2776 |
| *sqr*NP | -3.047 | -1.556 | 0.1188 |
| *sqr*NK | -0.384 | -0.185 | 0.3891 |
| *sqr*NSi | -0.373 | -0.425 | 0.3608 |
| *sqr*PK | 1.167 | 0.500 | 0.3483 |
| *sqr*PSi | 0.195 | 0.200 | 0.3879 |
| *sqr*KSi | 1.710 | 1.628 | 0.1065 |

The model derived based on regression analysis is a polynomial with square roots and has the form:

## Conclusions

As a result of the experiment with fertilization on Alluvial-meadow soil and maize as a test plant, after One-way Anova analysis of plant heights on the $30^{th}$, $37^{th}$, and $47^{th}$ day and the amount of aboveground biomass, the leading role of nitrogen fertilization in rate of 300 mg/pot was established ($p \leq 0.001$).

The distribution of the variants initially in 6, then in 7, and finally in 8 homogeneous groups – A, B, C, D, E, F, and J is an indicator for the increasing of the differences by variants with the progress of the vegetative development of maize.

The plants in variant 7 ($N_{200}P_{160}K_{280}Si_{800}$) and control variant 1 have the lowest values of height, followed by variant 2 ($N_0P_{160}K_{140}Si_{800}$). They are in homogeneous class A. The plants in variants 11 ($N_{300}P_{240}K_{70}Si_{400}$), 12 ($N_{300}P_{80}K_{210}Si_{400}$), and 13 ($N_{300}P_{80}K_{70}Si_{1200}$), with the high rate of $N_{300}$, formed homogeneous group F (30th day) and J (47th day). They have the strongest growth in all 3 periods of investigation. All other variants (8, 15, 6, 4, 9, 5, 3, 14, and 10) are in intermediate homogeneous classes AB, BC, CD, CDE, and CDEF, and the differences between them are not significant.

The established trends from the statistical processing of the data on plant height during the vegetation period of maize correlate with the data for the yield of fresh biomass from the aboveground part of plants and depend on the fertilization by variants. It is confirmed that the influence of nitrogen on the studied indicators is strongest during the first stages of maize development – V6 and V8.

It was found that the combination of high rates of fertilizers, especially potassium – variant 7 ($N_{200}P_{160}K_{280}Si_{800}$) does not have a favorable effect on maize development. The highest effect was achieved at the fertilization rate of $N_{300}$ in combination with $P_{80}$, $K_{210}$ or $K_{70}$ and $Si_{400}$ or $Si_{1200}$ mg/pot.

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