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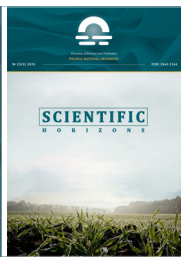

Soil microbiological activity in winter rye crops under different fertilisation systems and biopreparations

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Abstract. The aim of the study was to determine the effect of different fertilisation systems in combination with biological preparations on soil microbiological activity under winter rye crops in the Polissia region of Ukraine. The methodology was based on a field experiment conducted during 2019-2021 at the research plots of Polissia National University. Two fertilisation systems were used – biological and organo-mineral with different ratios of components (50:50 and 75:25) – as well as a mineral system for comparison. Soil microbiological activity was evaluated using the linen decomposition method at a depth of 0-20 cm, and the results were processed by analysis of variance. The study established that the highest levels of biological activity were observed under the organo-mineral system with an equal proportion of organic and mineral components, where microbial activity exceeded the control by 8-10%. It was demonstrated that the biopreparations Trichodermin, Organik D2M, and

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Mochevyn K No. 2 positively affected soil microflora development, enhanced enzymatic processes, and contributed to the stability of microbial communities. It was also found that, even without the application of mineral fertilisers, the use of biological preparations significantly increased microbial activity, whereas the mineral system maintained a lower but stable level of response. The generalisation of results confirmed the synergistic effect of combining organic and mineral nutrient sources, which ensured a balanced microbiological environment and sustained soil fertility. The practical value of the study lies in the potential use of the findings to optimise fertilisation systems and integrate biopreparations into cereal crop production technologies in the Polissia zone of Ukraine to enhance the ecological efficiency of agriculture

Keywords: soil microflora; organo-mineral nutrition; enzymatic activity; biological decomposition; agroecological stability; biologisation of agriculture; microbial consortia

INTRODUCTION

Maintaining soil microbiological activity is a fundamental condition for the sustainable functioning of agroecosystems and for ensuring food security. The activity of soil microorganisms determines the rate of mineralisation of organic residues, the transformation of nutrients, the formation of humus, and the overall fertility of the soil. Within the framework of intensive farming systems dominated by mineral fertilisers, there is a significant risk of microbiota degradation, decreased enzymatic activity, and deterioration of soil physico-chemical properties. Therefore, assessing the influence of fertilisation systems and biological preparations on soil biological activity is essential for developing environmentally safe technologies for cereal cultivation, particularly for winter rye.

Recent research increasingly emphasises that a combination of organic and mineral nutrient sources creates optimal conditions for the development of microbial communities. W. Liu *et al.* (2023) demonstrated that the application of organic amendments significantly enhances microbial diversity, increases the abundance of cellulolytic bacteria, and stimulates enzymatic activity across various agroecosystems. In the study by V. Seitz *et al.* (2024), it was shown that the combined use of organic and mineral fertilisers promotes the formation of stable microbial networks, improves nutrient cycling, and enhances agroecosystem resilience to external stress factors. Similar results were obtained by X. Chen *et al.* (2025), who proved that organic fertilisers slow down excessive mineralisation of organic matter and ensure the stability of microbial communities, which is key to the long-term maintenance of soil fertility. The research of J. Behr *et al.* (2023) confirmed that the introduction of microbial consortia in winter rye crops stimulates rhizosphere biota and increases the availability of macro- and microelements. In an extensive review, D.-C. Țopa *et al.* (2025) summarised the results of more than 120 studies and emphasised that integrated fertilisation systems combined with biopreparations deliver the highest ecological efficiency, balancing crop productivity with the restoration of soil biological functions.

Ukrainian researchers have made a substantial contribution to the study of organic matter mineralisation processes. L. Tsentylo (2019) found that indicators of soil microbiological activity serve as sensitive markers of agroecosystem sustainability, and that the intensity of biological processes significantly increases under organo-mineral fertilisation systems. The study by V. Ivanina and O. Tabachuk (2023) showed that the application of organo-mineral fertilisers on typical chernozem soils of the Forest-Steppe zone leads to an increase in microbial biomass and higher dehydrogenase activity. Similar findings were reported by Y. Borko *et al.* (2025), who noted that the use of biopreparations in cereal production enhances soil enzymatic activity by 20-30% and improves ecological condition. Moreover, P. Lykhovyd (2024) confirmed in their meta-analysis that the biological activity of Ukrainian soils depends on the cultivation and fertilisation system; organo-mineral combinations stimulate the formation of stable microbial communities and prevent degradation processes.

The analysis of these studies indicates that most contemporary research focuses on the beneficial effects of organic fertilisers and biological agents on microbial activity. However, the optimal ratio of organic and mineral components in fertilisation systems for specific cereal crops remains insufficiently studied. Despite available data on maize, soybean, and wheat, there is a lack of research addressing microbiological processes in winter rye under the conditions of the Polissia region of Ukraine. The degree of influence of different biological preparations – particularly *Trichodermin*, *Organik-D2M*, and potassium humate – on soil microbiological activity under varying proportions of organic and mineral nutrients also requires clarification. Therefore, studying the dynamics of soil microbiological activity under different fertilisation systems and biological agents in winter rye crops is crucial for improving modern environmentally oriented agricultural technologies.

The aim of the study was to determine the effects of various fertilisation systems – biological, organo-mineral, and mineral – in combination with biological preparations on the microbiological activity of soil

in winter rye cultivation under the conditions of the Ukrainian Polissia region.

MATERIALS AND METHODS

The field experiment was carried out during 2019-2021 at the experimental plots of Polissia National University. The object of the study was winter rye (*Secale cereale* L.). Two fertilisation systems were investigated – biological and organo-mineral with different ratios of organic to mineral components (50:50 and 75:25) – in combination with the following biopreparations: Trichodermin, Potassium Humate, Organik-D2M, Mochevyn K No. 1, and Mochevyn K No. 2. In addition to the biological and organo-mineral fertilisation systems, a mineral system ($N_{50}P_{40}K_{70}$) was included for comparative analysis. This treatment involved the application of nitrogen, phosphorus, and potassium at rates of 50, 40, and 70 kg ha^{-1} respectively, corresponding to the regionally recommended fertilisation standards for winter rye. The mineral system served as a reference to evaluate the compensatory and synergistic effects of biopreparations under conditions of mineral nutrient dominance.

Soil microbiological activity was assessed by determining the percentage of linen fabric decomposition at a depth of 0-20 cm. The linen samples were placed in triplicate, and the results were processed statistically using analysis of variance (ANOVA). Winter rye of the variety Khlibne was sown according to standard agronomic practices recommended for the Polissia region. Foliar application of the biopreparations was carried out twice during the intensive growth phase, in accordance with the manufacturers' recommendations. All applied preparations were included in the official State Register of Pesticides and Agrochemicals Approved for Use in Ukraine (n.d.).

Preparations

1. Trichodermin, solution (1 L/ha) – a biological fungicide designed to protect crops from a wide range of fungal and bacterial diseases. It suppresses pathogenic agents transmitted through soil and plant residues.

2. Mochevyn K No. 1, solution (1 L/ha) – the active ingredients are macroelements (NPK) and microelements (0.1%). It promotes root system development, increases plant biomass, and enhances plant immunity.

3. Mochevyn K No. 2, solution (1 L/ha) – the active ingredients are macroelements (NPK) and microelements (1 g/L). It reduces plant water demand, increases drought resistance, stimulates the formation of additional shoots, and accelerates maturation.

4. Organik-D2M, solution (1 L/ha) – the active ingredients are: N – 2.0-3.0%, P_2O_5 – 1.7-2.8%, K_2O – 1.3-2.0%, total calcium – 2.0-6.0%, and organic substances – 65-70% (in terms of carbon content). It strengthens plant immunity against various diseases, enhances seed germination and vigour, reduces nitrate accumulation in fruit and vegetable products, inhibits the uptake of heavy metals and radionuclides by plants, increases the content of easily available nutrients in the soil, and promotes higher microbiological activity.

5. Potassium Humate, solution (2 L/ha) – contains macroelements (NPK) and microelements (0.3-2.5 g/L). It improves plant tolerance to drought and frost, contributing to better growth and development.

The experimental layout for the organic and organo-mineral fertilisation systems is presented in Table 1.

***Table 1**. Experiment design*

Variant No.	Treatment name	Preparation / treatment	Application rate, L/ha
1	Control	Water treatment	–
2	Trichodermin	Biological fungicide	1.0
3	Mochevyn K No. 1	Complex of macro- and microelements (NPK + 0.1% microelements)	1.0
4	Mochevyn K No. 2	Complex of macro- and microelements (NPK + 1 g/L microelements)	1.0
5	Organik-D2M	Organo-mineral biostimulator	1.0
6	Potassium Humate	Humic preparation	2.0

***Source:** compiled by the authors*

The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

The obtained results indicated that, under the biological control variant without the application of mineral fertilisers, the indicators of soil microbiological activity were the lowest (Fig. 1). The control treatment demonstrated a level of 87.38% in 2019, followed by a decline to 38% in 2020 and a partial recovery to 63.69% in 2021. The application of biopreparations ensured a consistent increase in microbiological activity throughout all experimental years. In particular, Trichodermin enhanced microbial activity to 97.06% in 2019 and 70.12% in 2021, which exceeded the control by 10-12%. A similar trend was observed under the application of Mochevyn K No. 2**,** where activity reached 72.74% in 2021, while Organik-D2M and Potassium Humate demonstrated activity levels of approximately 70%.

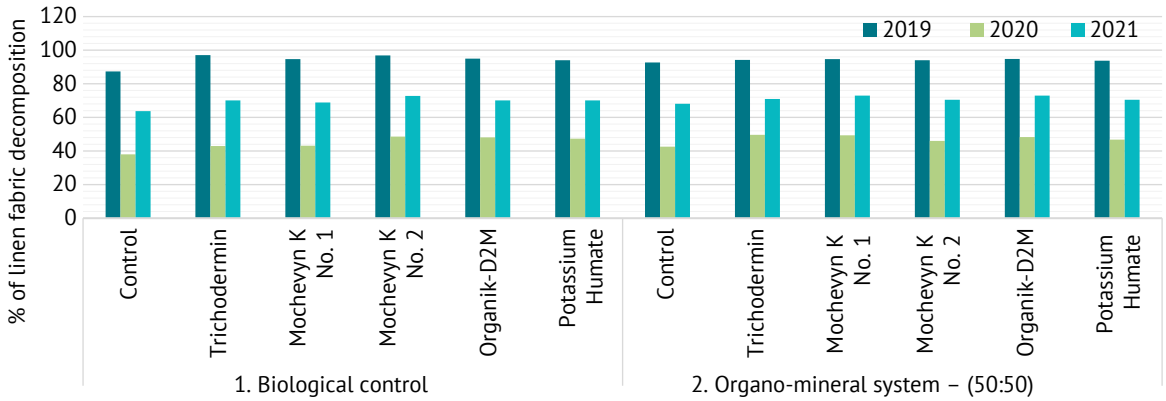

***Figure 1**. Soil microbiological activity in winter rye crops under biological and organo-mineral fertilisation systems with biopreparations, % of linen fabric decomposition*
***Source:** compiled by the authors*

Thus, even in the absence of mineral fertilisers, biopreparations positively influenced the development of soil microflora, particularly in the variants where Trichodermin and Mochevyn K No. 2 were applied. Under an equal ratio of organic and mineral fertilisers, soil microbial activity was the highest among all studied fertilisation systems. The control in 2021 accounted for 68.13%, whereas the variants treated with biopreparations exceeded this value by 3-5%. Specifically, Trichodermin ensured activity at 70.93%, Mochevyn K No. 1 at 73%, Organik-D2M at 73%, and Potassium Humate at 70.5%. On average, over the three years of the study, the organo-mineral fertilisation system (50:50) combined with Organik-D2M and Trichodermin demonstrated the highest biological activity. These findings confirmed the advisability of combining organic and mineral components to optimise soil microbiological processes.

The combination of 75% organic and 25% mineral fertilisers noticeably stimulated soil microbiota (Fig. 2). In the control variant, microbial activity reached 66.11% (2021), whereas under the application of Trichodermin, the value increased to 66.55%, and under Organik-D2M – to 71.73%. The application of Mochevyn K No. 1 and Potassium Humate provided activity levels of 70.0-70.1%, exceeding the control by 5-6%. The highest microbiological activity was recorded in 2021 under the Organik-D2M treatment, where activity reached 71.73%. These results indicate that the partial incorporation of mineral elements alongside organic inputs creates favourable conditions for the development of microorganisms and contributes to enhanced soil fertility.

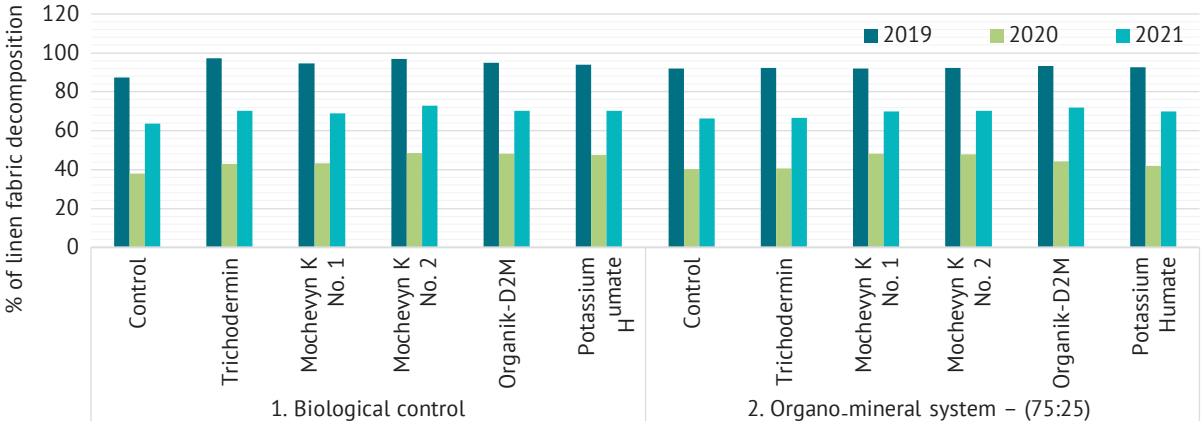

***Figure 2**. Soil microbiological activity in winter rye crops under the organo-mineral fertilisation system and biopreparations, % of linen fabric decomposition*
***Source:** compiled by the authors*

When mineral fertilisers were applied, microbial activity was slightly lower than under organo-mineral systems, yet it exceeded the level observed in the biological control (Fig. 3). The control treatment recorded 67.27% in 2021, whereas under the influence of Trichodermin, the indicator reached 71.23%, under Mochevyn K No. 1 – 70.25%, Organik-D2M – 71.11%, and Potassium Humate – 71.21%. The highest activity

was observed with Organik-D2M (71.11%), indicating the mitigating effect of biopreparations on the mineral load of the soil and their ability to stimulate microbial development.

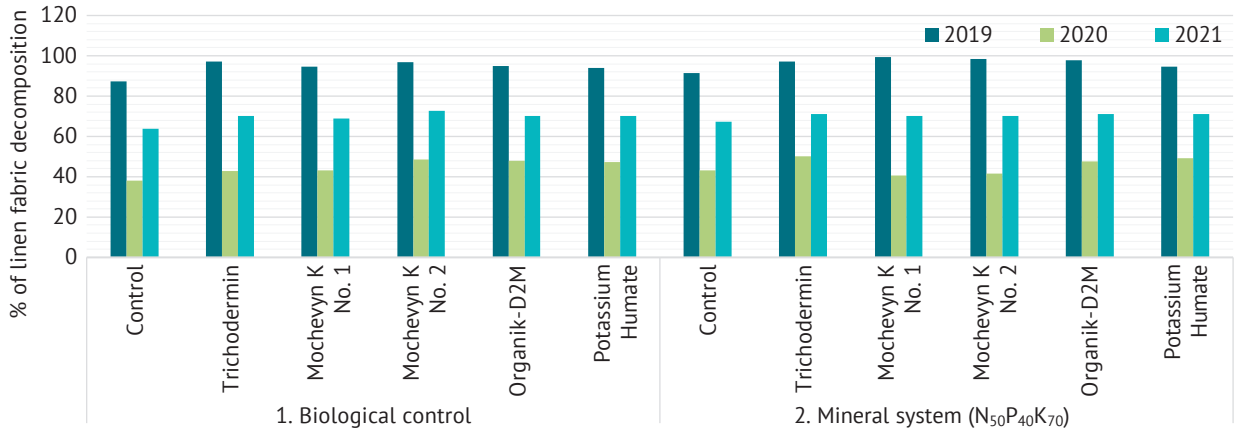

***Figure 3**. Soil microbiological activity in winter rye crops under the mineral fertilisation system and biopreparations, % of linen fabric decomposition*

***Source:** compiled by the authors*

Summarising the obtained results, all fertilisation systems involving biopreparations had a positive effect on soil microbiological activity; however, the extent of this effect depended on the ratio of organic and mineral components. The highest values were observed in variants combining organic and mineral inputs, confirming their synergistic influence on soil microbiota. The application of biopreparations, particularly Trichodermin and Organik-D2M, enhanced the activity of organic matter decomposers, intensified enzymatic processes, and improved the overall biological condition of the soil.

It was established that even in the complete absence of mineral fertilisers, the use of biopreparations led to a significant increase in microbial activity compared with the control, indicating the high potential of biological preparations in maintaining soil fertility. Nevertheless, the combination of organic and mineral nutrient sources in a 50:50 ratio proved to be the most effective, as it created a balanced environment for the development of microbial communities and stable mineralisation processes. Under this system, activity exceeded the control by an average of 8-10%, confirming its suitability for environmentally oriented agriculture. The findings demonstrate that the regulation of soil microbiological activity can be achieved through a rational integration of organic, mineral, and biological components within fertilisation systems. Biopreparations serve not only as plant growth stimulants but also as key agents maintaining the functional balance of soil microorganisms, ensuring sustainable nutrient cycling and the long-term preservation of fertility in the chernozem and sod-podzolic soils of the Polissia region of Ukraine.

The results of the study confirmed that the combination of organic and mineral fertilisation systems with biopreparations is an effective factor in enhancing soil microbiological activity. This pattern aligns with the findings of P. Cong *et al.* (2025), who reported that the application of organic amendments stimulates the growth of decomposer microorganisms and improves the structural and functional stability of microbial communities, even in saline soils. The data obtained in the present study demonstrated a similar tendency: organic components and biopreparations increased the percentage of linen fabric decomposition, indicating the activation of cellulose-based organic matter degradation processes.

The meta-analysis by D.P. Bebber and V.R. Richards (2022) emphasised that combined nutrient systems promote greater microbial diversity and enhance functional interactions among microorganisms. The results obtained for winter rye crops revealed a comparable relationship: microbiological activity under the organo-mineral system (50:50) exceeded that of the biological control, highlighting the positive influence of combining different nutrient sources. Similarly, Z. Yu *et al.* (2025) observed that the partial substitution of mineral fertilisers with organic inputs increases soil enzyme activity and improves crop quality, thereby supporting the rationale for an integrated fertilisation approach. According to A. Shamshitov *et al.* (2025) and X. Pan *et al.* (2025), the use of organic fertilisers fosters more stable microbial communities in the rhizosphere of leguminous crops, particularly under conditions of increased carbon availability. A similar trend was observed for winter rye, where the organic components of the nutrient system ensured long-term stability in soil biotic activity. Z. Wang *et al.* (2025) reported that the combined application of microbial agents and organic fertilisers enhances humus content and improves soil quality on saline-alkaline lands. The consistently high levels of microbiological activity identified under the organo-mineral system in this study suggest a broadly

positive effect of such combinations across different agroclimatic conditions.

The findings of C.A. Zeiner *et al.* (2024) demonstrated that even in urban agroecosystems, organic composts enhance dehydrogenase and urease enzyme activities. This observation aligns with the results obtained for potassium humate and Organik-D2M, which stimulated enzymatic processes and maintained high microbial activity throughout the three years of experimentation.

Ukrainian researchers M. Voitovyk and M. Zhovtun (2024) demonstrated that soil biological activity depends on the fertilisation system, confirming that organic components contribute to maintaining agroecological balance. The results of the present experiment supported this pattern, as the highest activity was recorded when mineral fertilisers were partially substituted with organic inputs. Similar conclusions were presented by Y. Borko *et al.* (2025), who noted that biological preparations combined with fertilisers enhance soil microflora activity and maize yield. The application of Trichodermin and Organik-D2M produced a comparable positive effect for winter rye crops. The study by O. Kuts *et al.* (2022) confirmed that the excessive use of mineral fertilisers reduces enzymatic activity and disrupts microbial balance. These findings align with the observations obtained in this research, where the mineral system demonstrated lower biological activity compared with the organo-mineral system.

Overall, the analysis of current studies indicates that combined fertilisation systems incorporating biopreparations form functionally stable microbial communities, improve soil structure, and contribute to the sustainable regeneration of its fertility. The findings highlight the need for further biologisation of cereal cultivation technologies and for scientifically substantiated optimisation of organic and mineral component ratios within nutrient management systems.

CONCLUSIONS

The conducted research demonstrated that soil microbiological activity serves as a sensitive indicator of fertilisation system efficiency and the level of agroecosystem ecological stability. Over the three-year observation period, it was established that the combination of organic and mineral components in fertilisation systems created the most favourable conditions for the development of soil microflora. The organo-mineral system with an equal ratio of components (50:50) provided the highest biological activity, exceeding the control treatments by an average of 8-10%. This finding indicates a synergistic effect between available nutrient forms and organic carbon sources, stimulating mineralisation and humification processes. The application of biopreparations, particularly Trichodermin, Organik-D2M, and Mochevyn K No. 2, increased microbial activity across all fertilisation systems, reduced the negative impact of mineral load, and improved the condition of soil microflora. These preparations enhanced enzymatic activity, accelerated the decomposition of organic matter, and contributed to the potential increase in soil fertility. The exclusive use of organic fertilisers also had a positive effect on soil biota; however, under combined fertilisation, the effect was more stable and consistent throughout the study years. The obtained results confirm the necessity of transitioning from one-sided mineral nutrition to integrated fertilisation schemes that combine biological agents with organic and mineral fertilisers. Prospects for further research include investigating the impact of biopreparations on the activity of specific groups of soil microorganisms, determining the dynamics of enzymatic processes during different phenological stages of winter rye development, and assessing long-term changes in the structure of microbial communities under the influence of combined fertilisation systems.

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CONFLICT OF INTEREST

None.

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Мікробіологічна активність ґрунту в посівах жита озимого за різних систем удобрення та біопрепаратів

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Анотація. Метою дослідження було визначити вплив різних систем удобрення у поєднанні з біопрепаратами на мікробіологічну активність ґрунту під посівами жита озимого в умовах Полісся України. Методологія роботи ґрунтувалася на польовому експерименті, який проводився протягом 2019-2021 років на дослідних ділянках Поліського національного університету. Було використано дві системи удобрення – біологічну та органо-мінеральну з різним співвідношенням компонентів (50:50 і 75:25), а також мінеральну систему як порівняльний варіант. Для оцінки мікробіологічної активності застосовувався метод розкладання лляного полотна у шарі ґрунту 0-20 см, результати оброблялися методами дисперсійного аналізу. У ході дослідження було встановлено, що найвищі показники біологічної активності спостерігалися за органо-мінеральної системи удобрення із рівним співвідношенням органічної та мінеральної складових, де активність мікроорганізмів перевищувала контроль на 8-10 %. Було доведено, що біопрепарати Триходермін, Органік Д2М і Мочевин К №2 позитивно впливали на розвиток мікрофлори, посилювали ферментативні процеси та сприяли стабільності мікробних угруповань. Проаналізовано, що навіть без внесення мінеральних добрив застосування біопрепаратів забезпечувало суттєве підвищення активності мікроорганізмів, тоді як мінеральна система мала нижчий, але стабільний рівень дії. Узагальнення результатів підтвердило синергетичний ефект поєднання органічних і мінеральних елементів живлення, який забезпечує збалансоване мікробіологічне середовище та підтримує родючість ґрунту. Практична цінність роботи полягає у можливості використання отриманих результатів для оптимізації систем удобрення та впровадження біопрепаратів у технології вирощування зернових культур у зоні Полісся України з метою підвищення екологічної ефективності землеробства

Ключові слова: ґрунтова мікрофлора; органо-мінеральне живлення; ферментативна активність; біологічна деструкція; агроекологічна стабільність; біологізація землеробства; мікробні консорціуми