

UDC 631.8:631.559:633.854.78

Doi: 10.31548/plant4.2024.64

Vladyslav Bolokhovskyy

PhD in Agricultural Sciences

LLC "TD "BTU-CENTER"

08131, 1/34 Akademika Amosova Str., Sofiiivska Borshchahivka Village, Ukraine

<https://orcid.org/0009-0007-0074-6362>

Valentyna Bolokhovska

PhD in Technical Sciences

LLC "TD "BTU-CENTER"

08131, 1/34 Akademika Amosova Str., Sofiiivska Borshchahivka Village, Ukraine

<https://orcid.org/0009-0005-2728-4589>

Tetiana Khomenko

Doctor of Philosophy

LLC "TD "BTU-CENTER"

08131, 1/34 Akademika Amosova Str., Sofiiivska Borshchahivka Village, Ukraine

<https://orcid.org/0000-0003-4095-3706>

Andrii Datsko

PhD in Agricultural Sciences

LLC Institute of Applied Biotechnology

01021, 13 Kloviskyi Uzviz Str., Kyiv, Ukraine

<https://orcid.org/0000-0001-7823-856X>

Olena Litvinova*

PhD in Agricultural Sciences, Associate Professor

National University of Life and Environmental Sciences of Ukraine

03041, 15 Heroiv Oborony Str., Kyiv, Ukraine

<https://orcid.org/0000-0002-0962-8406>

Optimisation of plant nutrition under the influence of biopreparations in integrated sunflower cultivation technologies

Abstract. The increasing production of sunflowers is driven by multiple factors, including the introduction of high-intensity hybrids, an advanced fertilisation system, a balanced plant protection strategy, and modern high-efficiency machinery. Further technological improvements

Suggested Citation:

Bolokhovskyy, V., Bolokhovska, V., Khomenko, T., Datsko, A., & Litvinova, O. (2024). Optimisation of plant nutrition under the influence of biopreparations in integrated sunflower cultivation technologies. *Plant and Soil Science*, 15(4), 64-75. doi: 10.31548/plant4.2024.64.

*Corresponding author



Copyright © The Author(s). This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (<https://creativecommons.org/licenses/by/4.0/>)

require identifying new approaches based on factor interactions or their combined application. One such approach involves the use of biopreparations, which not only enhance productivity but also reduce pesticide load, a crucial consideration in the current ecological context. This study aimed to determine the impact of mineral fertilisers and foliar application of a biopreparation on sunflower seed productivity. The effects of mineral fertilisers and biopreparations on seed productivity formation were examined. The influence of biopreparations on sunflower growth, development, and productivity under varying mineral nutrition conditions was established. It was found that the application of biopreparations during pre-sowing cultivation positively affected crop yield, both in the absence and presence of mineral fertilisers. The use of biopreparations contributed to increased sunflower yield, with one of the tested biopreparations leading to a 6.9% increase, while the combined application of two biopreparations resulted in a 10.7% increase compared to the unfertilised control. Under mineral nutrition conditions ($N_{60}P_{60}K_{60}$), the yield increase resulting from biopreparation application ranged from 0.21 to 0.17 t/ha, depending on the fertiliser dosage. The study also revealed positive changes in the microbiological state of the soil under the influence of biopreparations. The reduction in pathogenic fungi during the ripening phase reached 10.1% when a biopreparation was applied in the absence of fertilisers. The use of biopreparations also reduced the intensity of mineralisation processes, facilitating more efficient nitrogen uptake by plants. The dynamics of alkaline-hydrolysable nitrogen, available phosphorus, and potassium content confirmed the beneficial effects of biopreparations on the soil biogenic regime and plant nutrition. The findings support the feasibility of incorporating biopreparations into sunflower cultivation technologies, contributing to increased crop yields and improved soil ecological conditions. The results can be utilised to maximise the genetic potential of sunflower plants and ensure stable productivity

Keywords: yield; alkaline-hydrolysable nitrogen; available phosphorus; available potassium; soil microbiological state

INTRODUCTION

The high saturation of agrocenoses with sunflowers and the disruption of crop rotation intervals lead to an accumulation of toxic compounds in the soil, increased pathogen load, and intensified degradation processes, resulting in the deterioration of soil water, air, and nutrient regimes. This necessitates the search for alternative methods to improve soil fertility in agrocenoses (Kovalenko *et al.*, 2020). In modern plant nutrition strategies, the use of biopreparations is gaining prominence. These products aim to restore beneficial soil microorganisms, stimulate soil biological processes, and improve the uptake of macro- and micronutrients from fertilisers and the soil itself (Tsytsiura & Didur, 2021). As noted in the study by V. Tsyhanskyi (2020), in the context of modern agricultural production, where fertilisers represent one of the most costly components of crop cultivation technologies, optimising plant nutrition systems is critically important. The author highlights the growing

popularity of biological products that stimulate the development of beneficial soil microorganisms, enhance soil fertility, increase its suppressiveness against phytopathogens, and improve crop productivity and yield, including sunflower.

X. Wei *et al.* (2024) explain that microbial fertilisers not only enrich the soil with beneficial microorganisms but also actively attract specific fungal microorganisms through substances released by plant root systems. These recruited microorganisms, in turn, contribute to the physical strengthening of the soil, improving its structure and reducing compaction. They also enhance nutrient uptake by plants and protect them from pathogens. In essence, microbial fertilisers initiate a complex and targeted interaction between plants and microorganisms to optimise soil fertility and plant health. According to T. Wang *et al.* (2024), microorganisms introduced via biopreparations, due to their rapid reproduction and population changes, engage a

substantial amount of nutrients in the biological cycle. This prevents the migration of compounds to lower soil horizons, reducing environmental pollution. They also play a crucial role in optimising ecological balance in agricultural landscapes under various farming intensities. Furthermore, they improve the efficiency of mineral fertiliser and pesticide use, increase crop productivity, and enhance product quality (Karpenko, 2019).

According to A. Pavlichenko *et al.* (2023), the prolonged use of mineral fertilisers and chemical soil improvement methods (such as liming) significantly affects the dynamics of humus in grey forest soils. This alters the amount, quality, and processes of humus formation. Research indicates that only combining organic matter with moderate doses of mineral fertilisers, along with liming, promotes humus regeneration and increases the proportion of stable humic acids. This brings humus formation closer to that typical of the region's natural forest soils. Microorganisms play a crucial role by mobilising atmospheric nitrogen, breaking down organic nitrogen compounds, and converting them into plant-available forms. This reduces the need for nitrogen fertilisers, which are the most costly to produce (Potapenko & Horbachenko, 2021).

As highlighted by O. Litvinova *et al.* (2023), while most soils contain an abundance of phosphorus, approximately 40% of arable land experiences a deficiency in its available forms. The issue of phosphorus depletion due to crop harvests is becoming increasingly pressing, as phosphorus accumulation is primarily concentrated in grains and fruits rather than in vegetative biomass, which replenishes soil nutrient reserves after harvest. Consequently, the challenge lies in ensuring the availability of phosphorus compounds to plants by enhancing their mobility, specifically by converting insoluble forms into soluble ones (Kovalenko *et al.*, 2022). Microorganisms within biopreparations, by producing organic acids and enzymes, interact with minerals, releasing available potassium and silicon. This enhances the accessibility of these elements to plants. V. Hamayunova *et al.* (2021) highlight that in the face of climate change, particularly prolonged droughts, optimising crop nutrition, especially micronutrients, is crucial for achieving high-quality

yields. While the activation of beneficial soil biological processes by microorganisms in biopreparations has been extensively studied, the combined impact of microorganisms on the soil ecosystem in agricultural settings remains under-researched. Therefore, this study aimed to determine the changes in soil nutrient status and sunflower yield in response to the application of biopreparations.

MATERIALS AND METHODS

The study was conducted in 2022-2023 under agreements No. 04-2022-NP/98 dated 21 July 2022 and No. 04-2023-NP/62 dated 05 April 2023 on an agricultural land plot located in the administrative units of Kropyvnytskyi District, Kirovohrad Region, Ukraine. The land is managed by the Institute of Steppe Agriculture of the National Academy of Agrarian Sciences of Ukraine. The soil is an ordinary deep medium-humus heavy loam chernozem. In the arable soil layer where the study was conducted, the humus content was 3.97%, hydrolysable nitrogen – 10.8 mg per 100 g of soil, available phosphorus and potassium – 6.9 mg and 14.4 mg per 100 g of soil, respectively, with a pH of 5.9. Sunflower cultivation technology in the experimental plots followed standard practices for the Steppe zone. The preceding crop was spring barley after soybean. The fertilisation background was the natural soil fertility level. The experiment was conducted in triplicate. The sunflower hybrid used was LG 5555 CLP, with an established plant density of 55,000 plants per hectare at emergence.

During the flowering and ripening phases of sunflower growth, soil samples were collected from the 0-20 cm layer according to the variants of the experiment, following the DSTU 4287:2004 (2005) standard. The content of alkali-hydrolysable nitrogen was determined using the Kornfeld method, following DSTU 7863:2015 (2016). The available phosphorus and potassium compounds were analysed using the Kirsanov method, modified by the NSC ISA, in compliance with DSTU 4405:2005 (2006). The study investigated the effects of applying biopreparations with fertiliser properties during pre-sowing cultivation under different nutrient backgrounds:

- 1) No fertiliser (control 1);
- 2) $N_{60}P_{60}K_{60}$ applied during cultivation (control 2);
- 3) Groundfix, 5 L/ha applied during cultivation;
- 4) Groundfix, 2.5 L/ha + Azotofit, 1.5 L/ha applied during cultivation;
- 5) Groundfix, 2.5 L/ha + Azotofit, 1.5 L/ha + $N_{60}P_{60}K_{60}$ applied during cultivation;
- 6) Groundfix, 2.5 L/ha + Azotofit, 1.5 L/ha + $N_{42}P_{42}K_{42}$ applied during cultivation.

Groundfix is a soil-acting biopreparation. Its primary function is to enhance phosphorus and potassium nutrition in plants by converting phosphates into a soluble form, releasing retrograded phosphorus bound by secondary minerals, and mobilising potassium from hydromicas and montmorillonite-group minerals. Additionally, it increases the mobility and availability of silicon for plants throughout the entire growing season. Due to the complex of bacteria that produce organic acids, amino acids, enzymes, phytohormones, antibiotics, and other substances that positively impact plants, enhancing their adaptive and immune capabilities. A key advantage of this biopreparation is its ability to improve soil structure, aeration, and moisture retention. Composition: live bacterial cells of

Bacillus subtilis, *Bacillus megaterium* var. *phosphaticum*, *Azotobacter chroococcum*, *Enterobacter* sp., *Paenibacillus polymyxa*; other beneficial microflora (lactic acid bacteria, enzyme producers); vitamins, phytohormones, amino acids, and other physiologically active substances. The total number of viable cells is $(0.5-1.5) \times 10^9$ CFU/cm³.

Azotofit is a natural growth stimulant that actively fixes molecular atmospheric nitrogen, enriching the soil by up to 60 kg/ha (on average, 20 kg/ha). It synthesises growth-promoting substances that enhance root system development and vegetative biomass, improve seed germination, increase plant resilience to stress factors, optimise nutrient uptake, and boost crop yields. Composition: live cells of associative nitrogen-fixing bacteria.

RESULTS AND DISCUSSION

The research results demonstrated that applying biopreparations during pre-sowing cultivation positively influenced sunflower plant growth, development, and yield. Specifically, under conditions without mineral fertilisers, applying Groundfix during pre-sowing cultivation increased sunflower yield by 0.22 t/ha, or 6.9%, compared to the control (no fertiliser) yield of 3.18 t/ha (Fig. 1).

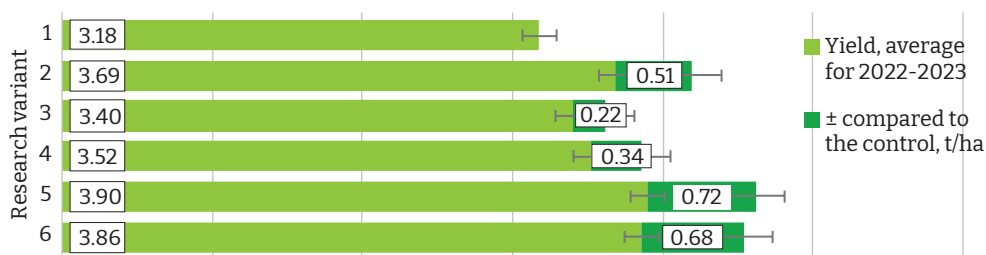


Figure 1. Sunflower yield depending on the application of biopreparations

Note: fertilisation treatments – 1. No fertiliser (control 1); 2. $N_{60}P_{60}K_{60}$ applied during cultivation (control 2); 3. Groundfix, 5 L/ha applied during cultivation; 4. Groundfix, 2.5 L/ha + Azotofit, 1.5 L/ha applied during cultivation; 5. Groundfix, 2.5 L/ha + Azotofit, 1.5 L/ha + $N_{60}P_{60}K_{60}$ applied during cultivation; 6. Groundfix, 2.5 L/ha + Azotofit, 1.5 L/ha + $N_{42}P_{42}K_{42}$ applied during cultivation

Source: developed by the authors

The combined application of Groundfix + Azotofit under these conditions increased crop productivity by 0.34 t/ha, or 10.7%, compared to control 1. It is worth noting that the application of mineral fertilisers at a dose of $N_{60}P_{60}K_{60}$

(control 2) had a significant impact on sunflower yield, with an increase of 0.51 t/ha, resulting in a yield of 3.69 t/ha. The combined use of the biopreparations Groundfix + Azotofit, with a full dose of mineral fertilisers ($N_{60}P_{60}K_{60}$) and a 30%

reduced dose ($N_{42}P_{42}K_{42}$), positively influenced crop productivity, with increases of 0.21 t/ha and 0.17 t/ha, respectively, compared to control 2, and 0.72 t/ha and 0.68 t/ha compared to control 1, yielding 3.9 t/ha and 3.86 t/ha, respectively. These results are supported by the research of V. Hama-yunova & V. Kudrina (2018) and Ye. Yurkevych *et al.* (2023), found that the application of Groundfix at a dose of 5 L/ha increased sunflower yield by 11.5% and 19.5%, respectively, compared to the treatment without the preparation.

When comparing the combined application of the biopreparations Groundfix + Azotofit with $N_{60}P_{60}K_{60}$ and $N_{42}P_{42}K_{42}$, a higher effectiveness of the biopreparations was observed when applied with a 30% reduced dose of mineral fertilisers, with the yield difference between them being minimal at 0.04 t/ha. Research conducted by Yu. Soroka *et al.* (2017) and Ye. Domarat-skyy (2018) suggests that the combined action of mineral fertilisers and biopreparations exceeded the combined effect of the two individual factors, thus demonstrating a synergistic effect: an increase in yield of 0.17 t/ha with the application of $N_{60}P_{90}$, 0.23 t/ha with the application of the biopreparation, and a 0.42 t/ha increase with the combined application.

Analysis of the yield data showed that the use of biopreparations in pre-sowing cultivation positively influenced sunflower productivity, both when no mineral fertilisers were applied and when they were used. It should be noted that the increase in sunflower productivity following the application of biopreparations to the soil occurred against the backdrop of positive changes within the soil, brought about by the action of the microbial complex. This was reflected in a reduction in the number of pathogenic fungi in the soil and the intensity of mineralisation processes, as well as a positive trend in the content of key biogenic nutrients. The findings of V. Volkogon (2018) also confirm that, under the influence of microorganisms present in biopreparations, there is mobilisation of unavailable phosphorus in the soil, particularly in the rhizosphere zone, where a gradient exists for the movement of nutrients from the soil to the roots. The application of biopreparations in pre-sowing cultivation in the current study reduced the number of pathogenic fungi in the soil, depending on the experimental variant. During the flowering phase, this reduction ranged from 2.55% to 8.6%, and during the maturation phase of the sunflower, it ranged from 5.65% to 10.1% (Fig. 2).

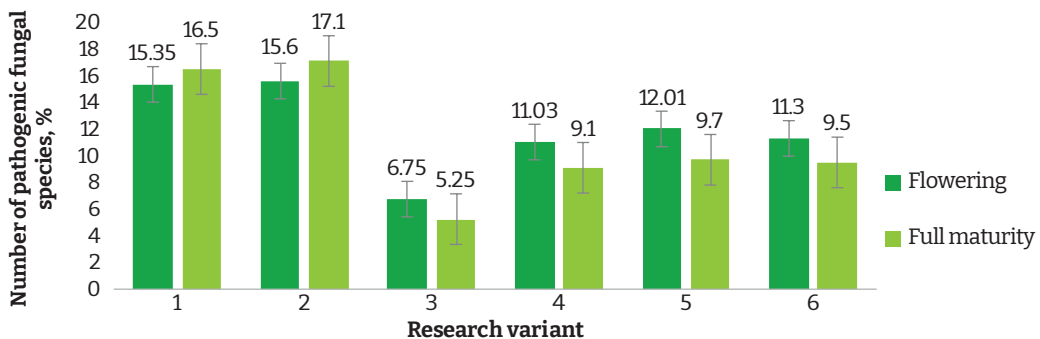


Figure 2. Number of pathogenic fungal species in the soil (%) in sunflower crops with the application of biopreparations

Note: fertilisation treatments – 1. No fertiliser (control 1); 2. $N_{60}P_{60}K_{60}$ applied during cultivation (control 2); 3. Groundfix, 5 L/ha applied during cultivation; 4. Groundfix, 2.5 L/ha + Azotofit, 1.5 L/ha applied during cultivation; 5. Groundfix, 2.5 L/ha + Azotofit, 1.5 L/ha + $N_{60}P_{60}K_{60}$ applied during cultivation; 6. Groundfix, 2.5 L/ha + Azotofit, 1.5 L/ha + $N_{42}P_{42}K_{42}$ applied during cultivation

Source: developed by the authors

Thus, the application of Groundfix in pre-sowing cultivation, with no fertilisers, resulted in a reduction of pathogens in the soil by

8.6% during the flowering phase and 10.1% during the maturation phase. When biopreparations Groundfix + Azotofit were applied together

on different nutrient backgrounds, the number of pathogenic fungi decreased by 3.34-4.32% during flowering and 5.65-6.25% during maturation. The combined use of biopreparations was less effective against pathogenic fungi in the soil, which can be attributed to the lower application rate of Groundfix, which contains microorganisms with high fungicidal activity. On the full rate of mineral fertilisers and a 30% reduced rate, with the application of Groundfix + Azotofit, the number of pathogenic fungi was slightly higher than with no fertilisers. This suggests that the application of mineral fertilisers promoted the growth of pathogenic fungi in the soil, both with the application of fertilisers alone and in combination with biopreparations. Ye. Domratskiy & O. Kozlova (2018) emphasise that the timely and rational use of biological growth

stimulants, combined with a biological fungicide, will ensure the expected sunflower yield and reduce plant infection by fungal diseases.

Changes in the soil microbiome also occurred under the influence of biopreparations. It is known that mineralisation-immobilisation ratios lower than 1.0 indicate a decrease in the rate of these processes while exceeding this value suggests undesirable intensity in mineralisation-immobilisation. When mineral fertilisers were applied (control 2), the intensity of the mineralisation processes of organic matter in the soil during the flowering phase of sunflower was the highest, with the mineralisation-immobilisation ratio at 1.45. This indicates the active use of mineral nitrogen forms from fertilisers by microorganisms, resulting in a reduction of nitrogen content in the soil and its uptake by plants (Fig. 3).

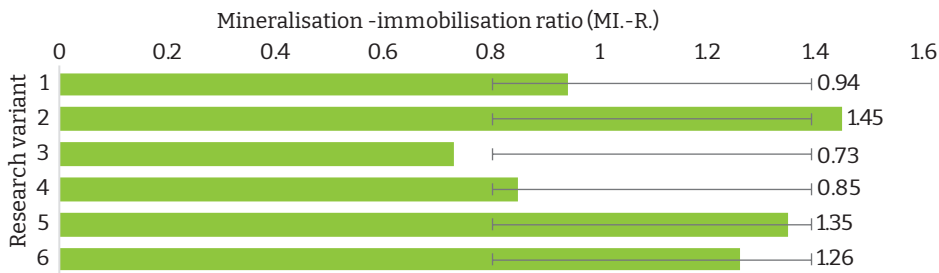


Figure 3. Mineralisation-immobilisation ratio during the flowering phase of sunflower depending on the application of biopreparations

Note: fertilisation treatments – 1. No fertiliser (control 1); 2. $N_{60}P_{60}K_{60}$ applied during cultivation (control 2); 3. Groundfix, 5 L/ha applied during cultivation; 4. Groundfix, 2.5 L/ha + Azotofit, 1.5 L/ha applied during cultivation; 5. Groundfix, 2.5 L/ha + Azotofit, 1.5 L/ha + $N_{60}P_{60}K_{60}$ applied during cultivation; 6. Groundfix, 2.5 L/ha + Azotofit, 1.5 L/ha + $N_{42}P_{42}K_{42}$ applied during cultivation

Source: developed by the authors

Such conditions result in the loss of soil organic matter. Biopreparation application reduced the intensity of mineralisation processes in the soil, improving nitrogen availability for plants. For example, the mineralisation-immobilisation ratio with Groundfix application without fertilisers was 0.73, and with the combined Groundfix + Azotofit application, it was 0.85. The positive effect of biopreparations Groundfix + Azotofit was also observed with full and 30% reduced mineral fertiliser doses, where the mineralisation-immobilisation ratio decreased to 1.26 and 1.35, respectively, compared to mineral

fertilisers alone. This indicates that biopreparations reduced competition for nitrogen between microorganisms and plants, contributing to increased yields as previously discussed. These findings are supported by research conducted by O. Tonkha *et al.* (2019). The study revealed that the level of alkaline hydrolysed nitrogen in the soil decreased throughout the growing season (from sunflower flowering to maturity) across all treatments. However, the variability of this indicator was low ($V = 4\%$). Changes in soil microbial processes, induced by the microorganisms in the biopreparations, affected soil nitrogen

dynamics and its uptake by plants. For example, in the unfertilised treatment and with Groundfix application, the alkaline hydrolysed nitrogen

content at flowering was 101 mg/kg soil (Table 1). However, the rate of nitrogen uptake by plants increased with biopreparation use.

Table 1. Changes in soil agrochemical indicators with biopreparation application in sunflower crops

Research variant	Hydrolysed nitrogen, mg/kg		Mobile phosphorus, P ₂ O ₅ , mg/kg		Mobile potassium, K ₂ O, mg/kg	
	Flowering	Full maturity	Flowering	Full maturity	Flowering	Full maturity
1. No fertiliser (control 1)	101	97	132	140	158	150
2. N ₆₀ P ₆₀ K ₆₀ applied during cultivation (control 2)	109	103	145	152	165	157
3. Groundfix, 5 L/ha applied during cultivation	101	94	142	150	161	154
4. Groundfix, 2.5 L/ha + Azotofit, 1.5 L/ha applied during cultivation	103	96	140	149	161	154
5. Groundfix, 2.5 L/ha + Azotofit, 1.5 L/ha + N ₆₀ P ₆₀ K ₆₀ applied during cultivation	109	102	151	158	172	160
6. Groundfix, 2.5 L/ha + Azotofit, 1.5 L/ha + N ₄₂ P ₄₂ K ₄₂ applied during cultivation	106	98	147	156	165	156

Source: developed by the authors

Applying Groundfix in combination with Azotofit improved the soil nitrogen status by 2 mg/kg compared to using Groundfix alone. This is attributed to the high nitrogen-fixing capacity of the bacteria in Azotofit. In treatments with mineral fertilisers alone (N₆₀P₆₀K₆₀) and in combination with biopreparations Groundfix + Azotofit, the alkaline hydrolysed nitrogen level in the soil increased to 109 mg/kg. Applying Groundfix + Azotofit with N₄₂P₄₂K₄₂ resulted in a slight decrease in nitrogen. According to the authors, this is due to the increased mineralisation processes in the soil and the enhanced nitrogen uptake during sunflower vegetative growth.

During sunflower maturity, there was a slight decrease in alkaline hydrolysed nitrogen content in the soil with biopreparation use, both with and without mineral fertilisers. This indicates increased nitrogen uptake by sunflower plants and the inability of nitrogen-fixing microorganisms to fully compensate for nitrogen demand. The available phosphorus content in the soil increased throughout the growing season, with low variability (V=4-5%) observed during this period.

The complex of microorganisms introduced with the Groundfix biopreparation facilitated the more efficient conversion of unavailable phosphorus compounds, both organic

and mineral, into plant-available forms. This is evidenced by the increased levels of available phosphorus in the soil and its uptake in the crop yield. Applying Groundfix during pre-sowing cultivation increased available phosphorus in the soil by 10 mg/kg during flowering, reaching 145 mg/kg, compared to the control level of 132 mg/kg. Applying Groundfix in combination with Azotofit during presowing cultivation reduced available phosphorus in the soil by 2 mg/kg compared to using Groundfix alone, resulting in 140 mg/kg. This is attributed to the lower dose of Groundfix and the primary function of Azotofit, which focuses on nitrogen fixation and plant stimulation. Applying Groundfix + Azotofit with N₆₀P₆₀K₆₀ and N₄₂P₄₂K₄₂ increased available phosphorus in the soil by 6 and 2 mg/kg, respectively, compared to applying the full mineral fertiliser dose alone (control 2).

Analysis of available phosphorus in the soil during sunflower maturity indicates the continued activity of the Groundfix biopreparation's microorganisms in decomposing organic matter and converting sparingly soluble phosphates into available forms. For example, applying Groundfix at 5 L/ha during pre-sowing cultivation increased available phosphorus by 10 mg/kg compared to the control, reaching 150 mg/kg (Table 1). With the combined

application of Groundfix + Azotofit, available phosphorus decreased by 1 mg/kg compared to Groundfix alone, resulting in 149 mg/kg. This slight reduction is within a trend and is attributed to higher phosphorus uptake by the crop yield. Applying Groundfix + Azotofit with $N_{60}P_{60}K_{60}$ and $N_{42}P_{42}K_{42}$ increased available phosphorus by 8 and 6 mg/kg, respectively, compared to mineral fertiliser application alone (control 2), reaching 158 and 156 mg/kg. It is important to note that available phosphorus in the soil increased with the application of Groundfix + Azotofit under different nutrient conditions, particularly with mineral fertiliser application.

Sunflower is a potassium-demanding crop, making potassium crucial for its nutrition. A deficiency in this element significantly impacts yield, oil content in the seeds, and plant susceptibility to diseases. Analysing the seasonal dynamics of available potassium in the typical medium-humus, deep, heavy loam chernozem soil, a decrease in potassium content was observed across all treatments throughout the growing season. From flowering to maturity, available potassium levels declined, although they remained within high sufficiency ranges. The decrease in available potassium in the soil is due to its uptake by plants. As plants grow and develop, nutrient absorption naturally leads to a reduction in potassium concentration in the soil solution.

As indicated by the soil sample analysis from the sunflower flowering stage, available potassium increased from 158 mg/kg in the control to 161 mg/kg with Groundfix application. Adding Azotofit (variant 4) did not affect the available potassium in the soil, remaining at 161 mg/kg. The combined application of Groundfix + Azotofit with $N_{60}P_{60}K_{60}$ increased available potassium in the soil by 7 mg/kg (172 mg/kg) compared to applying $N_{60}P_{60}K_{60}$ alone (control 2). With $N_{42}P_{42}K_{42}$, the potassium level was similar to control 2 (165 mg/kg). Samples taken at sunflower maturity showed a similar trend in available potassium dynamics. Changes in available potassium in sunflower crop soil are directly influenced by the complex of microorganisms introduced into the soil, alterations in microbial processes, and plant uptake. Nutrient absorption naturally leads to a decrease in potassium concentration in the soil solution.

CONCLUSIONS

This study found that using biopreparations during pre-sowing cultivation positively influenced sunflower growth, development, and yield. Applying biopreparations without mineral fertilisers increased sunflower yield: Groundfix increased yield by 0.22 t/ha (6.9%), and the combined application of Groundfix + Azotofit increased yield by 0.34 t/ha (10.7%) compared to the control. With mineral fertiliser application at $N_{60}P_{60}K_{60}$, sunflower yield increased by 0.51 t/ha (3.69 t/ha total), and when combined with biopreparations, yield increased by an additional 0.17-0.21 t/ha. Biopreparations were more effective with a 30% reduced mineral fertiliser dose, with only a 0.04 t/ha yield difference between the full and reduced doses.

Biopreparation application reduced pathogenic fungi in the soil by 2.55-8.6% during flowering and by 5.65-10.1% during sunflower maturity. Groundfix was most effective without mineral fertilisers, while the combined biopreparation application was less effective due to the reduced Groundfix dose. Biopreparations reduced the intensity of mineralisation processes in the soil, enhancing nitrogen availability for plants. The mineralisation-immobilisation ratio was 1.45 with mineral fertilisers alone, but only 0.73 with Groundfix application, indicating reduced soil organic matter loss and improved nitrogen availability.

The application of biopreparations positively influenced the content of essential nutrients in the soil. The level of alkaline hydrolysed nitrogen at flowering increased to 101 mg/kg with Groundfix, and by an additional 2 mg/kg with the combined application of Groundfix + Azotofit. Groundfix application increased available phosphorus at flowering by 10 mg/kg (to 145 mg/kg), and the combined application with Azotofit reached 140 mg/kg. In treatments with mineral fertilisers, biopreparations further increased available phosphorus by 6-8 mg/kg compared to mineral fertilisers alone. Analysis of potassium dynamics showed a decrease in soil potassium content throughout the growing season, attributed to active sunflower uptake. However, sufficiency levels remained high, indicating effective potassium mobilisation by the biopreparation microorganisms.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

REFERENCES

- [1] Domaratsky, Ye.O. (2018). The influence of growth regulators and mineral fertilisers on the nutritional regime of sunflower. *Scientific Reports of the National University of Life and Environmental Sciences of Ukraine*, 1(71). doi: [10.31548/dopovidi2018.01.018](https://doi.org/10.31548/dopovidi2018.01.018).
- [2] Domaratsky, Ye.O., & Kozlova, O.P. (2018). [The influence of biological fungicides on the damage level of the sunflower hybrids by the pathogenic microflora](#). *Podilian Bulletin: Agriculture, Engineering, Economics*, 29, 9-16.
- [3] DSTU 4287:2004. (2005). *Soil quality. Sampling*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page?id_doc=54569.
- [4] DSTU 4405:2005. (2006). *Soil quality. Determination of mobile forms of phosphorus and potassium by the Kirsanov method in the modification of NNC IGA*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=60252.
- [5] DSTU 7863:2015. (2016). *Soil quality. Determination of easily hydrolysable nitrogen by the Kornfield method*. Retrieved from https://online.budstandart.com/ua/catalog/doc-page.html?id_doc=62745.
- [6] Hamayunova, V., & Kudrina, V. (2018). [Water consumption of sunflower, depending on the use of biological products when grown in the Southern Steppe of Ukraine](#). *Scientific Horizons*, 21(7-8), 27-35.
- [7] Hamayunova, V.V., Kovalenko, O.A., Khonenko, L.H., & Hyrlya, L.M. (2021). [Sunflower yield under the influence of microfertilizers and biopreparations in the conditions of the Southern Steppe of Ukraine](#). In *Innovative agricultural technologies under the conditions of climate change: Materials of the III International science and practice conference dedicated to the 75th anniversary of the birthday of Professor V. Kalitka* (pp. 26-29). Melitopol: Institute of Climate-Specific Agriculture of the National Academy of Agrarian Sciences of Ukraine.
- [8] Karpenko, A. (2019). *Geography, productivity, areas: How has the cultivation of top crops changed during the years of Independence?* Retrieved from <https://surl.li/yjwoko>.
- [9] Kovalenko, A.M., Kovalenko, O.A., & Pilyarsky, V.G. (2020). Yield of crops of short-rotation crop rotation under conditions of application of microbial preparations in the Southern Steppe of Ukraine. *Agrarian Innovations*, 1, 52-56. doi: [10.32848/agrar.innov.2020.1.8](https://doi.org/10.32848/agrar.innov.2020.1.8).
- [10] Kovalenko, O., Neroda, R., & Bahliuk, U. (2022). Sunflower cultivation: Foliar top-dressing with mikrofertilizers. *Grail of Science*, 16, 127-132. doi: [10.36074/grail-of-science.1706.2022.022](https://doi.org/10.36074/grail-of-science.1706.2022.022).
- [11] Litvinova, O., Dehodiuk, S., Litvinov, D., Havryliuk, O., Kyrychenko, A., Borys, N., & Dmytrenko, O. (2023). Efficiency of technology elements for growing winter wheat on typical chernozem. *Agronomy Research*, 21(3), 1199-1212. doi: [10.15159/AR.23.079](https://doi.org/10.15159/AR.23.079).
- [12] Pavlichenko, A., Dmytrenko, O., Litvinova, O., Kovalova, S., Litvinov, D., & Havryliuk, O. (2023). Changes in gray forest soil organic matter pools under anthropogenic load in agrocenoses. *Agronomy Research*, 21(3), 1266-1277 doi: [10.15159/AR.23.095](https://doi.org/10.15159/AR.23.095).
- [13] Potapenko, L.V., & Horbachenko, N.I. (2021). Influence of fertilization systems and microbial preparations of the formation of nutrient status of sod-podzolic soil. *Agricultural Microbiology*, 34, 53-60. doi: [10.35868/1997-3004.34.53-60](https://doi.org/10.35868/1997-3004.34.53-60).
- [14] Soroka, Yu.V., Tarariko, Yu.O., & Saydak, R.V. (2017). [Complex application of biopreparates and growth stimulants in the conditions of the Left-bank Forest-Steppe](#). *Agriculture*, 1, 85-92.
- [15] Tonkha, O., Pikovska, O., Balaev, A., Kovalyshyna, G., Zavgorodniy, V., & Kovalenko, V. (2019). Monitoring of the microbiological condition of virgin chernozem under different management. In *Monitoring of geological processes and ecological condition of the environment: Conference paper* (pp. 1-5). Utrecht: European Association of Geoscientists & Engineers. doi: [10.3997/2214-4609.201903256](https://doi.org/10.3997/2214-4609.201903256).

- [16] Tsyhanskyi, VI. (2020). Optimization of the sunflower fertilization system based on the use of modern microbiological fertilizers. *Agriculture and Forestry*, 4, 65-75. [doi: 10.37128/2707-5826-2020-4-6](https://doi.org/10.37128/2707-5826-2020-4-6).
- [17] Tsytsiura, Ya., & Didur, I. (2021). Optimization of sunflower fertilization according to the application of biological preparations in the conditions of the right bank forest-steppe. *Agriculture and Forestry*, 4, 36-51. [doi: 10.37128/2707-5826-2021-4-4](https://doi.org/10.37128/2707-5826-2021-4-4).
- [18] Volkogon, V. (2018). Agricultural microbiology in Ukraine: Achievements, problems, prospects. *Bulletin of Agricultural Science*, 11, 20-27. [doi: 10.31073/agrovisnyk201811-03](https://doi.org/10.31073/agrovisnyk201811-03).
- [19] Wang, T., Xu, J., Chen, J., Liu, P., Hou, X., Yang, L., & Zhang, L. (2024). Progress in microbial fertilizer regulation of crop growth and soil remediation research. *Plants*, 13(3), article number 346. [doi: 10.3390/plants13030346](https://doi.org/10.3390/plants13030346).
- [20] Wei, X., Xie, B., Wan, C., Song, R., Zhong, W., Xin, S., & Song, K. (2024). Enhancing soil health and plant growth through microbial fertilizers: Mechanisms, benefits, and sustainable agricultural practices. *Agronomy*, 14(3), article number 609. [doi: 10.3390/agronomy14030609](https://doi.org/10.3390/agronomy14030609).
- [21] Yurkevych, Ye.O., Valentiuk, N.O., Petrenko, S.O., Rodionov, A.V., & Hrabovetska, O.A. (2023). The effectiveness of the use of biological preparations in the cultivation of confectionery sunflower in the conditions of the Southern Steppe of Ukraine. *Agrarian Innovations*, 21, 118-125. [doi: 10.32848/agrar.innov.2023.21.18](https://doi.org/10.32848/agrar.innov.2023.21.18).

Владислав Болоховський

Кандидат сільськогосподарських наук

ТОВ «ТД «БТУ-ЦЕНТР»

08131, вул. Академіка Амосова, 1/34, с. Софіївська Борщагівка, Київська область, Україна

<https://orcid.org/0009-0007-0074-6362>

Валентина Болоховська

Кандидат технічних наук

ТОВ «ТД «БТУ-ЦЕНТР»

08131, вул. Академіка Амосова, 1/34, с. Софіївська Борщагівка, Київська область, Україна

<https://orcid.org/0009-0005-2728-4589>

Тетяна Хоменко

Доктор філософії

ТОВ «ТД «БТУ-ЦЕНТР»

08131, вул. Академіка Амосова, 1/34, с. Софіївська Борщагівка, Київська область, Україна

<https://orcid.org/0000-0003-4095-3706>

Андрій Дацько

Кандидат сільськогосподарських наук

ТОВ «Інститут прикладної біотехнології»

01021, вул. Кловський узвіз, 13, м. Київ, Україна

<https://orcid.org/0000-0001-7823-856X>

Олена Літвінова

Кандидат сільськогосподарських наук, доцент

Національний університет біоресурсів і природокористування України

03041, вул. Героїв Оборони, 15, м. Київ, Україна

<https://orcid.org/0000-0002-0962-8406>

Оптимізація живлення рослин під дією біопрепаратів в інтегрованих технологіях вирощування соняшнику

Анотація. Феномен зростання виробництва соняшнику має поліфакторіальне походження – нові високоінтенсивні гібриди, довершена система удобрення, збалансована система захисту рослин, сучасна високоефективна техніка. Тому для подальшого удосконалення технології потрібно знаходити нові шляхи, пов'язані із взаємодією факторів, або комбінативне їх використання. Одним з напрямів такої взаємодії є застосування біопрепаратів, які водночас вирішують не лише питання росту продуктивності, але й зменшують пестицидне навантаження, що є своєчасним і актуальним в сучасних екологічних умовах. Метою досліджень було встановлення впливу мінеральних добрив та позакореневого підживлення біопрепаратом на продуктивність насіння соняшнику. Досліджувався вплив застосування мінеральних добрив і біопрепаратів на формування продуктивності насіння соняшнику. Встановлено вплив біопрепаратів на ріст, розвиток та продуктивність рослин соняшника за різних фонових умов мінерального живлення. Встановлено, що внесення біопрепаратів під передпосівну культивування позитивно впливало на врожайність культури як за відсутності мінеральних добрив, так і за їх внесення. Використання біопрепаратів сприяло підвищенню врожайності соняшника, зокрема, внесення одного з досліджуваних біопрепаратів забезпечило приріст на 6,9 %, а сумісне застосування двох – на 10,7 % порівняно з контролем без добрив. На фоні мінерального живлення ($N_{60}P_{60}K_{60}$) приріст врожаю від застосування біопрепаратів становив 0,21-0,17 т/га залежно від дози добрив. Дослідження також виявили позитивні зміни в мікробіологічному стані ґрунту під дією

біопрепаратів. Зниження кількості патогенних грибів у фазу дозрівання досягало 10,1 % за застосування біопрепарату на фоні без добрив. Використання біопрепаратів також знижувало інтенсивність мінералізаційних процесів, що сприяло ефективнішому використанню азотурослинами. Динаміка вмісту лужногідролізованого азоту, рухомого фосфору та калію підтверджувала позитивний вплив біопрепаратів на біогенний режим ґрунту та живлення рослин. Дослідження підтвердили доцільність застосування біопрепаратів у технології вирощування соняшника, що сприяло підвищенню врожайності культури та поліпшенню екологічного стану ґрунтів. Результати дослідження можуть бути використані для реалізації генетичного потенціалу рослин соняшнику з метою формування стабільної його продуктивності

Ключові слова: урожайність; лужногідролізований азот; рухомий фосфор; рухомий калій; мікробіологічний стан ґрунту