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Fertilization and maize yields in a four-year cycle crop rotation under various soil and climatic conditions

Торенето и добивите от царевица в четириполно сеитбообращение при различни почвено-климатични условия

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ABSTRACT

Crop rotation is the main factor in reducing losses caused by weeds, diseases, and pests and increasing yields, which has been used little in recent years in intensive agriculture. The study aimed to estimate the influence of two rates of nitrogen-phosphorus mineral fertilization on the yield of maize grown in a four-year cycle crop rotation - under various soil and climatic conditions. During the period 2020-2023 field experiments on two different soil types with their specific characteristics have been carried out - Leached Smolnitsa (Haplic Vertisol) and Alluvial-meadow soil (Eutric Fluvisol) in the experimental station of ISSAP "N. Poushkarov", the town of Bozhurishte (Sofia region) and the village of Tsalapitsa (Plovdiv region). The maize was included in the structure of a four-year cycle crop rotation: 1) maize, 2) wheat, 3) maize and 4) wheat. A test crop was a mid-early maize hybrid "P-8834" by "Pioneer" from group 310, according to FAO. Two factors from the general agrotechnical complex were studied: soil-climatic conditions and rates of mineral fertilization. It was established that the studied fertilizer rates were an important factor in increasing the yields, which determined more than 57.82% and 97% of the variation of the data, respectively for Leached Smolnitsa and Alluvial-meadow soil. With the increase in the rate of nitrogen and phosphorus fertilizers, the productivity of maize grown on both soil types also increases. As a result of the use of nitrogen-phosphorus mineral fertilization, more than twice as high yields were obtained, compared to the non-fertile variants. The influence of the soil-climate conditions (precipitation and temperature conditions) during this period was also analyzed. It was established that they are a significant factor which has a strong influence on the obtained high (good) yields of non-irrigated maize cultivated in the field of Bozhurishte.

Keywords: maize, crop rotation, fertilization, yield, soils, climatic conditions

РЕЗЮМЕ

Сеитбообращението е важен фактор за намаляване на загубите причинени от плевели, болести, неприятели, за повишаване на добивите, който е малко използван през последните години в интензивното земеделие. Целта на изследването е да се проследи влиянието на две норми на азотно-фосфорно минерално торене върху добива от царевица, отглеждана в четириполно сеитбообращение при различни почвено-климатични условия. През периода 2020-2023г. са изведени полски опити на два различни по своите характеристики почвени типа - Излужена смолница и Алувиално-ливадна почва в опитните бази на ИПАЗР „Н. Пушкаров", в гр. Божурище, Софийскои в с. Цалапица, Пловдивско. Царевицата е включена в структурата на четириполно сеитбообращение: 1) царевица, 2) пшеница, 3) царевица, 4) пшеница. Използван е средно-ранен хибрид царевица „P-8834" на „Пионер" от група 310 по FAO. Проучвани са два фактора от общия агротехнически комплекс: почвено-климатични условия и норми на минерално торене. Установено е, че изследваните торови норми имат основно значение за увеличаване на добивите, като този фактор определя повече от 57,82 % и 97% от варирането на данните, съответно при Излужена смолница и Алувиално-ливадна почва. С нарастване на нормата на азотните и фосфорни торове се повишава и продуктивността на царевица, отглеждана и на двата почвени типа. В резултат на използването на азотно-фосфорно минерално торене са получени над два пъти по-високи добиви спрямо неторените варианти. Анализирано е и влиянието на почвено-климатичните условия (валежи и температурни условия) през този период. Установено е, че те са съществен фактор, оказващ несъмнено ценно влияние за получаване на високи (добри) добиви от неполивната царевица в опита в гр. Божурище.

Ключови думи: царевица, сеитбообращение, торене, добив, почви, климатични условия

INTRODUCTION

Obtaining optimal and sustainable crop yields in modern agriculture is the main purpose. The achievement of that purpose is possible only through optimization of growing conditions which makes it possible for faster adaptation of plants to constantly changing environmental conditions (Dimitrov et al., 2011; Kiniry et al., 2004). Crop rotations are one of the main agro-technical measures that largely increase agricultural production without additional resources. However, its design may need to consider different conditions to maximize its agronomic and ecological benefits (Zhao et al., 2020). The principles are a variation of crops through time and space of the field and landscape; increasing the ability of crops to suppress weeds, pests and diseases; alternation of crops through different rooting depths; any complete crop rotation must maintain or increase soil organic matter (Boincean and Dent, 2019; West et al., 1996; Karlen et al., 2013).

Maize (*Zea mays* L.) is an important cereal and multifunctional crop in the Poaceae family, it is used in human food, animal and poultry feed, and industry for a variety of purposes including maize starch, dextrose, maize syrup, and maize flakes (Gul et al., 2021; Berzsenyi et al., 2000). It also grows well in a wide range of soil and climate conditions. It extracts more nutrients than other crops, such as tiny grain cereals and grain legumes (Gheith et al., 2022). Balanced nutrition is an imperative feature which shows a main function in achieving quality production of maize. The presence of nutrients like magnesium, phosphorus, nitrogen and potassium in well-balanced forms is necessary for plant growth, development and final yield (Adnan, 2020; Wyszkowski and Brodowska 2021; Li et al., 2020). The fungal diseases and a stronger increase in weed cause a decrease in grain yield. The adverse water, air regime and soil structure also have a negative impact. Another reason could be a negative balance of humus and nutrients in the soil. The disrupted balance of the agroecosystem can be compensated by the rotation of crops with different physiological nutrient requirements. The stability of the agrosystem can be achieved by using scientifically based fertilization rates, as well as by appropriate pesticide applications (Babulicová, 2014). The efficiency of nitrogen fertilization is evaluated most often with respect to the amount of quality changes in grain yield (Merbach and Schulz, 2013). It is an essential component of a wide range of biological chemicals that play critical roles in photosynthetic activity, and agricultural productivity. Nitrogen availability can influence maize plant growth and grain yield (Gheith et al., 2022; Yue et al., 2022). Nitrogen fertilizer affects maize dry matter production by influencing leaf area development, maintenance, and photosynthetic efficiency (Shah et al., 2021a).

Studying the effect of 4 increasing norms of nitrogen fertilization on maize Shapiro and Wortmann (2006) showed that nitrogen fertilization increased biomass production by an average of 22% and grain yield by 24%. In addition, the provision of an appropriate nutritional regime through mineral fertilization, as one of the factors for stable crop productivity, is a condition for sustainable and effective development of grain production (Petkova et al., 2011; Ogunlela et al., 1998). Fertilizers are an effective means of increasing yields, but they often harm the environment. An understanding of the processes, related to the efficient use of nitrogen fertilizers, is important in determining strategies for the development of sustainable agriculture, as well as for environmental protection (Kogbe et al., 2003; Masood et al., 2003; Mikova et al., 2011).

The present study aimed to estimate the influence of two rates of nitrogen-phosphorus mineral fertilization on the yield of maize grown in a four-year cycle crop rotation under various soil and climatic conditions.

MATERIALS AND METHODS

During the period 2020-2023, field experiments were carried out on two different soil types according to their characteristics: Leached Smolnitsa and Alluvial-meadow soil in the experimental stations of ISSAPP "N. Poushkarov", in the town of Bozhurishte, (Sofia region) and the village of Tsalapitsa, (Plovdiv region). The experiment was set up on an area of 0.3 ha according to the block method in four replications (with the size of the experimental plots 90 m^2). The maize (*Zea mays*, L.) was included in a four years cycle crop rotation with the following rotation: maize (2020) - wheat (2020-21) - maize (2022) - wheat (2022-23). A test crop was a mid-early maize hybrid "P-8834" by “Pioneer” from group 310, according to FAO, with good productivity and resistance to stress factors. Two factors from the general agro-technical complex were studied: soil-climatic conditions and rates of mineral fertilization.

The field experiment in Bozhurishte (Sofia region) was carried out under non-irrigated conditions on Leached Smolnitsa (Haplic Vertisol; FAO, 2015). This type of soil is representative of the heaviest soil variety, in terms of mechanical composition and is described by Koinov et al. (1998) in Bulgaria (Table 1).

The field experiment in Tsalapitsa (Plovdiv region) was carried out under irrigation conditions on Alluvial-meadow soil (Eutric Fluvisol), (IUSS Working Group WRB, 2015). In terms of mechanical composition, the Eutric Fluvisol is light to medium sandy loam with a predominance of sandy mechanical elements over the silty fraction (Stoichev, 1997) (Table 1).

In relation to climate, the two experimental fields differ significantly from each other. The Bozhurishte experimental field is located in the Sofia soil-geographical region of Southwestern Bulgaria. The climate is relatively cool. The average annual amount of precipitation for the 80 years (1901 – 1980) is 593 mm. The maximum precipitation in the V-VI months and the minimum in the I-III months are clearly expressed.

The Tsalapitsa experimental field is located in the Plovdiv region, South Bulgaria. The climate in the area is hot with dry summers, mild winters, and irregular rainfall distribution. The period accepted as a norm 1961-1990 has an amount of precipitation of 492 mm. The average annual air temperature is 12.5-12.8 °C, in July – 23.4, and in January it is around zero degrees Celsius.

Data for the amount of precipitation and air temperature for the growing season of maize, grown on both soil types, were collected through the "Agrila" weather station.

Three increasing rates of nitrogen-phosphorus mineral fertilization were tested as follows in both soil types: T_1 – $N_{120}P_{80}$ and T_2 – $N_{160}P_{120}$ kg/ha. The control was a variant without fertilization (T_0), in which no fertilizers were used for many years. Fertilization rates were determined based on the soil's supply of nutrients, according to

Table 1. Soil properties of the two investigated soil differences

Soils characteristics	Power of Humus horizon (cm)	Content of physical clay (%)	Dry bulkdensity (g/cm^3)	pH (H_2O)	Total N %	Hummus %	Mechanical composition
Haplic Vertisol (Bozhurishte)	100	78 - 80	1.95 - 2,0	6.20	0.139	3.02	Medium clay
Eutric Fluvisol (Tsalapitsa)	30	18,6	1.54 - 1.66	6.0	0.052	1.23	Light to medium sandy loam

the model of giving recommendations for fertilization (Archiv „N. Pushkarov" Institute of Soil Science, 1982). Mineral fertilizers were imported as ammonium nitrate and superphosphate. Fertilization with nitrogen and phosphorus was carried out before sowing the crop with spring pre-sowing treatments. In the experimental field of Tsalapitsa, 3-4 irrigations were carried out with a drip irrigation system with a rate of about 80 m^3, in July and August for both years of maize cultivation. Main and additional production in kg/ha was reported.

The statistical processing of the maize grain yield data was done by a two-factor analysis of variance with factors of "year" of experiment and "rates of mineral fertilization", Multifactor ANOVA from the statistical package Statgraphics 18.

RESULTS AND DISCUSSION

Soil-climatic conditions strongly influence plant growth and productiveness (Marijanovic et al., 2010). The temperature conditions for a vast part of our country, are favorable for the cultivation of cereal crops, but precipitation is a determining factor for yield formation (Zarkov, 2001; Bruce et al., 2002). Extreme weather conditions are often the cause of a strong reduction in yields (Toncheva, 2016). During the two experimental years, the weather conditions differed by the total amount of precipitation during the growing season. In the experimental field of Bozhurishte, Sofia region, the growth and development of maize during the 2020 growing season were carried out with a very good rainwater inflow from germination to full maturity (428.5 mm). This amount was higher than the average for a multi-year period (1901 – 1980), but a dry period was reported in July with precipitation of only 43 mm. Despite this deficiency, a plant's development in the variants with fertilization was normal and the stress was not observed. In August, the rainfall of 89 mm ensured a good development of the maize plants and a favorable passing to the phase "milk maturity". The precipitation in October of 113 mm, at the end of the maize growing season, was the reason for the later ripening of the grain and its harvesting (Figure 1). In 2020, in the experimental field of Tsalapitsa, Plovdiv, during the spring period, the amount of precipitation of 188 mm was sufficient and even higher than the requirements of the crop for its phenological development. Precipitation amounts by month for the period of active vegetative development were below the norm, except for during June (50 mm), which in terms of amount was quite close to the amount for the multi-year period 1961-1990 (Figure 2). In Figure 2 the periods of drought were presented, which appeared to be stronger and longer during the summer months - starting from May and until November in 2020. This period was most prominent, starting from the winter months. During the growing season, extremely high temperatures (above 30-35 °C) were not observed, which had a positive effect on the development and the yield obtained for the cultivated crop (Figure 1). Thermal conditions during the year do not hinder the development of maize (Figure 2). Comparing climatographies for Tsalapitsa and Bozhurishte for the studied year 2020, it could be observed that the drought periods for the whole period were longer for Tsalapitsa.

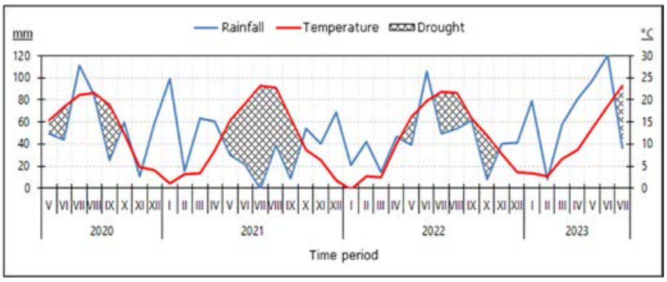

Figure 1. The average monthly temperature, the monthly amount of precipitation and the drought period (Bozhurishte, 2020-2023)

From the presented climatography (Figure 1), it was established that in 2022, during the maize growing season (the period May – September), the amount of precipitation was 365 mm., This is above the average for a multi-year period. The amount of precipitation in the experimental field Bozhurishte was the highest in the second week of June (110 mm), which had a favorable effect on the growth and development of maize. The rainy period lasts until the end of June, after which a drought period occurs (from the end of July, through August till the beginning of September), with at least 50 mm of precipitation in August (Figure 1). Despite the reported rainfall deficit, stress in the vegetation of the plants was not observed and relatively good yields were obtained from the grown hybrid maize under non-irrigated conditions. From the presented climatography for the Tsalapitsa experimental field (Figure 2), it was established that 2022 was characterized as drier, compared to the multi-year period. This trend was observed almost throughout the year. Close to the norm are the winter months of January and February, as well as June. Total precipitation for the period was 308.3 mm, at a multi-year norm of 497.8 mm. Regarding the temperature factor, there was also a tendency for an increase in the average monthly air temperature by an average of 1.9 °C for the whole year. During the summer months - June, July and August, the air temperature was on average 2.4 °C higher than the multi-year norm. Regardless of the lower humidity in the March-April period, the winter precipitation provides relatively good soil moisture retention. The low amount of precipitation that fell in May - only 16.5 mm, compared to the norm – (59.9 mm), was adversely affected. A satisfactory amount of precipitation has fallen in the middle of June, which supports the development of the crop and compensates for the lack of moisture in the soil. Thanks to the installed drip irrigation system and the well-timed supply of the necessary irrigations, the maize developed well during the hot and dry summer months from July to September, which led to obtaining very good yields – 11,000 kg/ha from the variants with applied mineral fertilization.

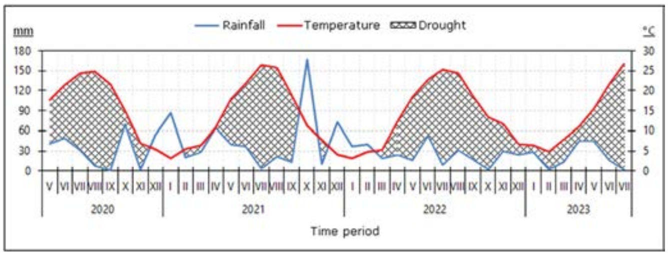

Figure 2. The average monthly temperature, the monthly amount of precipitation and the drought period (Tsalapitsa, 2020-2023)

From the assessment of the weather conditions of the experimental field Bozhurishte and Tsalapitsa, it can be concluded that they are an important factor for the vegetative development of the plant. The fallen precipitation in the Bozhurishte experimental field was extremely important for growth and biomass formation, especially for non-irrigated maize. However, it was established that in 2020 and 2022 the agroclimatic conditions in Tsalapitsa experimental field were less favorable (with high average temperatures, less precipitation and significant periods of drought. That is why it was essential to carry the agro-technical measures out promptly and provide the necessary number of irrigations to obtain high yields and quality maize production.

The results show that in both studied soil types, higher maize yields were obtained in the 2020 growing year compared to those in 2022. In the Bozhurishte experimental field of the Haplic Vertisol soil type, the soil-climatic conditions are an essential factor influencing the good development of plants. The fallen precipitation during the maize growing season (July and August 2020) of 120 mm and the good temperature conditions during the main phenological phases "growth stage", "milk maturity" and "pouring the grain of the maize", favored obtaining stable yields from the studied maize variety, grown under non-irrigated conditions. In the first year, the reported maize grain yield ranged from 4,310 kg/ha in the unfertilized variant (T_0) to 10,992 kg/ha in the variant with the highest fertilization norm (Table 2). In 2022, yields were lower, with at least 50 mm of fallen precipitation in August, and this hurt the phenological phases of the "tasselling" and the "pouring period of the maize grain". The reported maize grain yield was in the boundaries of 3,358 kg/ha in the no-fertilization variant (T_0) to 8,088 kg/ha in the fertilized variant (T_2). The effect of soil-climate conditions on the growth and yield of different maize hybrids was studied by Khaliq et al. (2009). Three maize hybrids and five nitrogen fertilization rates are compared. An estimation of the yield and components of the yield in different soil-climatic conditions was conducted. Optimum temperatures and precipitation contribute to an increase in the growth rate, nitrogen export, and ultimately to an increase in yield (Mikova et al., 2011). The results show that the factor "fertilization" had the largest share in yield formation, as on average for the study period (2020/2022). A higher yield was reported in the fertilized variant with a higher T_2 fertilization rate applied ($N_{160}P_{120}$) - an average of 9,540 kg/ha. This is twice as much, compared to the no-fertilization variant. The obtained average yield for the study period from the non-fertilized variant was 3,834 kg/ha. This relatively high level of yield in the control shows that the Haplic Vertisol soil type has a favorable natural fertility considering the fact that for more than 25 years this area has not been fertilized (Table 2).

In Tsalapitsa experimental field the climatic conditions during 2022 are characterized by a low amount of precipitation. The precipitation amounts per month for the period of active vegetative development were below the norm, and in the summer months, only 16.5 mm (with the norm - 59.9 mm), with high average temperatures and significant periods of drought. Through the installed drip irrigation system in July and August, 3-4 irrigations with a rate of about 80 m^3 were carried out in the experimental field "Tsalapitsa". This contributed to the good development of maize during the hot and dry summer months from July to September and obtaining very good yields. In 2020, the reported average maize grain yield varied from 3,818 kg/ha in the control variant T_0 - without fertilization to 12,096 kg/ha in the variant with the maximum level of fertilization $T_2(N_{160}P_{120})$. The amount of difference between these two variants was three times. High yields were also found in the variant with lower fertilization levels $T_1(N_{120}P_{80})$ - on average 10,961 kg/ha. In 2022, the yields were lower, with an average yield of 2,188 kg/ha in the non-fertilized variant, which proved to be different from the two variants with applied fertilization. The highest yield was obtained at the variant $T_2(N_{160}P_{120})$ - an average of 11,889 kg/ha and was five times higher than the variant without fertilization. The results show that fertilization had the largest share in yield formation, as on average for the study period (2020/2022), a higher yield was reported in the fertilized variants with a higher fertilization rate applied (T_2 - $N_{160}P_{120}$), an average of 11,993 kg/ha, which is four times more than the non-fertilization variant (Table 2).

The effect of soil-climate conditions on the growth and yield of different maize hybrids was also studied by (Ahmad et al., 2007). They observed significant variability of the investigated parameters in individual regions with increasing nitrogen rates. In the present study, it was established that the applied fertilization with nitrogen and phosphorus fertilizers had a significant influence on the obtained yields in both investigated soil types.

Table 2. Maize yield (in kg/ha) in experimental fields Bozhurishte and Tsalapitsa (2020 and 2022)

Fertilization rates	Yields from years of research and experimental field								
	2020			2022			Average over the study period		
	кg /ha	to T_0		кg /ha	to T_0		кg /ha	to T_0	
		кg /ha	%		кg /ha	%		кg /ha	%
Bozhurishte experimental field									
T_0	4,310	-	100.0	3,358	-	100.0	3,834	-	100.0
$T_1(N_{120}P_{80})$	10,728	6,418***	248.9	7,247	3,889***	215.8	8,987	5,153***	234.4
$T_2(N_{160}P_{120})$	10,992	6,682***	255.0	8,088	4,730***	240.8	9,540	5,706***	248.8
Tsalapitsa experimental field									
T_0	3,818	-	100.0	2,188	-	100.0	3,003	-	100.0
$T_1(N_{120}P_{80})$	10,961	7,143***	287.1	10,241	8,053***	468.0	10,601	7,598***	353.0
$T_2(N_{160}P_{120})$	12,096	8,278***	316.8	11,889	9,701***	543.3	11,993	8,990***	399.3

*** Statistical significance at 0.001%

The favorable weather and soil conditions of Leached Smolnitsa (Haplic Vertisol) and the applied mineral fertilization were major factors contributing to the optimal development of plants and the good average yields obtained from grain maize grown under non-irrigated conditions. They were highest in variant T_2 ($N_{160}P_{120}$), respectively - 10,992 kg/ha for 2020 and 8,088 kg/ha for 2022 (which was lower). The obtained average yields of maize for grain grown under irrigated conditions (Alluvial meadow soil) are higher, compared to those reported at Leached Smolnitsa. They are highest again in the variant with applied high rates of T_2($N_{160}P_{120}$) fertilization, respectively - 12,096 kg/ha for 2020 and 11,889 kg/ha for 2022. The applied mineral fertilization was a main factor that had an impact on obtaining high yields, and the irrigation carried out during the maize vegetation also significantly contributed to this.

The two-factor analysis of the maize grain yield data (kg/ha) is presented in Table 3. It was established at the Bozhurishte experimental field, Sofia, the proven impact of factor C - fertilization, $P \leq 0.05$. A very high percentage (57.82 %) of the reason for the variation in the experiment is due to this factor. The "year" of research – factor A had a proven impact of 28.18% (Table 3).

Table 4 presents the grouping of the years of research into homogeneous classes, LSD = 109.1 at a confidence level of 95%. When comparing the years of research, yields in the first year form a homogeneous class "b", and in the second a homogeneous class "a", i.e. significant differences have been demonstrated between these years. Fisher's method was used to separate the means (least significant difference - LSD).

Table 4. Grouping of research years into homogeneous classes at a confidence level of 95%

Year	Count	LS Mean	LS Sigma	Homogeneous Groups
2	18	5307.25	283.405	a
1	18	8408.22	283.405	b

Contrast	Sig.	Difference	+/- Limits
1 - 2	*	3100.97	817.43

* denotes a statistically significant difference

Graphical distribution of maize grain yield in the two studied years 2020 and 2022 on the Leached Smolnitsa soil type was presented in Figure 3.

From the two-factor dispersion analysis of the yield of maize (kg/ha) in the Tsalapitsa experimental field, Plovdiv region, it was established the proven impact of the factor C "fertilization", $P \leq 0.05$. A very high percentage (97.02 %) of the reasons for variation in the experiment was due to this factor. The "year" of research – factor A had not a proven impact and is characterized only by 2.17% (Table 5).

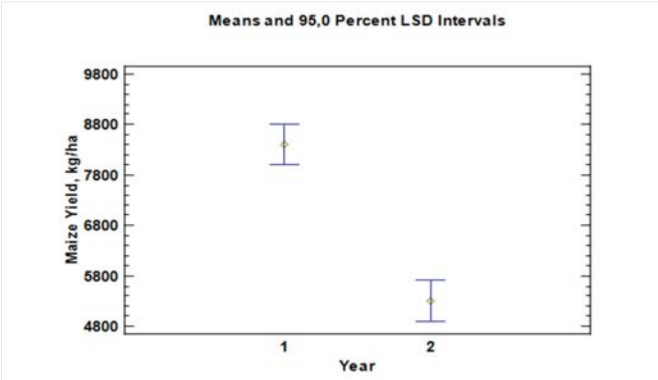

Figure 3. Influence of the years on the average yield of maize (in kg/ha, Bozhurishte)

Table 3. Effect of year and norms of fertilization on maize yield (in kg/ha) (Bozhurishte, 2020 and 2022)

Source	Sum of Squares	%	Mean Square	F-Ratio	*P*-value
Main effects					
A: Year	8,654	28.18	8,654	59.86	0.000
C: Norm fertilization	1,851	57.82	9,256	64.03	0.000
Residual	4,481	14.00	1,445		
Total (corrected)	3,201				

Table 5. Effect of year and norms of fertilization on maize yield (in kg/ha) (Tsalapitsa, 2020 and 2022)

Source	Sum of Squares	%	Mean Square	F-Ratio	*P*-value
Main effects					
A: Year	2,459	2.17	2,459	8.07	0.065
C: Norm fertilization	1,098	97.02	3,662	120.14	0.001
Residual	914633	0.81	304878		
Total (corrected)	1,132				

All F-ratios are based on the residual mean square error

The analysis of variance shows that only the factor "fertilization norms" from the studied factors gave statistically significant and proven differences at a confidence level of 95.0% on the yields of maize (kg/ha).

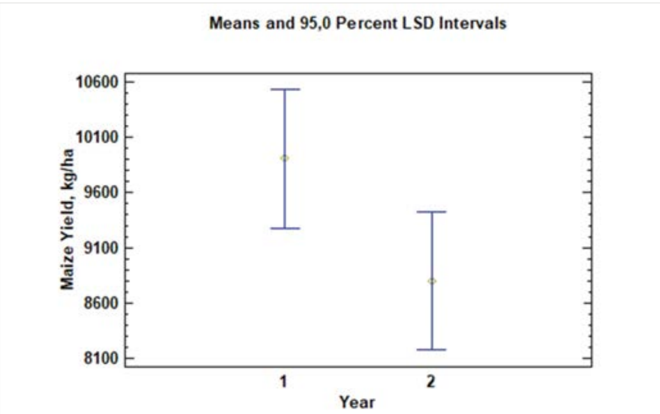

Figure 4. Influence of the years on the average yield of maize (in kg/ha, Tsalapitsa)

Table 6 shows that the two studied years fall into one homogeneous group and there are no statistically significant differences between them at the 95.0% confidence level.

Table 6. Grouping of research years into homogeneous classes at a confidence level of 95%

Year	Count	LS Mean	LS Sigma	Homogeneous Groups
2	3	8800.0	276.079	a
1	3	9909.0	276.079	b

Contrast	Sig.	Difference	+/- Limits
1 - 2		1109.0	1242.54

* denotes a statistically significant difference

CONCLUSION

From the assessment of the soil-climatic conditions (precipitation and temperature conditions) of the Bozhurishte experimental field, it can be concluded that they were a significant factor influencing the yield of non-irrigated maize. The role of soil moisture on the growth rate and the formation of maize yields was confirmed. In 2020 and 2022, in the Tsalapitsa experimental field, the agro-climatic conditions were less favorable, which necessitates the timely implementation of agro-technical measures to provide the required number of irrigations during the vegetation of the crop. The results for the grain yield prove the leading role of fertilization. It was established that the applied higher rate of nitrogen and phosphorus fertilization $T_2(N_{160}P_{120})$ when growing maize was more effective in both soil types, despite the differences in their characteristics. The statistical analysis found that the studied fertilizer norms were of primary importance for increasing maize yields, and this factor determined more than 57.82% and 97% of the data variation in Leached Smolnitsa and Alluvial-meadow soil, respectively. With an increase in the norm of nitrogen and phosphorus fertilizers, the productivity of maize grown on both soil types increases. The norms of fertilization are similar. The use of nitrogen-phosphorus mineral fertilization contributes to more than twice higher yields compared to those obtained from the no-fertilization variant.

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