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STATISTICAL ANALYSIS OF THE IMPACT OF MINERAL NITROGEN AND PHOSPHORUS FERTILIZATION ON PRODUCTIVE AND MORPHOLOGICAL TRAITS IN MAIZE (*Zea mays* L.) GROWN AS MONOCULTURE

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Abstract

A five-year field experiment with maize (*Zea mays* L.) grown as a monoculture investigated the effect of mineral fertilization with nitrogen as ammonium nitrate at a rate of 240 t ha⁻¹ and phosphorus as triple superphosphate at a rate of 140 kg ha⁻¹ on ten key agronomic traits. Statistical evaluation of the results was performed using analysis of variance (ANOVA) and correlation analysis.

The ANOVA test confirmed that the differences between the unfertilized control and the fertilized treatments were statistically significant. Correlation analysis revealed strong positive relationships between yield and morphological traits, especially in the fertilized variants. Mineral fertilization significantly increased both grain yield and plant height, while also strengthening the interrelations between productive and morphological traits under monoculture growing conditions. Over the five-year period, the average yield in the fertilized treatments was 46% higher compared to the unfertilized control.

Over the five-year period from 2019 to 2023, a complex effect of precipitation on maize yields was observed. A positive correlation was established between the amount of rainfall and productivity; however, higher rainfall did not always correspond to increased yields. For instance, in 2019, lower rainfall (259.2 mm) was accompanied by a higher yield in the fertilized variant (8.189 t/ha) compared to 2021, when rainfall was greater (331.2 mm) but the yield was lower (5.487 t/ha).

Keywords: correlation analysis, maize, monoculture, mineral fertilization

INTRODUCTION

Maize is a crop that highly responds to nitrogen fertilization, with productivity increasing after fertilization. The uptake of nitrogen before the flowering stage is especially important, as this nutrient supports ear development and affects both the number and size of kernels.

Nitrogen can influence the development and maintenance of leaf area as well as the efficiency of photosynthesis (Arduini et al., 2006), and it also affects the distribution of dry matter to the reproductive organs (Vouillot & Devienne-Barret, 1999; Prystupa et al., 2004). The grain is the most active sink for carbon and nitrogen assimilates during the post-flowering period. Detailed studies in recent years have shown that the nitrogen required for grain filling is assimilated both from the soil and remobilized from the leaves, stems, and ears (Burzaco et al., 2013; DeBruin et al., 2013; Haegele et al., 2013; Duffy, 2014).

The growth and development of crops depend on the supply of nutrients from the soil, and the efficiency of their uptake by the roots plays a key role in determining the productivity potential of cultivated plants (Tegeder and Masclaux-Daubresse, 2017). The efficiency of nutrient uptake by the roots depends on their morphological structure (Lynch, 2019). Nitrogen uptake occurs mainly before flowering and is the primary factor of productivity. Nitrogen determines 75–90% of the final nitrogen content in the grain (Cox et al., 1985a; 1985b). The rate of nitrogen accumulation is determined by the plant's ability to uptake and distribute it (Fageria & Baligar, 2005). Besides nitrogen, phosphorus also influences the number of kernels and the yield, reducing biomass accumulation through a different mechanism than nitrogen (Batten, 1992; Prystupa et al., 2004).

Phosphorus uptake occurs throughout the entire plant lifecycle and, unlike nitrogen, continues until physiological maturity (Batten, 1992). Phosphorus remobilization depends on genotype, mobile phosphates in the soil, growing conditions (drought, high temperatures, salinity), and plant density. Globally, there are limited studies on donor-acceptor processes related to phosphorus, especially under field conditions (Prystupa et al., 2004; Masoni et al., 2007).

MATERIALS AND METHODS

The study was conducted at the experimental field of the Maize Research Institute in Kneja during the period 2019–2023. Field trials were established in three replications under rainfed conditions. As part of the agro-technical practices of maize growing in the region, deep autumn ploughing was performed in November to a depth of 25–30 cm to loosen the soil, create optimal moisture retention conditions, and control the weed infestation. In March of the following year, cultivation was carried out for further soil loosening, breaking up the soil layer, and preparing the seedbed surface. The experiment was conducted with the maize hybrid Kneja 435 (A high-yielding, medium-early maize hybrid bred at the Maize Research Institute – Kneja, characterized by good adaptability to various climatic and soil conditions, a short growing period, and stable productivity under rainfed conditions). The planting density was 55,000 plants per hectare.

In this study, the influence of mineral fertilization with nitrogen (ammonium nitrate) at a rate of 240 kg ha⁻¹ and phosphorus (triple superphosphate) at a rate of

140 kg ha⁻¹ was investigated on grain maize cultivated as a five-year monoculture. The effect of fertilization was evaluated on ten key quantitative traits: ear length (cm), ear spindle weight (g), number of kernels per ear, 1000-kernel weight (g), plant height (cm), height of upper ear setting, number of kernel rows per ear, grain weight per ear, stem diameter, and grain yield. Nitrogen fertilization was applied in spring before sowing, while phosphorus fertilization was applied in autumn.

The statistical analyses performed included Analysis of Variance (ANOVA) to determine the effect of fertilization, environment (year), and their interaction on the studied parameters, as well as correlation analysis to show relationships between the traits.

RESULTS AND DISCUSSION

Meteorological data

The growing seasons (April–September) over the five years were characterized by relatively stable average temperatures and moderate to significant variations in rainfall.

The average temperatures were similar across all years, ranging from 18.65 °C to 19.45 °C, creating favorable conditions for maize development without extreme temperature fluctuations. The lowest rainfall was recorded in 2020 (222.8 mm), and the highest in 2021 (331.2 mm). The other years ranged between 259 and 326 mm, providing varying degrees of soil moisture availability for the crop during the different seasons.

The results are presented in Figure 1.

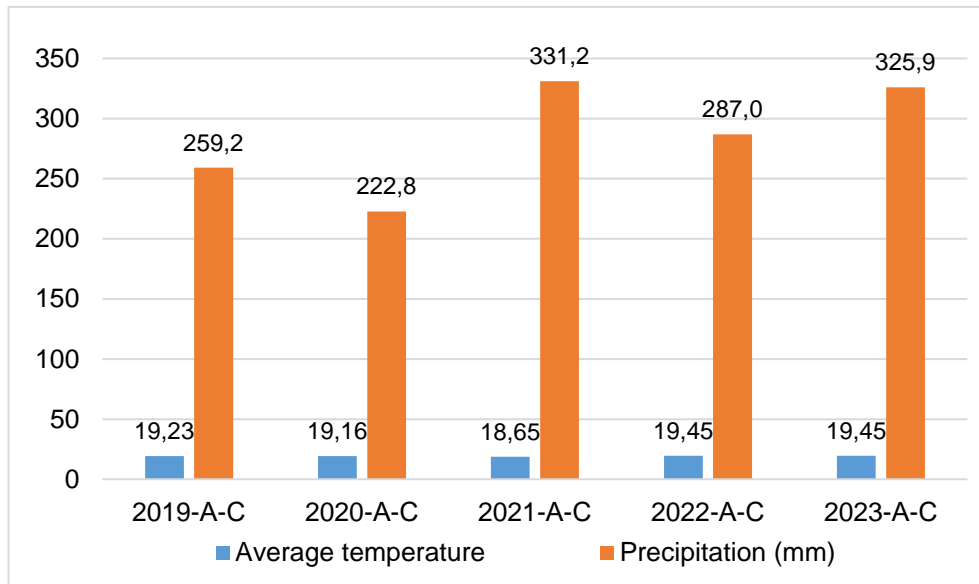


Fig 1. Meteorological Data for the Period 2019–2023

Table 1. Effect of Mineral Fertilization with N₂₄₀P₁₄₀ on Yield, 1000-Grain Weight, and Plant Height in Maize Grown as a Monoculture (2019–2023)

Variants	2019	2020	2021	2022	2023	Average, t ha ⁻¹	% to B ₀
Yield, t ha⁻¹							
Unfertilized	5,129	2,809	4,139	4,699	3,688	4,093	100,00
N₂₄₀P₁₄₀	8,189	3,386	5,487	7,073	5,784	5,984	146,20
Mass of 1000 grains, g							
Unfertilized	376,4	265,1	261,1	268,7	297,4	293,7	100,00
N₂₄₀P₁₄₀	310,4	269,8	270,7	335,5	297,4	296,7	101,02
plant height, cm							
Unfertilized	250,4	220,5	226,5	226,4	258,2	236,4	100,00
N₂₄₀P₁₄₀	278,4	256,7	261,1	263,6	310,1	273,9	115,8

When maize is grown without the application of mineral fertilizer, the recorded yield varies significantly – from 2.809 t ha⁻¹ in 2020 to 5.129 t ha⁻¹ in 2019. In the absence of additional mineral nutrition, it was influenced by the agrometeorological and environmental factors. The analyzed results show that the maximum yield of 8.189 t ha⁻¹ was recorded after the fertilization with N₂₄₀P₁₄₀ in 2019, representing an increase of 59.6% compared to the unfertilized control variant. The data from the table indicate that, compared to the control, fertilized variants increased maize yield throughout all five experimental years.

The average productivity in the fertilized variants under the experimental conditions exceeded the control by 46.20%. The highest increases were observed in 2019 and 2022, demonstrating a stable positive effect of the fertilizer combination even under varying climatic conditions. Similar results were reported by Onasanya (2009) and Zaman Khan (2011), who noted that grain yield increased with higher nitrogen and phosphorus application rates.

Analysis of the thousand kernel weight (TKW) showed that application of N₂₄₀P₁₄₀ did not cause a significant change compared to the control. The recorded increase of 1.02% relative to the unfertilized variant was not statistically significant. These results indicate that the main effect of mineral fertilization manifests primarily in quantitative yield parameters, while individual kernel size remains unchanged.

Under natural soil nutrient availability, the greatest total plant height of 258.2 cm in 2023 was measured, and the shortest (220.5) cm – in 2020. The maximum total plant height of 310.1 cm in 2023 under N₂₄₀P₁₄₀ fertilization was recorded. On average, plants from all fertilized variants treated with N₂₄₀P₁₄₀ were the tallest, with an average height of 273.9 cm, which is 15.8% higher than the control. Khalil (1988) reported that nitrogen and phosphorus, applied separately or in combination, increased plant height.

Analysis of variance of the main indicators (ANOVA)

After performing a dispersion (ANOVA) analysis of the traits, it is proven that there are real, statistically significant differences between the mean values of the studied groups.

The F-value (86.82) is much higher than the critical value (F crit = 1.99).

The p-value (0.01) is extremely low, practically zero.

This means that the factors by which the data are grouped have a strong effect on the results

Table 2. Correlation Relationships Between Major Morphological and Productive Traits in Maize Grown as a Monoculture During the Period 2019–2023

	1	2	3	4	5	6	7	8	9	10
Column 1	1									
Column 2	0,295777	1								
Column 3	0,588798	0,587975	1							
Column 4	-0,04878	0,334765	0,259576	1						
Column 5	0,032403	0,90571	0,313065	0,33569	1					
Column 6	0,078084	0,824631	0,536037	0,581197	0,833524	1				
Column 7	0,417564	-0,02642	0,100127	-0,05461	-0,09075	0,166368	1			
Column 8	0,405796	0,790768	0,747846	0,31036	0,771364	0,816107	0,098055	1		
Column 9	0,39292	0,704782	0,590746	0,221415	0,757721	0,73221	0,045493	0,958959	1	
Column10	-0,26785	0,452292	0,137353	0,487314	0,591473	0,686033	0,330797	0,449551	0,322747	1

1.Ear length (cm) | 2. Spindle weight (g) | 3. Number of kernels per ear | 4. 1000-kernel weight (g) | 5. Plant height (cm) | 6. Height of upper ear placement (cm) | 7. Number of rows | 8. Grain weight per ear (g) | 9. Stem diameter (cm) | 10. Grain yield (t ha⁻¹)

Each column (from 1 to 10) represents a separate year over a five-year period, where:

Columns 1, 3, 5, 7, 9 – years without fertilization (control)

Columns 2, 4, 6, 8, 10 – years with fertilization (N and P)

Values for each trait were recorded annually for both fertilization variants. The correlation between plant height (5) and grain yield (10) was 0.591 (moderate positive correlation) under fertilization; in control years the values were much lower (around 0.03). Spindle weight (2) and grain yield (10) under fertilization showed a moderate positive correlation (0.452), while in the control it was approximately 0.29. Thousand kernel weight (4) showed a weak to moderate correlation with yield under fertilization (0.487) and no correlation under control (-0.049).

The height of the upper ear placement (6) and grain yield had a strong positive correlation after fertilization (0.686), indicating an important anatomical relationship. Grain weight per ear (8) correlated positively with yield under nitrogen and phosphorus fertilization (0.45), stronger than in the control (0.41).

Correlation coefficients in fertilized variants were significantly higher overall, indicating a stronger and more stable relationship between productive and morphological traits as a result of mineral fertilization. Under the control's conditions, correlations were low, which is typical under suppressed or limited growth and greater variability.

Key morphological parameters (plant height and stem diameter) strongly influence productivity, especially when mineral nutrition is provided. Traits such as kernel number per ear and thousand kernel weight are key for yield, which is confirmed by moderate to strong correlations.

Variables with small or negative values (e.g., correlation between ear length and yield in the control) are less strongly related. In the analysis of the unfertilized variant, grain yield showed moderate to strong positive correlations with some key morphological characteristics, reflecting the biological role of these parameters in yield formation.

A particularly strong positive correlation was observed between grain yield and the height of the upper ear placement, with coefficients ranging approximately $r \approx 0.60$ – 0.70 . A higher-positioned ear is a reliable indicator of better overall plant development, leading to increased contribution to final yield.

Additionally, plant height shows a positive correlation with yield with values around $r \approx 0.55$ – 0.65 , indicating that taller plants are associated with better growth and higher yield due to greater biomass and more efficient resource utilization.

Other traits such as grain weight and stem diameter show moderate positive relationships with yield, with correlation values around $r \approx 0.30$ – 0.45 . These factors influence both qualitative and quantitative aspects of production but have less significance for yield compared to ear height and plant height.

Ear length and kernel number per ear are more weakly connected to yield. This can be explained by compensatory morphological mechanisms in maize; for example, shorter but thicker ears with more rows can maintain high productivity, limiting a direct relationship between ear length and total yield.

These results highlight the complex interaction between morphological traits and productivity in maize without additional mineral fertilization. They provide an important reference point for understanding the agrobiological potential and physiological dynamics of the crop under optimal and suboptimal conditions.

In the fertilized variant, with mineral fertilization consisting of 240 kg ha^{-1} nitrogen and 140 kg ha^{-1} phosphorus ($\text{N}_{240}\text{P}_{140}$), stronger correlation dependencies

between grain yield and main morphological traits were observed compared to the unfertilized variant. This shows that fertilization not only increases yields but also stabilizes relationships between the quantitative and qualitative traits of the crop.

Specifically, grain yield correlates positively with the height of upper ear placement with coefficients $r > 0.70$. The strengthened relationship under fertilization shows that a higher-positioned ear is a sign of better morphological development, which leads to increased productivity.

Plant height exhibits an even stronger positive correlation with yield ($r > 0.65$), reflecting improved nutrition and increased biomass supporting higher photosynthetic activity and growth.

Thousand kernel weight also shows a strong positive relationship with yield ($r > 0.50$), indicating that fertilization favors greater kernel filling and weight, thus contributing to increased productivity.

Grain weight and stem diameter also have moderate to strong positive correlations with yield ($r > 0.45$), reflecting the influence of fertilization on the physiological status and structural stability of the plants.

Additionally, the number of kernel rows and kernel number per ear show stronger positive correlations with yield in fertilized variants, which is not as clearly observed in the unfertilized controls. This indicates that mineral fertilization stimulates a more complex morphological response, optimizing the structure of the productive organs.

In summary, the effect of mineral fertilization manifests not only as an increase in absolute yield values but also as enhanced correlations between productive and morphological traits. This suggests a reduction in the influence of random factors on yield and a more efficient integration of growth processes.

Three morphological indicators stand out – plant height, upper ear height placement, and thousand kernel weight – which are the most reliable and statistically significant predictors of high-yielding maize under optimal mineral fertilization.

These data support the use of integrated agronomic strategies including nitrogen-phosphorus fertilization at recommended rates to increase yield and improve morphological characteristics of maize in monoculture systems.

The temperature conditions in our country are generally favorable for growing cereal crops, but precipitation remains a yield-determining factor (Zarkov, 2001). Drought affects most plants and can be the limiting factor for yield (Bruce et al., 2002). During all analyzed years, the average temperature for the April–September period is relatively stable (18.65–19.45°C), which creates favorable conditions for the normal progression of maize phenological stages. The absence of extreme temperature anomalies minimizes the risk of heat stress and ensures uniform plant development.

Precipitation varies significantly between years – from 222.8 mm (2020) to 331.2 mm (2021). The lowest yields were recorded in the years with the least rainfall (2020), confirming that moisture deficiency during critical phases (tasseling, grain filling) limits the yield potential. In years with higher precipitation (2021, 2023), yields increased, especially in the fertilized variant. The obtained data clearly demonstrate that climatic conditions during the growing period are closely

connected to the maize yield, with mineral fertilization applying N₂₄₀P₁₄₀ significantly increasing productivity and reducing the negative effects of the climate conditions.

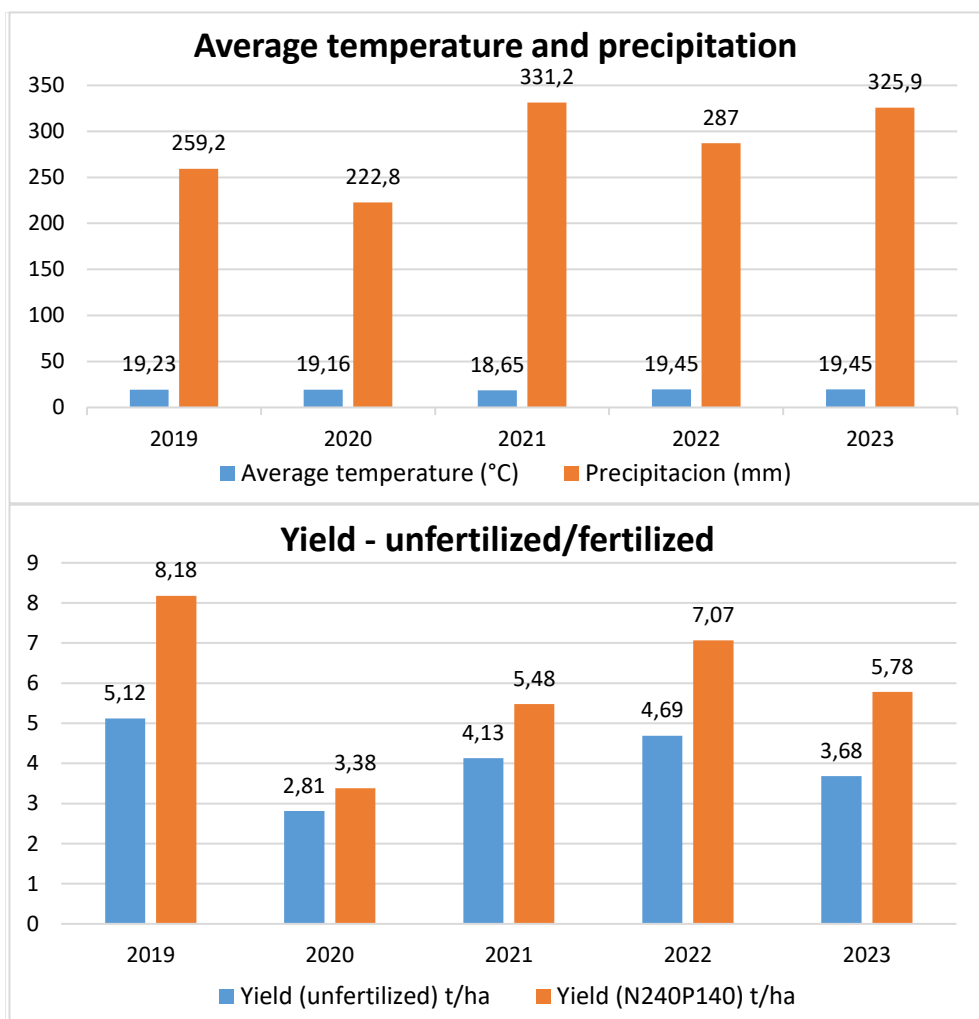


Fig. 2. Relationship Between Climatic Conditions and Maize Yield in Monoculture During the Period 2019–2023

CONCLUSIONS

1. Mineral fertilization with nitrogen and phosphorus had a significant positive effect on maize yield. The average yield under fertilization was approximately 46% higher compared to the unfertilized control over the five-year period. The highest yield of 8.189 t ha⁻¹ was recorded in 2019 under N₂₄₀P₁₄₀ fertilization, which is 59.6% higher compared to the unfertilized variant (5.129 t ha⁻¹) in the same year

2. Mineral fertilization improved maize morphological characteristics, such as plant height, upper ear placement height, stem diameter, and grain weight, all of which show positive correlations with the yield. The average total height of plants in the fertilized group is 273.9 cm, which is 15.8% higher than that of the control group (236.4 cm). In 2023, a maximum height of 310.1 cm was recorded under N²⁴⁰P¹⁴⁰ fertilization, whereas the control reached 258.2 cm. These results confirm that nitrogen and phosphorus stimulate plant growth.

3. Thousand kernel weight was not significantly affected by mineral fertilization. The observed difference compared to the control was statistically insignificant.

4. Correlation analysis revealed a significant positive relationship between morphological and productive traits, with this dependence being especially pronounced in the fertilized variant.

5. Monoculture intensified the need for external mineral fertilization due to the depletion of natural nutrient resources in the soil.

6. Statistical analyses (ANOVA and correlation) confirmed the significance of nitrogen and phosphorus fertilization as factors determining the quantitative and qualitative traits of maize.

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