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Comprehensive assessment of the influence of biopreparations on the morpho-physiological indicators and yield of maize

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ABSTRACT

The article presents the results of a three-year (2023–2025) field study. Its purpose was to investigate the effect of complexes of microbiological preparations and organo-mineral fertilizers with an anti-stress effect on the productivity of the SY Fregat maize hybrid in the Khmelnytskyi region on deep low-humus chernozem soil. The research compared three options for foliar treatment–biopesticides; biopesticides plus organo-mineral fertilizers; and biopesticides plus organo-mineral plus biodynamic preparations–against a control group. A highly reliable, statistically significant influence of all treatment options on the structural elements of the harvest and the total yield was established. The maximum yield was achieved using the integrated system (Treatment No. 3), which combined biological protection (Trichodermin, Planriz, Biplan, Bitoxibacillin, Lepidocid), organo-mineral nutrition (Shchedrodar), and biodynamic stimulation (Barrel compost, 500P), mainly due to the highest number and mass of grains per cob. However, the economic assessment (ROI) showed that Treatment No. 2 (biopesticides plus organo-mineral fertilizers) was the most profitable, providing the highest return on investment with a yield of 15.44 t ha^{-1}. The study concluded that complex foliar nutrition (Treatment No. 2) is the most economically viable and effective technology for increasing the stability of maize production.

Keywords: organo-mineral fertilizers, bio fertilizers, growth stimulators, biodynamic methods, maize productivity, profitability, environmental safety.

INTRODUCTION

The current problem of increasing the efficiency of grain maize cultivation in new short-rotation crop rotations is extremely relevant. This is especially true for organic farming, which not only ensures the production of environmentally friendly products but also contributes to the conservation of natural resources and reduces the negative impact of agrochemicals on the environment [Patyka et al., 2020; Organic Standard, 2024]. Research conducted on improving technologies for organic maize cultivation allows for the substantiation and implementation of agrotechnical measures for foliar nutrition under the conditions of biological plant protection against diseases and pests, aimed at increasing yield [Ivashchenko, 2019; Basanets, 2020; Dindaroglu et al., 2022]. Moreover, effective organic cultivation technologies can also be adapted in conventional farming systems, which helps reduce the pesticide load on the environment [Syngenta Group, 2024; Valagro, 2024].

Characteristically, organic maize cultivation requires adherence to a number of specific technological measures aimed at ensuring the environmental purity of the produce and the rational use of regional natural resources [Ovsinsky, 2009; Kharchenko et al., 2019; Organic Corn, 2024]. It is indicated that the main elements of the technology include crop rotation and predecessors, soil cultivation, nutrition system, seed preparation, sowing dates and methods, as well as timely and effective weed control, protection against diseases

and pests, harvesting, and yield certification [Basanets, 2020; Organic Standard, 2024].

A number of authors have proven the effectiveness of using fertilizers created with the use of effective microorganisms. Specifically, a series of studies were conducted in the conditions of the northeastern Forest-Steppe (Sumy region) to investigate the effect of the Leanum biofertilizer on Lidea company hybrids with FAO 280 and 380. It was established that the most effective practices, which significantly influenced the biometric indicators and crop yield, were the application of in-furrow inoculation and two foliar treatments [Zakharchenko et al., 2023, 2024; Datsko et al., 2024; Hryhoriv et al., 2024]. At the same time, [Palamarchuk et al., 2021; Karbivska et al., 2022a] studied the effect of biofertilizers on the productivity and yield structure elements of the mid-season maize hybrid DKS 4014. The scientists established that the combined application of Groundfix 4 L ha^{-1} + Mycofriend 6 kg ha^{-1} provided a yield level of 13.65 t ha^{-1}, which is almost 30% higher than the control. The study [Televatyuk, 2025] investigated the optimal fertilization system and plant stand density to increase the productivity of maize hybrids P8834 and P9074 on gray forest soils. The experiments proved that the highest yield indicators were achieved through the complex application of mineral fertilizers at a dose of $N_{120}P_{60}K_{60}$ and the soil biofertilizer Groundfix 6 L ha^{-1}, applied before pre-sowing cultivation, combined with a plant stand density of 70000 ha^{-1}. Specifically, in this variant, the yield of the P8834 hybrid was 11.15 t ha^{-1}, and P9074 was 10.93 t ha^{-1}, which confirms the effectiveness of combining chemical and biological methods to maximize maize yield. The results of a three-year study [Karbivska et al., 2022b; Tsytsyura, 2025] confirmed the effectiveness of organic farming methods, particularly the use of green manure crops (oilseed radish and white mustard) combined with the biofertilizer "Organic Balance" (2 L ha^{-1}) on grey forest soils under maize cultivation for grain. The best treatment involved incorporating 18 t ha^{-1} of shredded green manure biomass combined with mineral fertilization at $N_{60}P_{60}K_{60}$. This technology resulted in a high yield of 8.18 t ha^{-1}, representing a 21.2% increase compared to the control without green manuring and biofertilizers. In the study by Tsyliuryk and Solohub [2023], plant growth regulators were investigated to improve maize productivity in the Steppe zone of Ukraine. Preparations such as "Avangard Grow Amino" and "Avangard Grow Humate" not only significantly increased chlorophyll content but also ensured the highest yield increase – up to 18.5% – in the medium-early hybrid DN Khortytsia. Moreover, these stimulants improved grain quality by increasing crude protein and fat content. At the same time, adherence to crop rotation is an essential element of organic technology, as it helps maintain natural soil fertility and optimizes the control of weeds, diseases, and pests [Patyka et al., 2020; Lopushniak et al., 2022; Kovalenko et al., 2024]. The optimal predecessors for maize are legumes and perennial grasses, which enrich the soil with nitrogen and reduce the number of pathogenic organisms, as well as winter and spring cereal crops. It is not recommended to sow maize after sunflower or sugar beet [Organic Standard, 2024].

Therefore, the aim of the study was to investigate the effect of complexes of microbiological preparations and organo-mineral fertilizers with anti-stress properties on the productivity formation of maize hybrid SY Fregat (Syngenta).

MATERIAL AND METHODS

The study was conducted in the Khmelnytskyi region during 2023–2025. The soil of the experimental site was a deep, low-humus chernozem characterized as follows: humus content – 3.8%, pH (H_2O) – 6.2. The average content of the main nutrients was: nitrogen (according to the Kornfield method) – 128.5 mg kg^{-1} of soil, phosphorus (according to the Chirikov method) – 211.6 mg kg^{-1}, and potassium (according to the Chirikov method) – 81.1 mg kg^{-1}. Due to these properties, this soil type has a high natural potential for achieving significant yields. The vegetation period of 2023 was characterized as warm and sufficiently moist (a total of 450 mm of precipitation). The average monthly temperature during the season exceeded the long-term norm by 1.5–2.0 °C. In 2024, the vegetation period had a near-normal level of precipitation (380 mm) with variable temperature conditions. The season began cool and dry in April, while June was cooler than average (+17 °C), slightly slowing down crop development. However, August marked a heat peak, with an average temperature of +23 °C, significantly exceeding long-term averages. This August heat, compounded by a lack of rainfall (55 mm), caused heat stress during the critical grain-filling stage, which could have negatively affected the final 1000-grain weight.

The 2025 growing season was dry and hot (a total of 300 mm of precipitation). The temperature regime remained consistently high throughout the season: May, June, and July showed significant deviations above the norm (up to +21 °C in June), while August was the hottest month with an average temperature of +24 °C. This prolonged and intense heatwave, combined with a critical moisture deficit, caused severe hydrothermal stress, significantly limiting yield formation and necessitating the use of hybrids with high drought resistance. Field experiments were conducted using biopesticides and plant growth biostimulants. The experimental design is presented in Table 1. Treatments were applied at the stages of the first, fourth, and ninth leaves of the maize hybrid SY Fregat (Syngenta) with FAO 250.

The experiment was conducted in four replications. The accounting plot area was 70 m², the sowing plot area was 108 m², with a total accounting area of 1120 m² and a total sowing area of 1536 m². The effect of treatments was evaluated based on maize growth and development parameters, grain yield formation, and overall productivity. To assess the effectiveness of the experiment, the following indicators were used: average number of grains per ear, average grain weight per ear, 1000-grain weight, and yield (c ha^{-1}). The values of the control plot were taken as 100%. Statistical data analysis was performed using the analysis of variance (ANOVA) method in Statistica 10.0.

Economic efficiency was evaluated using the return on investment (ROI) method, which reflects the ratio of additional income to the cost of investment. The calculation was performed according to the following formula:

$$ROI = (VD - VI) / VI \times 100\% \quad (1)$$

where: *VI* is the investment cost – the cost of the preparations used in the corresponding treatment; *VD* is the gross income – the value of the additionally obtained products calculated at current market prices.

RESULTS AND DISCUSSION

The results of the study, presented in Figure 1, show that treatments №2 and №3 had the most significant positive impact on the yield structure elements of maize. In both treatments, the maximum number of grains per ear (approximately 635) and the highest grain weight (205 g) were achieved compared to the control (590 grains and 180 g, respectively). Although this indicates a substantial improvement in the individual productivity of plants, the effect on overall yield was more moderate. The yield in treatments No. 2 and No. 3 increased to 11.5 t ha^{-1}, representing an increase of about 15% compared to the control value of 10.0 t ha^{-1}, while treatment No. 1 showed only a minor deviation from the control. Thus, treatments No. 2 and No. 3 proved to be the most effective for improving maize productivity.

The analysis of variance (ANOVA) results are presented in Table 2. The application of different treatment options has a highly reliable and statistically significant effect on all three studied indicators of maize productivity: the number of kernels per cob, the kernel weight per cob, and the yield ($p < 0.05$). The extremely low p-values and high F-values for all indicators indicate that the differences between the mean values of the treatments are not random but are caused by the influence of the experimental factors, thereby confirming the effectiveness of the conducted experiments.

The results of the economic evaluation of the effectiveness of different experimental treatments demonstrated the high economic feasibility of the studied technological practices. The maize yield in the control treatment was 13.68 t ha^{-1}, providing a product value of 1072.3 € ha^{-1}. All experimental treatments showed a statistically significant increase in yield, with the highest value observed in Treatment No. 3 – 15.72 t ha^{-1}, corresponding to a product value of 1233.2 € ha^{-1} and providing an additional income of 160.9 € ha^{-1}.

Table 1. Scheme of the field experiment

Scheme of the field experiment	V1 – first leaf	V4 – fourth leaf	V9 – ninth leaf
Control	–	–	–
Treatment No. 1	Trichodermin 2 L ha^{-1}; Planriz 1 L ha^{-1}; Biplan 2 L ha^{-1}	Trichodermin 2 L ha^{-1}; Planriz 1 L ha^{-1}; Biplan 2 L ha^{-1}	Trichodermin 2 L ha^{-1}; Planriz 1 L ha^{-1}; Biplan 2 L ha^{-1}
Treatment No. 2	No. 1 + Shchedrodar K 1 L ha^{-1}	No. 1 + Shchedrodar K 1 L ha^{-1}	No. 1 + Shchedrodar K 1 L ha^{-1}
Treatment No. 3	No. 2 + biodynamic preparation (Barrel compost – CPP)	No. 2 + biodynamic preparation (Barrel compost – CPP)	No. 2 + biodynamic preparation (Barrel compost – CPP)

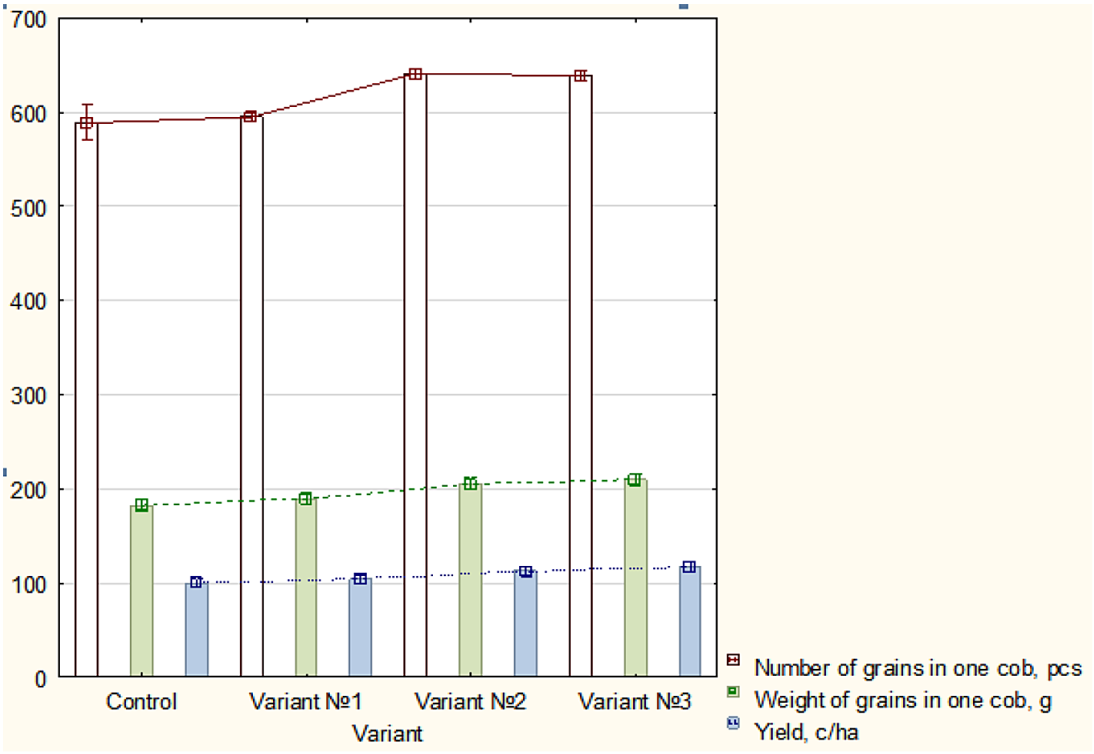

Figure 1. Structure of yield and productivity of maize

Table 2. Results of variance analysis according to treatment options

Indicator	SS_{Effect}	MS_{Effect}	SS_{Error}	MS_{Error}	F	p	Duncans` criterion
Number of grains in one cob, pcs	7026.250	2342.083	138.66	17.33	135.12	0.000000	7.84
Weight of grains in one cob, g	1518.810	506.270	46.08	5.76	87.89	0.000002	4.52
Yield, c ha^{-1}	547.043	182.348	32.00	4.0	45.58	0.000022	3.76

However, from the perspective of return on investment (ROI), the most efficient treatment was Treatment No. 2, which, with a yield of 15.44 t ha^{-1} and product costs of 47.6 € ha^{-1}, achieved the highest ROI value – 288.4%. At the same time, Treatment No. 1, with the lowest costs (26.8 € ha^{-1}) and a yield of 14.24 t ha^{-1}, also demonstrated high profitability – 156.7%.

Thus, despite the highest yield obtained in Treatment No. 3, Treatment No. 2 proved to be the most economically justified option for production (Table 3). The obtained results demonstrate that the highest yield does not always ensure the greatest economic efficiency. For example, in the study by Krutyakova et al. [2021], the use of bio-organic fertilizers based on sewage sludge combined with plant fillers (such as straw or sunflower husks) and phosphate-mobilizing bacteria significantly increased both yield and profit. Due to the growth in yield exceeding the increase in costs, the profit rose by up to 52.9%, confirming the high economic efficiency of these bio-organic

Table 3. Economic efficiency of using corn growing technologies (average for 2023–2025)

Experimental treatment	Maize yield, t ha^{-1}	Product value per ha, €	Value of additional grain per ha, €	Cost of applied products per ha, €	ROI, %
Control	13.68	1072.3	-	-	-
Treatment No. 1	14.24	1114.2	42.0	26.8	156.7
Treatment No. 2	15.44	1209.6	137.3	47.6	288.4
Treatment No. 3	15.72	1233.2	160.9	68.3	235.7

fertilizers in enhancing the profitability of maize grain production.

Similarly, a study on the economic efficiency of maize cultivation in Iran confirmed that the use of biofertilizers is economically viable despite their higher cost. The analysis of variance showed that fertilizer treatments had a statistically significant effect on both revenue and farm profit, with the lowest profit recorded in the control treatment (mineral fertilizers only) [Hasanpour et al., 2021; Kolisnyk et al., 2024].

Research by Memari-Tabrizi and Babashpour-Asl [2021] showed that applying the biofertilizer *Glomus mosseae* increased the total maize yield by 25% and positively affected key yield components. The best performance was observed in hybrid 704 under full irrigation combined with biofertilizer application.

The results of Reddy et al. [2023] clearly demonstrated that the use of a combination of biofertilizers and organic liquid nutrients significantly optimized both agronomic and economic parameters of maize. The highest efficiency was achieved with the combined treatment of *Azotobacter* + *Azospirillum* + Panchagavya (4%). This nutrient management scheme resulted in the greatest improvements in biometric parameters, yield structure, and consequently, overall productivity. From an economic perspective, this treatment was the most cost-effective and profitable, as it maximized net income

CONCLUSIONS

Based on three years of field research (2023–2025) conducted on deep low-humus chernozem soils in the Khmelnytskyi region, a highly reliable and statistically significant influence of the treatment factors on the productivity of the maize hybrid SY Fregat was established. The comprehensive statistical analysis showed that Treatment No. 3 (a combination of biopesticides, organo-mineral fertilizers, and biodynamic preparations) ensured the highest yield – 15.72 t ha^{-1}, which is 15.0% higher than the control. This result was achieved due to the optimal formation of key yield components: 635 kernels per cob and a kernel mass of 205 g, confirming the high effectiveness of multicomponent bioproducts for stimulating plant growth and providing crop protection.

From an economic efficiency standpoint, the most advantageous option was Treatment No. 2 (a combination of biopesticides and organo-mineral fertilizers). Although its yield (15.44 t ha^{-1}) was slightly lower than that of Treatment No. 3, the lowest cost of products (47.6 € ha^{-1}) allowed achieving the highest return on investment (ROI) – 288.4%. Therefore, to maximize financial returns and stabilize maize production under temperate continental climatic conditions, the implementation of complex foliar nutrition with an anti-stress effect (Treatment No. 2) is recommended as the most economically justified technology. Therefore, under modern conditions of crop production, it is advisable to integrate the use of biological and biodynamic agents into corn growing technology. This allows reducing the chemical load on the environment, increasing plant resistance to stress factors and ensuring consistently high yields. The practical significance of the study lies in the possibility of adapting elements of organic and biodynamic technologies in traditional farming systems to increase the efficiency of corn grain production in the Forest-Steppe of Ukraine.

Further research should be directed at studying the long-term impact of biodynamic preparations on the agrophysical properties of the soil, the biodiversity of microorganisms and the stability of yield in various soil and climatic conditions of Ukraine.

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