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Partial economic assessment of maize grain yield under rainfed conditions using fertilizers of different origins

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Abstract

Maize is the most important feed grain crop worldwide and plays a central role in global food, feed, and industrial production systems. It covers more than a half of the cultivated areas (55%) and nearly three-quarters (72%) of the grain production of all feed crops worldwide. It is a major raw material used for the production of a wide variety of products, mainly concentrated and compound feeds, as well as various food and industrial products such as starch, alcohol, cellulose, paper, construction and insulation materials, among others.

Economic analysis of fertilizer use is increasingly recognized as a key component of sustainable agricultural decision-making. This study presents an extended partial economic assessment of grain maize production under non-irrigated conditions, based on real experimental data obtained at the Bozhurishte experimental field in 2023. The analysis was conducted for all experimental variants, as seven fertilization variants were evaluated using grain yield, taking into account the most important indicators characterizing economic efficiency in maize production. The following indicators were analyzed: grain yield (GY), grain revenue (GR), direct production costs (DPC), net income (NI), profitability rate (PR) and benefit–cost ratio (BCR).

The results revealed that yield maximization does not coincide with economic optimization. Variants characterized by lower input intensity achieved higher economic efficiency, while excessive fertilization resulted in negative economic outcomes. The findings provide a solid economic basis for optimizing fertilization strategies under rainfed maize production systems.

Under conditions of increasing climatic variability, particularly irregular precipitation, economic efficiency becomes a decisive factor in crop management. Rainfed maize production systems are exposed to high yield risk, which amplifies the negative economic consequences of high input intensity. The results of the present study clearly demonstrate that fertilization variants with excessive input costs are economically vulnerable under such conditions.

Key words: maize, economic efficiency, benefit–cost ratio (BCR), grain yield (GY), grain rev-

enue (GR), direct production costs (DPC), net income (NI), and profitability rate (PR), fertilization strategies

Introduction

Maize is the most important feed grain crop worldwide and plays a central role in global food, feed, and industrial production systems (Tilman et al., 2002; Mueller et al., 2012). Traditionally, maize is the second most important cereal and agricultural crop in Bulgaria, after wheat. Improving nutrient management is essential for increasing productivity while reducing environmental impacts, particularly nitrogen losses (Cassman et al., 2002). Nitrogen fertilization has been and will continue to be indispensable for achieving high maize yields in order to meet the growing global demand for food (Zhang et al., 2013; Chen et al., 2015; Li et al., 2021; Yue et al., 2021). However, excessive use of nitrogen fertilizers in agriculture has contributed to a range of environmental problems, including increased greenhouse gas emissions and serious water pollution (Duan et al., 2016; Nazarkov, 2024; Boiko et al., 2024). Determining the appropriate fertilizer rates, forms, application methods, and timing is of crucial importance for ensuring optimal crop development while minimizing negative impacts on the environment (Nikolova et al., 2014).

Materials and Methods

A field experiment was conducted during the 2023 growing season with an early maize hybrid (*Zea mays* L.), Phenomen (FAO 160) by Syngenta, at the experimental base Bozhurishte of the Institute of Soil Science, Agrotechnologies and Plant Protection “N. Pushkarov” (ISSAPP), Sofia Province. The experimental basis is located in the High Plains region of Western Bulgaria, within the Sofia Kraishte ecological region.

The experiment was established using a randomized block design (standard) with long plots, covering a total area of 0.615 da. The study

included seven fertilization variants (V1–V7), arranged in three replications, with a harvest plot size of 25 m².

The present scientific study includes a total of seven fertilization variants and the applied amounts of mineral and organic fertilizers, as well as their combined use, expressed in kg.da⁻¹. Variant 1 (V1) was unfertilized. The second variant (V2) included the application of a combined NPK fertilizer at 20 kg.da⁻¹ plus ammonium nitrate (NH₄NO₃) at 40 kg.da⁻¹. The third variant (V3) involved the application of NPK at 20 kg.da⁻¹ combined with a plant-based organic fertilizer, Leili Alga Soil, at a rate of 20 kg.da⁻¹. The fourth variant (V4) consisted of NPK at 20 kg.da⁻¹ combined with an animal-based organic fertilizer, Fertipolina, at 40 kg.da⁻¹. The fifth variant (V5) included the application of reduced mineral fertilizer rates by 50% - NPK at 10 kg.da⁻¹ plus NH₄NO₃ at 20 kg.da⁻¹, combined with the plant-based organic fertilizer Leili Alga Soil, at the recommended application rate of 20 kg.da⁻¹. The sixth variant (V6) involved the application of reduced mineral fertilizer rates by 50% - NPK at 10 kg.da⁻¹ plus NH₄NO₃ at 20 kg.da⁻¹, combined with the animal-based organic fertilizer Fertipolina, at the standard application rate of 40 kg.da⁻¹. The seventh variant (V7) represented combined fertilization with increased application rates (150%) of organic products of plant and animal origin - Leili Alga Soil (30 kg.da⁻¹) and Fertipolina (60 kg.da⁻¹). Organic amendments contribute to long-term soil fertility by improving soil structure, microbial activity, and nutrient availability.

The soil at the Bozhurishte experimental field is classified as Leached Smolnitsa and, according to the Bulgarian soil classification system (Koinov, 1987), it is defined as a Haplic Vertisol (FAO, 2006). The experiment was conducted under rainfed conditions on Leached Smolnitsa soil, which represents the heaviest soil type in terms

of mechanical composition, and is a typical representative of clayey Smolnitsa soils in the Sofia region. The content of physical clay is 78 - 80%, while the silt content is 62%. The particle density of the soil is 2.68 g.cm^{-3} . The bulk density in a dry state ranges from 1.95 to 2.0 g.cm^{-3} , while at field capacity it ranges from 1.23 to 1.25 g.cm^{-3} .

Pre-sowing soil tillage operations were carried out on the maize field, including two crosswise passes with a disc harrow with a working width of 4 m, followed by cultivation with a chisel cultivator with a working width of 4 m. Fertilization was applied before sowing, during the final pre-sowing soil tillage operation. As a result of the frequent rainfall recorded in May, sowing of the crop was carried out 25 - 30 days later than the optimal agrotechnical period for the region. Maize was sown on 23 May, 2023, using a Gaspardo pneumatic precision planter for row crops, on a field without a preceding crop, which had been maintained as fallow during the previous year. After sowing, rolling was performed using a Cambridge-type roller. According to the manufacturer's recommendations, maize was sown at a density of 6 400 plants per da, of which 6 000 plants per da were harvested. During the early growth stages of the crop, a foliar application of a vegetative broad-spectrum herbicide against annual and perennial grass and broadleaf weeds was carried out using Elumis OD (nicosulfuron 30 g.L^{-1} and mesotrione 75 g.L^{-1}) at a rate of 0.2 L.da^{-1} , applied in a tank mixture with the organic biostimulant Leili Alga 600 at a rate of 0.05 kg.da^{-1} . The spray volume used was 30 L.da^{-1} , and the treatment was applied at an appropriate growth stage for both the crop (6 - 7 leaf stage), and the weeds (grass weeds at the 1 - 3 leaf stage and broadleaf weeds at the 2 - 4 leaf stage). Eleven days after the herbicide and biostimulant application, inter-row soil cultivation was performed by loosening and hoeing the maize using a Gaspardo inter-row cultivator.

Results and Discussion

Under conditions of increasing climatic variability, particularly irregular precipitation,

economic efficiency becomes a decisive factor in crop management. Rainfed maize production systems are exposed to high yield risk, and the systems are particularly vulnerable to climatic variability, especially under conditions of rising temperatures and irregular precipitation (Lobell et al., 2011). Climate-induced yield instability amplifies the economic risks associated with high input intensity in maize production (Pretty and Bharucha, 2014). Closing yield gaps requires balanced nutrient and water management, but excessive fertilization often leads to diminishing economic returns under rainfed conditions (Mueller et al., 2012).

From a climatic perspective, the 2023 growing season was drier and characterized by higher temperatures compared to the long-term average. During the establishment of the field experiment, a lower mean monthly temperature in May was recorded, 1.5°C lower than the long-term average monthly temperature. In June, mean temperatures did not differ substantially and showed similar values. During the months July - October, a clear tendency toward higher mean monthly temperatures was observed. For the period from June to October 2023, temperatures were 2.9 to 4.5°C higher than the long-term average. The total precipitation amounted to 317.6 L.m^{-2} , which was 8.2% below the long-term average. The highest precipitation was recorded in June (161.4 L.m^{-2}). During the period from 1 to 15 May, 11 days with rainfall were recorded, which adversely affected the early developmental stages of maize (from emergence to the 3-leaf stage). Following this period, a drought phase occurred during July, August, and October, with the lowest monthly precipitation totals recorded in July (11.8 L.m^{-2}) and October (4.4 L.m^{-2}).

The 2023 field experiment examined the impact of pre-sowing basal applications of granular mineral and organic fertilizers on maize grain yield and associated economic indicators.

A partial economic analysis was conducted for seven fertilization variants, using grain yield and key indicators characterizing economic efficiency in maize production. The following indicators were analyzed: grain yield (GY), grain revenue

(GR), direct production costs (DPC), net income (NI), profitability rate (PR), and benefit–cost ratio (BCR), (Fig. 1; Fig. 2; Fig. 3).

Net income (NI) is an important indicator for assessing the economic efficiency of the crop grown in the experiment. It is directly dependent on the value of total output - grain revenue (GR) - and direct production costs (DPC). The evaluation of grain production and the resulting net income (NI) in the investigated variants indicates that the highest value was recorded in the first variant (71.79 BGN.da⁻¹), followed by the second variant with a minimal difference (71.59 BGN.da⁻¹). In variant V2 (NPK – 20 kg.da⁻¹ + NH₄NO₃ – 40 kg.da⁻¹), direct production costs were 58 BGN.da⁻¹ higher than those in V1. The lowest net income was observed in variant V7 (Leili Alga Soil – 30 kg.da⁻¹ + Fertipolina – 60 kg.da⁻¹), where it had a negative value (–5.67 BGN.da⁻¹). In this variant, the incurred direct production costs exceeded the revenue obtained from grain sales.

Profitability (rate of return – PR) is one of the most important parameters that best characterizes economic efficiency. The profitability rate (PR) is directly dependent on the level of net income (NI) and the incurred direct production costs

(DPC). In the analysis of direct production costs, material expenses were considered, including the purchase of seeds, fertilizers, plant protection products and herbicides, as well as an organic biostimulant. The averaged values of production costs in maize cultivation showed that they were highest in the seventh variant (132.15 BGN.da⁻¹) and lowest in the unfertilized variant (V1). This is explained by the lowest incurred costs in the first variant, in which neither mineral nor organic fertilizers were applied. In variant V1 (unfertilized), the profitability rate exceeded that of the fertilized variant V2 - the fertilized variant with the highest recorded value among all fertilized treatments - by 3.14 times. Following the second variant were V5 (NPK – 10 kg.da⁻¹ + NH₄NO₃ – 20 kg.da⁻¹ + Leili Alga Soil – 20 kg.da⁻¹) and V6 (NPK – 10 kg.da⁻¹ + NH₄NO₃ – 20 kg.da⁻¹ + Fertipolina – 40 kg.da⁻¹), with profitability rates of 55.89% and 42.15%, respectively. In the seventh variant (Leili Alga Soil – 30 kg.da⁻¹ and Fertipolina – 60 kg.da⁻¹), a negative profitability rate was recorded, while the closest value to it was observed in the fourth variant (NPK – 20 kg.da⁻¹ + Fertipolina – 40 kg.da⁻¹), amounting to 27.55%, (Table 1).

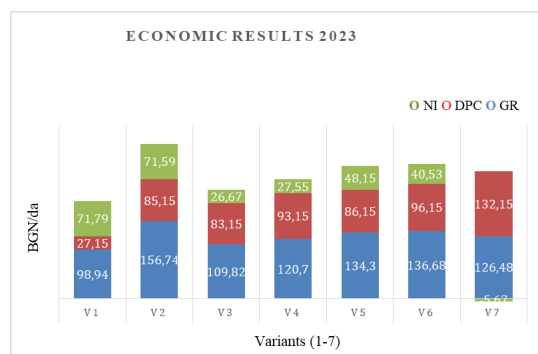


Fig. 1. Analysis of grain revenue, net income (NI), and direct production costs (DPC) in maize, 2023 (BGN.da⁻¹)

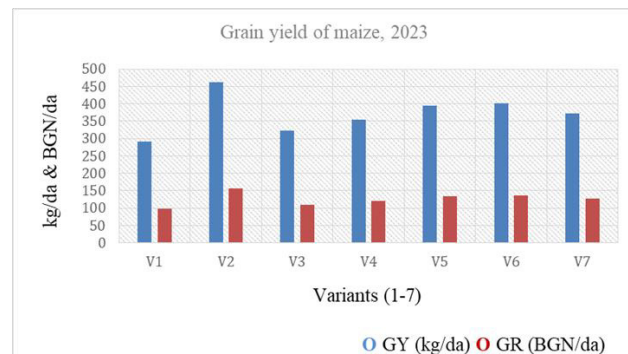


Fig. 2. Analysis of grain revenue (GR), (BGN.da⁻¹) and grain yield (GY), (kg.da⁻¹) in maize, 2023

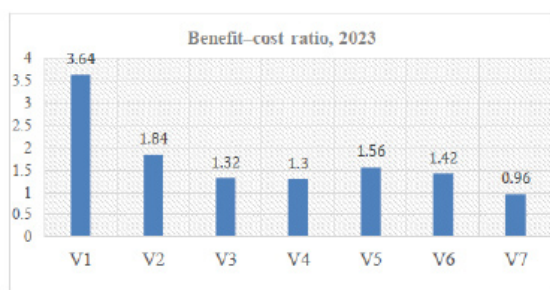


Fig. 3. Benefit–cost ratio (BCR) of maize production by fertilization variant

Table 1. Economic indicators of maize grain yield: GY, GR, DPC, NI and PR, 2023 (BGN.da⁻¹), (%)

Variants	Grain yield (GY) (kg.da ⁻¹)	Grain revenue (GR) (BGN.da ⁻¹)	Direct production costs (DPC) (BGN.da ⁻¹)	Net income (NI) (BGN.da ⁻¹)	Profitability rate (PR) (%)
V1	291	98.94	27.15	71.79	264.42
V2	461	156.74	85.15	71.59	84.08
V3	323	109.82	83.15	26.67	32.07
V4	355	120.7	93.15	27.55	29.58
V5	395	134.3	86.15	48.15	55.89
V6	402	136.68	96.15	40.53	42.15
V7	372	126.48	132.15	-5.67	-4.29

In addition to conventional indicators such as net income and profitability rate, the benefit - cost ratio (BCR) provides additional insight into the economic efficiency of the fertilization variants. The highest BCR value was recorded in variant V1, reflecting very low production costs relative to gross revenue. Although the yield was lowest in this variant, economic efficiency was maximized. Variants V2–V6 exhibited moderate BCR values, indicating diminishing economic returns with increasing fertilization intensity. In variants 1 - 6, the benefit - cost ratio is greater than 1, indicating that the benefits exceed the costs and the variants are economically viable. In variant V7, a BCR value below unity was observed, confirming economic inefficiency under the applied fertilization scheme. Figure 3 clearly illustrates the differences in BCR among the vari-

ants, and supports the conclusion that intensive fertilization under rainfed conditions should be economically justified. In variant 7, the BCR is less than 1, indicating that costs exceed benefits and the variant is economically unviable. The negative economic outcome observed in variant V7 highlights the risk associated, with intensive fertilization strategies when yield response is limited by environmental factors. These findings are consistent with previous studies, emphasizing that economically optimal fertilization rates under rainfed conditions are substantially lower than agronomically optimal rates, (Fig. 3).

Under conditions of increasing climatic variability, particularly irregular precipitation, economic efficiency becomes a decisive factor in crop management. Rainfed maize production systems are exposed to high yield risk, which

amplifies the negative economic consequences of high input intensity. The results of the present study clearly demonstrate that fertilization variants with excessive input costs are economically vulnerable under such conditions.

Long-term experiments demonstrate that fertilizer efficiency and profitability cannot be reliably assessed based on short-term yield responses alone.

Conclusion

The partial economic analysis confirmed that fertilization strategies with moderate or low input intensity provide superior economic performance under non-irrigated conditions. Although higher fertilization rates increase grain yield, they also substantially raise production costs, which reduces net income, profitability, and benefit - cost ratio. Consequently, fertilization decisions in rainfed maize production should prioritize economic efficiency rather than yield maximization alone.

Based on the obtained results, fertilization strategies for grain maize under non-irrigated conditions should prioritize economic efficiency rather than maximum yield. Farmers are recommended to apply moderate fertilization rates, and to carefully assess fertilizer prices relative to expected grain market prices. Integrated nutrient management approaches may provide a compromise between yield stability and cost control.

The study was conducted during a single growing season, which limits the extrapolation of results across years with different climatic conditions. Future research should focus on multi-year economic assessments to capture interannual variability and long-term economic stability of fertilization strategies

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Conflict of interest: The authors declare that they have no conflict of interest.

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