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MATHEMATICAL APPROACH FOR ASSESSING THE IMPACT OF FOLIAR NUTRITION ON THE MAIN INDICATORS IN MAIZE HYBRIDS

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Abstract

Climate changes towards global warming and drought are leading to disruption of the world`s water balance. Maize is a crop of strategic importance for agriculture. Therefore, it is important to study the potential capabilities of the crop at different levels of agrotechnics. For this purpose, a field experience with five hybrids of corn was set. Observations were made on the productivity of hybrids for silage and for grain. The development of the hybrids during the growing season was monitored. We tested three levels of foliar fertilization. The obtained yields and parameters of the structural elements of the yield of the five hybrids show how responsive each is to optimizing the nutritional regime. The field experience was carried out under irrigated conditions. Trends are registered after conducting a statistical analysis of the results.

Key words: *maize, fertilization, yield, regression.*

INTRODUCTION

Maize is an important grain forage and food crop. There are a number of yield-limiting factors that determine the economic efficiency of growing maize. Factors that affect productivity, such as climate change, dwindling natural resources, and others, lead to a reduction in the productivity potential of crops (Easterling, 2007; Lobell et al., 2008; Battisti & Naylor, 2009; Robinson et al., 2015; Popa et al., 2021). The world market offers a wide variety of hybrid varieties of corn. This requires producers to know their qualities well and the agro-meteorological conditions in the area where they will be grown. Dynamic climate change, prolonged droughts, insufficient water resources and, last but not least, the ever-increasing population of the planet and hence the need to produce more produce from less and less land put the production of field crops to a serious test and challenge agricultural science.
Driven by climate projections and land use intensity in the form of nitrogen fertilizers, simulations of corn yield and nitrogen leaching were most sensitive to nitrogen applications followed by climate, reports Blanke (2017). The increase in wheat and maize yields in Europe is accompanied by an increase in nitrogen leaching in many regions. A number of studies have established the positive influence of mineral fertilization with macro-elements on the quantity and quality of the harvest (Samodova, 2008; Dimitrov et al., 2013; Bąk et al., 2016; Lato et al., 2021; Bojtor et al., 2022). To study the effect of different nitrogen sources on the growth, yield and quality of forage maize (*Zea mays* L.) Amin (2011) monitored plant growth parameters. According to studies by Brzozowska (2008), the one-sided application of mineral fertilizers leads to a disruption of the ecological balance and a decrease in the quality of the production.
Nutrient counts can vary within the same soil profile, Enakiev et al reported. (2018). The need to use microfertilizers in growing crops is due to several reasons: use of highly productive hybrids, whose increased yield can reduce the content of microelements in the productive mass; improved quality of the grain; increased resistance to disease and unfavorable factors; balanced plant nutrition and enrichment of plant production with microelements. According to study results by Safyan et al. (2011), foliar sprayed micronutrients, especially iron and zinc, play an important role in increasing maize yield. Ghazvineh (2012) also supported the trend that high grain yield was obtained in foliar treatment. The level of

fertilization affects maize biometrics, such as number of rows in one ear, number of grains in one row, number of grains in one ear and weight of grain in one ear (Petrovska et al., 2010; Kuneva et al., 2014).

The interaction between nitrogen fertilizer with 130 kg N/forage and foliar spraying by mixed treatment with Zn + Mn + Fe leads to a significant increase in the values of some parameters characterizing maize, viz. plant height, number of green leaves/plant and leaf area index, grain yield, number of grains, grain protein content reported by Gharibi et al. (2016). A similar trend was also established by Sarheed et al. (2022) on cob length, cob diameter, number of kernels per cob, 500-kernel weight, yield per plant and total yield, after treatment with products rich in micronutrients. A 17% increase in grain yield and a 25% increase in grain zinc concentration when fertilizing grain maize with zinc was reported by Mutambu et al. (2023). However, the average Zn concentration was 31.48 mg kg^{-1}, 6.52 mg kg^{-1} below the recommended 38 mg kg^{-1} grain Zn level in maize.

After foliar treatment with zinc-rich fertilizer, in order to study the effect of zinc application on grain yield, nitrogen and carbon content in grain of three maize genotypes belonging to different maturity groups, Stepić et al. (2022) found that the nitrogen content of the grain was increased. Mustafa et al. (2020) studying the effect of foliar feeding with the trace elements Zn, Fe and Cu, individually and in combination on corn grain (*Zea mays* L.), recorded an increase in grain yields and an increase in the content of trace elements in the grains.

Djalovic et al. (2022) found that, under nitrogen and zinc treatments, precipitation at critical growth stages of maize was a more important factor than temperature in terms of grain yield and quality.

Using a mathematical approach, with the present study we set ourselves the following goals:

1) To investigate the presence of correlation dependence between the investigated indicators, in order to make a more objective assessment;

2) To analyze the influence of the variety factors and the fertilizing regime on the biometric parameters and yield, establishing the influence of their independent action and their interaction.

MATERIALS AND METHODS

In order to achieve the set goal, in the period 2022-2023, in the Stara Zagora region, a field experiment with several hybrids of corn was carried out. Five hybrids of corn - DKC 4416, LG 31.390, Premeo, Pionner P9889 and Knezha-461 - are the subject of the study. The studied hybrids are of different origin and with different FAO, but belong to the group of mid-early hybrids. The field experiment was set up using the method of fractional plots in 4 repetitions with the experimental area size of 15 m^2. The experiment was performed at 3 fertilization levels. The study options are as follows: Var. 1 (control) included fertilization with N_{14} (in the form of ammonium nitrate); Var. 2 includes N14 fertilization plus foliar feeding with the products Aminozol, Boron, Zinc 700SK and Nutriplant 36; Var. 3 includes fertilization with N_{14} plus foliar feeding with Kinsidro Grow and N-loc. The application doses are as follows: Kinsidro Grow 15 g/day; H-lok 250 ml/day; Aminozol 200 ml/da, Boron 200 ml/da, Zinc 700SK 100 ml/da and Nutriplant 36-1 l/da.

Of the products that were used for foliar feeding, Aminozol is an organic liquid fertilizer that contains 9.4% total Nitrogen (115 g/l N), 1.1% total potassium oxide (15 g/l K_2O), also contains: total Sulfur (S) 0.25%, of which water soluble 0.23%; total Sodium (Na) 1.28%, of which water-soluble 1.26%; 66.3% organic matter. Boron and zinc are single-component inorganic fertilizers with microelements, which contain respectively 11% water-soluble boron; borethanolamine (150 g/l B) and 40% of total zinc in the form of oxide (700 g/l Zn). Nutriplant 36 is a one-component liquid inorganic fertilizer with macronutrients and contains 27% total nitrogen (350 g/l N) (18.7% amide nitrogen, 3.6% ammonium nitrogen, 4.7% nitrate nitrogen) 3% water-soluble magnesium oxide (40 g/l MgO). The ones included in var. 3 foliar fertilizers are Kinsidero Grow, which is an organo-mineral fertilizer containing sulfur, microelements, chelating and complexing materials - water-soluble potassium K (9.5%), sulfur (4.3%), boron

(0.07%), cobalt (0.045%), copper (0.05 %), manganese (0.04%), zinc (0.05%), humic and fulvic acids. N Lock is a nitrogen stabilizer whose aim is to reduce nitrogen loss from the soil.

The soil type in the experimental field is a meadow-cinnamon soil. It is characterized by a powerful humus horizon, which is strongly expressed in the range of 0-50 cm. According to the humus content, the soil is moderately rich (3.93%). The agrochemical characterization of the soil was made by determining the nutrient content. The soil type in the experimental field is characterized by an average stock of mineral nitrogen - 33.2 mg/1000 g, poorly stocked with mobile phosphorus - 3.9 mg/1000 g, and well stocked with digestible potassium - 44 mg/1000 g. According to its mechanical composition, the soil type is sandy-loamy.

The field experience with maize hybrids was brought out under irrigated conditions. Irrigation was carried out with a drip irrigation system with built-in drippers at 0.15 m, with an irrigation rate of 15 mm when soil moisture reaches below 75% field capacity for the layer 0-50 cm. Soil moisture dynamics were measured periodically with a soil moisture probe.

The evaluation of the tested variants was carried out by comparing the following indicators determining the quality of the maize: X_1 - plant height, X_2 - number of leaves, X_3 - length of the cob, X_4 - number of rows in the cob, X_5 - number of grains in a row, X_6 - weight per 1000 seeds, X_7 - yield of green mass, X_8 - yield of grain.

A correlation analysis was carried out, aiming to establish the existence of statistically significant correlations between the studied indicators.

The experimental data were processed by correlation analysis (Barov, 1982), with the help of which the interrelationship between the studied indicators was established and assessed. It is expressed by the correlation coefficient r, determined by means of the SPSS statistical program. Such an approach was used to establish the relationship between important agronomic parameters in wheat (Kuneva, 2015), rye (Kuneva, 2018) and soybeans (Mathev, 2014).

RESULTS AND DISCUSSIONS

Agro-climatic conditions

In terms of the dynamics of the average day-night temperature, the first year of the field study was characterized by temperatures close to the norm (Figure 1). The amount and distribution of precipitation during the growing season of corn is characterized by an extremely uneven distribution of the precipitation.

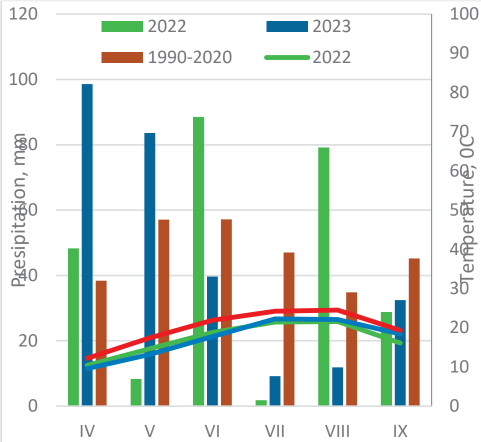

Figure 1. Meteorological characteristics, for the period of corn vegetation, for the region of Stara Zagora

The amount of precipitation recorded in May 2022 was 8.3 mm, 81.4% less than the norm (1990-2020), while in the second year a greater amount of precipitation was recorded (83.6 mm). In the month of June, 88.5 mm was recorded, which is 36.5% above the average amount for a multi-year period. Only 1.8 mm of precipitation fell in July, when the average day-night temperatures started to rise. August is characterized by higher temperatures, but in terms of rainfall, it is better secured. In 2023, July and August are characterized by little rainfall. The agro-climatic conditions during the two years are characterized by an uneven distribution of precipitation during the crop's vegetation. Relatively less rainfall in the spring months and higher temperatures create unfavorable conditions for the development of maize. The deficit of readily available moisture during the months of July and August, against the background of high average daily temperatures, leads to a delay in the development of plants.

Productivity of maize hybrids

Figure 2 presents the results of the first and second experimental year for the production of green mass. From the data, it can be seen that the yield for the two years was highest at Knezha-461 - at Var. 1 (6412.58 kg/day). The productivity of DKC 4416 under Var. 1 is 5805.78 kg/da, and for Pionner P9889, 5937.05 kg/da respectively. LG 31.390 (5405.57 kg/da) and SYNG Premeo (5732.05 kg/da) hybrids are characterized by lower productivity.

After feeding with foliar fertilizers, the results at Var. 2 show that the hybrids were responsive to the introduced nutrients. Of the five hybrids tested, Knezha-461 stands out as the most productive. Green mass yield, on average for the period, was measured at 8,674.72 kg/da. After Knezha-461, P 9889 with a green mass yield of 8305.88 kg/da is not inferior. The lowest results are for the Premeo hybrid, 7529.71 kg/da. The productivity of foliar feeding of the other two herbs is: DKC 4416 - 7890.64 kg/da, LG 31.390-7858.53 kg/da. According to Stewart, (2020) the concentration of Boron in the leaves was not affected by the applied foliar fertilizers. The authors point out that only for manganese an increase was reported.

For Var.3, the hybrids with the highest productivity are Pionner P9889 (8182.65 kg/da) and Knezha-461 (7889.65 kg/da). In this year, the hybrids LG 31.390 (7780.48 kg/da), DKC 4416 (7490.45 kg/da) and the lowest productivity Premeo (7160.08 kg/da) are characterized by lower productivity.

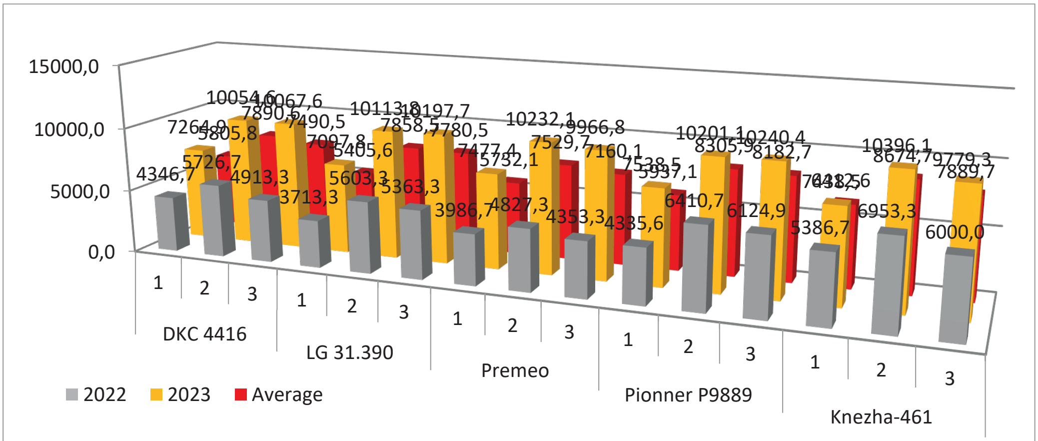

Figure 2. Green mass production for the period 2022-2023, kg/da

Figure 3 shows the results of the first and second experimental years for grain yield. The data shows that the grain yield at Var. 1 is highest at Knezha-461, respectively 1138.04 kg/da. Productivity for hybrids Pionner P9889 is 1040.46 kg/da, and for LG 31.390 is 1059.87 kg/da. Syngenta Premeo hybrids (1022.57 kg/da) and DKC 4416 (980.64 kg/da) are characterized by lower productivity.

After fertilizing with foliar fertilizers, the results at Var. 2 show that the hybrids were responsive to the introduced nutrient elements. Of the five tested hybrids, the highest yielding Pionner P9889 (1379.87kg/da). Pionner P9889 is followed by Premeo with 1356.19 kg/da. The hybrids LG 31.390 (1286.09 kg/da) had lower productivity, then DKC 4416 (1209.89 kg/da), Knezha 460 (1245.41). Foliar fertilization method affects maize growth, Khalafi et al. (2021). The single or combined effects of the experimental treatments with Fe and Z clearly affected the measured parameters - plant height, weight of 1000 grains, corn yield, cob weight, number of rows in a cob, number of grains in a row, the authors found.

In Var.3, the highest grain yield was recorded for the Pionner P9889 hybrid (1310.35 kg/da), followed by Knezha-461 (1197.95 kg/da). With the Premeo hybrid, a reported yield of 1191.30 kg/day was reported. The lowest productivity was reported for DKC 4416 (1163.48 kg/da) and for the LG 31.390 hybrids (1134.50 kg/da).

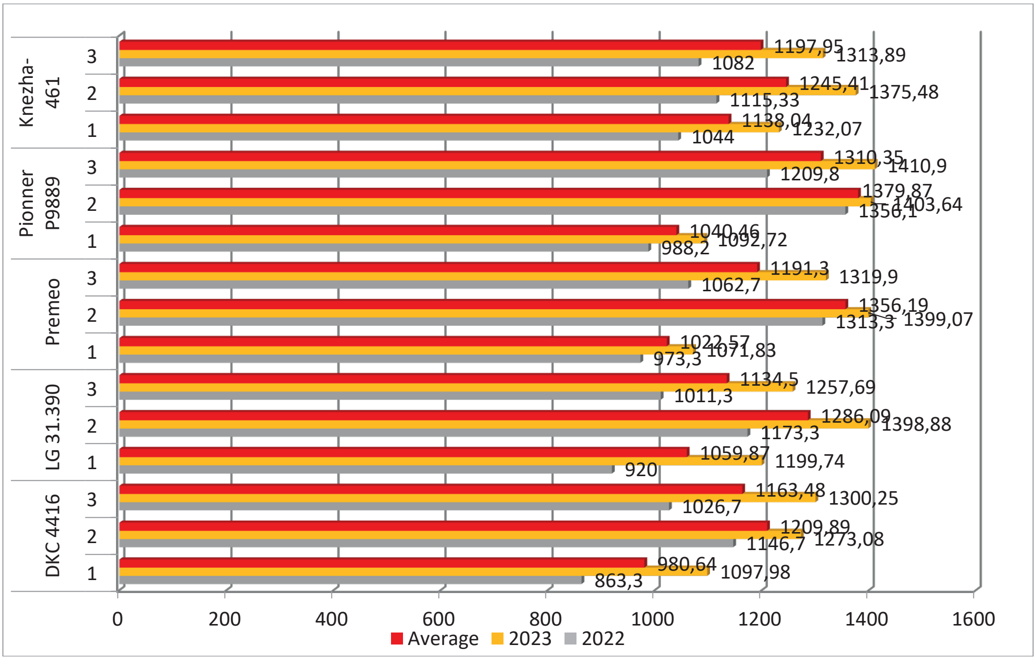

Figure 3. Grain yield for the 2022-2023 period, kg/da

Correlational Analysis

In order to establish the interrelationship between the variables (quantitative and qualitative characteristics) in corn, a correlation analysis was performed. The correlation coefficients, expressing the relationship between the studied indicators, are indicated in the correlation matrix (Table 1).

Quantitative signs are measured in absolute quantities – a concrete numerical expression presented in natural measures - fractions (kg/da), meter (m), number, etc. The strongest positive correlation was found between the number of grains in a row and the mass of 1000 seeds and r = 0.967.

Table 1. Correlation matrix of the quantitative indices

Indicators	X_1- height of the plant	X_2 - number of leaves	X_3 - length of the cob	X_4 - number of lines in a cob	X_5 - number of beans in a row	X_6 - weight per 1000 seeds	X_7 - green mass yield	X_8 - grain yield
X_1- height of the plant	1	0,865	-0,321	0,306	0,528	0,605	0,306	0,473
X_2 - number of leaves		1	-0,315	0,381	0,571	0,701	0,025	0,539
X_3 – length of the cob			1	-0,980**	0,560	0,453	0,743	0,604
X_4 - number of lines in a cob				1	-0,535	-0,388	-0,689	-0,525
X_5 - number of beans in a row					1	0,967**	0,601	0,917*
X_6 - weight per 1000 seeds						1	0,505	0,959**
X_7 - green mass yield							1	0,493
X_8 - grain yield								1

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

Strong positive correlation dependences with grain yield with mass of 1000 seeds, number of grains in a row, respectively with coefficients r = 0.959 and r = 0.917. There is a strong negative correlation between the indicators cob length and number of rows in cob r = - 0.980.

Two-factor analysis of variance

In order to establish the influence of fertilization preparations on the five varieties of corn hybrids, a two-factor variance analysis (ANOVA) was performed. By means of the model of the two-factor dispersion analysis, the power of influence of Plochinsky's method of fertilization on the considered hybrids of corn is investigated.

For the "cob length" indicator (Table 2), the strongest influence of factor A - hybrid with a dominant influence of 36% and with clear reliability $p \leq 0.001$ on the change of the indicator is observed. The unexplained influence due to chance factors is 40%. The interaction between the two factors has not been statistically proven.

Table 2. Two-factor analysis of variance for cob length

Variation Source	SS	df	MS	F	P-value	F crit	Power of influence,%
Hybrid (A)***	22,1923022	4	5,548076	6,549218	0,000	2,689628	36
Variants of treatment (B) ***	7,38519111	2	3,692596	4,358919	0,002	3,31583	11
Interaction (A x B) n.s.	8,55903111	8	1,069879	1,262937	0,29	2,266163	13
Errors	25,4140667	30	0,847136				40

***, **, * - proven at p≤0.001, p≤0.01, and p≤0.05, respectively; n.s. – unproven

The biometric indicator "number of rows in the cob" (Table 3) with the strongest influence is again the factor A - hybrid at $p \leq 0.001$ and a power of influence of 32%, while fertilization rates have a secondary importance and a power of influence of 6% . The interaction between the two factors has not been statistically proven. The unexplained influence due to chance factors is also 55%.

Table 3. Two-factor variance analysis for number of rows in the cob

Variation Source	SS	df	MS	F	P-value	F crit	Power of influence,%
Hybrid (A)***	9,72108	4	2,43027	4,328123	0,000	2,689628	32
Variants of treatment (B) ***	1,77484	2	0,88742	1,580426	0,223	3,31583	6
Interaction (A x B) n.s.	1,88436	8	0,23554	0,419487	0,900	2,266163	7
Errors	16,8452	30	0,561507				55

For the indicator "number of grains in one row" (Table 4), the strongest influence of factor A - variety is observed with a dominant influence of 42% and with a clear credibility $p \leq 0.001$ on the change of the indicator. The unexplained influence due to random factors was 25 %. The interaction between the two factors is statistically unproven.

Table 4. Two-factor variance analysis for number of grains in one row

Variation Source	SS	df	MS	F	P-value	F crit	Power of influence,%
Hybrid (A)***	239,947	4	59,98675	12,15578	0,000	2,689628	42
Variants of treatment (B) ***	141,169	2	70,5845	14,30332	0,000	3,31583	25
Interaction (A x B) n.s.	44,411	8	5,551375	1,124937	0,37	2,266163	8
Errors	148,045	30	4,934833				25

For the "weight of 1000 seeds" indicator, dominant with 32% is the assessment of the power of influence of treatment options, while the character of the variety is significantly less expressed (Table 5). The interaction between the two factors was again not statistically proven.

Table 5. Two-factor analysis of variance for the mass of 1000 seeds

Variation Source	SS	df	MS	F	P-value	F crit	Power of influence, %
Hybrid (A)***	1620,06252	4	405,0156	0,536464	0,71	2,689628	4
Variants of treatment (B) ***	12934,1808	2	6467,09	8,565986	0,000	3,31583	32
Interaction (A x B) n.s.	3287,04576	8	410,8807	0,544232	0,81	2,266163	8
Errors	22649,1982	30	754,9733				56

As a result of the conducted dispersion analysis, a dominant influence of factor A - variety was found, which was most pronounced in the indicator "number of grains in one row" with 42%. The influence of factor B - fertilization rates is much weaker. The dependence between the interaction of the factors in the observed indicators has not been proven statistically.

CONCLUSIONS

As a result of the conducted correlation analysis, correlation dependences were established between the biometric indicators investigated. Strong positive correlation dependences with grain yield with mass of 1000 seeds, number of grains in a row, respectively with coefficients r = 0.959 and
r = 0.917. There is a strong negative correlation between the indicators cob length and number of rows in cob r = - 0.980.

Correlation dependences between green mass yield and the rest of the considered indicators are mathematically unproven.

As a result of the dispersion analysis, a dominant influence of factor A - hybrid was found, which was most strongly expressed in the number of grains in one row with 42%. The influence of factor B is weaker - fertilization rates.

The dependence between the interaction of the factors (A x B) in the analyzed indicators has not been statistically proven.

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