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Development of winter wheat productivity under the influence of biopreparations and different moisture conditions in the steppe zone

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ABSTRACT

The article presents the results of research on the influence of moisture conditions and biopreparations on the productivity of plants of different biological characteristics of winter soft wheat varieties. The yield of winter wheat significantly depends on the genetic characteristics of the variety, moisture and nutrition conditions. Pre-sowing seed treatment and foliar fertilization of winter wheat with modern biological products increase grain yields and reduce the chemical load on agrocenoses, which is especially important in today's market economy. The highest level of winter wheat yield under non-irrigated conditions in 2021–2023 on average was formed by the variety Duma Odeska (6.79 t/ha) in the variant with pre-sowing seed treatment with the biological product Azotophyt-r in combination with foliar fertilization with the biological product Helprost, while the lowest productivity was formed by the variety Ovid (5.63 t/ha) in the control variant (pre-sowing seed treatment with clean water without preparations). It has been established that to form a grain yield of 8.43 t/ha, it is necessary to grow a variety of soft winter wheat Duma Odeska under irrigation conditions, the seeds should be treated with the biological product Mycofriend in combination with the foliar application of the biological product Helprost before sowing. When grown under non-irrigated conditions, among the four winter wheat varieties studied, Ozerna cultivar showed the highest grain yield (6.31 t/ha). Under irrigation conditions, the highest grain yield (7.92 t/ha) was on average produced by Duma Odeska winter wheat. Thus, when grown under non-irrigated conditions, a higher yield of winter wheat grain (6.61 t/ha) was obtained by treating seeds with the biological product Azotophyt-r and foliar treatment of plants with the biological product Helprost. A higher grain yield (8.02 t/ha) under irrigation conditions, on average, was formed by winter wheat plants in the variant with pre-sowing seed treatment with the biological product Mycofriend and foliar feeding with the biological product Mycohelp.

Keywords: soft winter wheat, cultivars, biopreparations, irrigation, pre-sowing seed treatment, foliar feeding, grain yield.

INTRODUCTION

In recent years, world food and fertilizer prices have increased significantly, which is closely related to the COVID-19 pandemic, global climate change, and economic crises in countries that export agricultural resources. The result is a disruption in the supply chains of agricultural products and the countrys export-import potential (AL-Rousan et al., 2024).

In this regard, spring field work and harvesting of grain crops, in particular winter wheat, have been threatened. As a result, the gross grain harvest has significantly decreased. One way to improve this situation is to increase the yield of winter wheat based on innovative resource- and energy-saving smart technologies using modern irrigation systems (Esposito, 2021).

In addition, global warming and crop rotation imbalances in Ukraine have negatively affected soils - the main resource of Ukrainian agriculture. Therefore, soil restoration is the main task of agricultural development and increasing the gross grain harvest in the country. One of the main stages of soil restoration is the restoration of microbiota (Al-Mebayedh et al., 2023; Solokha et al., 2023). Indeed, without the necessary set of microorganisms and a decrease in their number, which often occurs due to improper agricultural management, excessive use of agrochemicals and environmental pollution, soils quickly degrade (Makarova et al., 2021; Rasool et al., 2022; Lin et al., 2023).

Equally important in increasing crop yields, especially in the context of climate change, is the correct choice of variety, which is one of the most rational and economical means of increasing winter wheat grain yields (Domaratskiy et al., 2018, 2020; Korkhova et al., 2023). In order to form stable and high yields, wheat plant breeding should be aimed at creating varieties adapted to growing conditions (Pichura et al., 2024).

Irrigation is one of the factors that determines the overall state of agricultural production, exports and food security. The once powerful water management complex of Mykolaiv, Odesa, and Kherson oblasts is not being fully utilized today. One of the reasons for this situation today is the military actions that resulted in the reduction of irrigated land in the Ingulets irrigation system (Biyashev et al., 2024). Researchers have found that one of the reserves for increasing the yield of winter wheat grain is the use of biological products (mycorrhizal agents, biostimulants, biofungicides, etc.) for pre-sowing seed treatment (Macholdt et al., 2021; Lamichhane et al., 2022).

Scientists have proven that the use of environmentally friendly growth stimulants of biological origin for pre-sowing seed treatment contributed to an increase in the coefficient of total plant bushiness by 0.3 stems per plant compared to the control (without seed treatment) (Blandino et al., 2009; Korkhova et al., 2023).

Studies by Ukrainian scientists, conducted at the Scientific and Research Center of Mykolaiv National Agrarian University in 2020–2022, have shown that pre-sowing seed treatment with biological products increases the productivity of winter wheat in both irrigated and non-irrigated conditions. In addition to pre-sowing treatment of wheat seeds, it is important to apply foliar fertilization, taking into account the biological needs of the crop. Scientists have found a positive effect of foliar fertilization of plants with organic fertilizers in combination with growth stimulants and micronutrient fertilizers on productive stem growth, ear watering, grain yield of *T. aestivum* L. and its quality under irrigation conditions in southern Ukraine (Panfilova et al., 2023).

Researchers have found that foliar feeding with biological products "Biocomplex BTU-r" and "Organic Balance" during the main periods of winter wheat vegetation allows to optimize plant nutrition and form a stable grain yield (Gamayunova et al., 2022).

The results of a field experiment conducted in the northern steppe of Ukraine showed that at the initial stages of winter wheat organogenesis, foliar application of humic acid-based preparations has a positive effect on the growth, development and productivity of winter wheat plants. Pre-sowing bacterization of seeds and foliar feeding of plants with the Biocomplex-BTU biological product increases wheat grain yield by 3.3–12.4% and 3.6–7.2%, respectively (Voloschuk et al., 2021).

The spectrum of environmentally friendly preparations of biological origin, which is widely represented on the EU market, requires a more substantial study of the reaction of winter wheat plants to their use. The aim of the study was to determine the effect of pre-sowing seed treatment and foliar feeding with biological products produced in Ukraine on the productivity of different varieties of soft winter wheat under irrigated and non-irrigated conditions.

MATERIALS AND METHODS

The field research was conducted for over three years (2020–2024) at the Educational and Practical Center of Mykolaiv National Agrarian University, located in the southern part of the Steppe zone of Ukraine, Senchyne village, Mykolaiv region, Ukraine (GPS: 46.935489, 31.653750) (Figure 1).

The program of the research was aimed at studying the effect of seed treatment and foliar treatment with environmentally friendly preparations of biological origin on the productivity and quality of the products obtained when growing different types of winter wheat cultivars. The implementation of scientific research was carried out by establishing two three-factor field

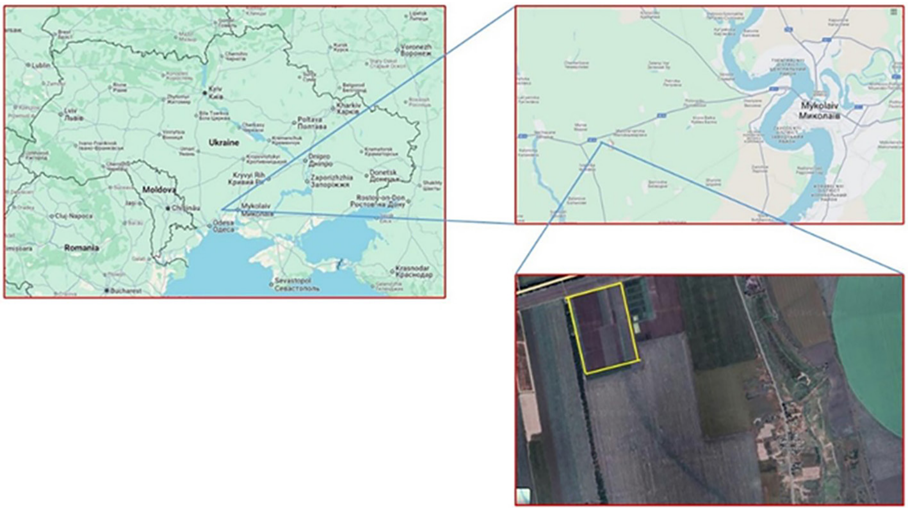

Figure 1. The place of research

experiments (without irrigation and under irrigation conditions), which included the following factors and variants:

- Factor A – Cultivars: Ovidii, Ozerna, Duma Odeska, Anatolia (originator – Plant Breeding and Genetics Institute – National Centre of Seed & Cultivar Investigation, Ukraine).
- Factor B – seed treatment with biopreparations: Control (treatment of seeds with clean water without preparations); Azotophyt-r (0.6 l/t); Phytocid-r (1.7 l/t); Mycofriend-p (1.1 l/t); Organic-Balance Monophosphorus (0.6 l/t); Humifriend (1.1 l/t).
- Factor C – foliar feeding of plants: Treatment of plants with clean water (without preparation); MikoHelp (2.0 l/ha); Helprost Grain (3.0 l/ha).

In 2021–2024, a two-factor field experiment was conducted with the winter wheat variety Pearl of Odesa, which included pre-sowing seed treatment with Azotophyt-r and Organic Balance biological products, as well as foliar feeding of plants during the growing season with Helprost

"Azotophyt-r" contains Agrobacterium pusense (Azotobacter chroococcum); titer: not less than 1.0 × 109 CFU/cm^3.

"Phytocid-r" contains live natural bacteria *Bacillus subtilis* – not less than 1.0 × 109 CFU/cm^3.

Mycofriend contains: mycorrhizal fungi - *Glomus* sp., microorganisms that support the formation of mycorrhiza and plant rhizosphere – *Trichoderma harzianum*, *Streptomyces* sp, *Pseudomonas fluorescens*; phosphate-mobilizing bacteria – *Bacillus megaterium* var. phosphaticum, *Bacillus subtilis*, *Bacillus muciloginosus*, *Enterobacter* sp. and biologically active substances – phytohormones, vitamins, amino acids. The total number of viable cells of microorganisms-producers is not less than (1.0–1.5) × 108 CFU/cm^3.

"Organic-Balance Monophosphorus" contains phosphorus-mobilizing bacteria, bacteria with fungicidal and bactericidal properties, biologically active substances: phytohormones, amino acids and vitamins. The total number of viable microorganisms - producers - is not less than 1.0 × 109 CFU/cm^3. The composition of Humifriend includes: potassium salts of humic and fulvic acids, 120 g/l; a complex of microorganisms from 5 strains of the *Bacillus genus*; trace elements, amino acids, peptides, polysaccharides, succinic acid.

"Mikohelp" has biofungicidal properties due to the content of saprophytic fungi antagonists of the genus Trichoderma, live cells of bacteria *Bacillus subtilis*, *Azotobacter chrococcum*, *Enterobacter* sp, *Enterococcus* sp and biologically active products of microorganisms-producers. The total number of viable cells of microorganisms is not less than 1.0 × 109 CFU/cm^3.

Helprost for grain contains macro- and microelements: S – 16.0; Zn – 5.5; Mg – 1.5; B – 4.5; Mn – 10.0; Cu – 10.0; Mo – 0.2; Co – 0.02, as well as organic acids, amino acids, peptides, polysaccharides and a complex of microorganisms.The soil of the experimental field is a typical southern chornozem, residual slightly saline heavy loamy loess, humus content (0–30 cm) is 3.1–3.3%, soil solution is neutral (pH 6.8–7.2). The topsoil contains 15–25 mobile forms of nitrate, 41–46 mobile phosphorus, and 389–425 mg/kg of exchangeable potassium.

Foliar treatments of winter wheat plants with these environmentally friendly preparations were carried out in the tillering phase in spring, when the average daily temperatures were above 100 °C. The experimental plots of winter wheat were placed in field experiments using the split-plot method, sowing was carried out with a grain seeder with a row spacing of 15 cm and simultaneous application of starting mineral fertilizers at a rate of $N_{30}P_{10}$. The registered area of the plots was 35 m^2. Repeatability – four times. The forecrop for soft winter wheat was peas. Further care of the crops was reduced to herbicidal, fungicidal and insecticidal protection: in the spring, during the interphase period of tillering - tube emergence, a herbicide (with the active ingredient tribenuron methyl, 562.5 g/kg) was applied in a tank mixture with a fungicide (with the active ingredient tebuconazole, 500 g/l). During the period of grain ripeness, an insecticide (with the active ingredient alpha-cypermethrin, 200 g/l) was applied to protect the ear from *Eurygaster integriceps Put.* and *Haplothrips tritici.* Harvesting and accounting was carried out by a Sampo-2010 combine harvester with a basic grain moisture content of 14%.

The obtained experimental data were processed using multivariate analysis of variance (Ushkarenko et al. 2020) and the Acutis method (Acutis et al., 2012). Modeling of yield formation was carried out using the licensed program "Statistica 10.0".

RESULTS AND DISCUSSION

Plant growth regulators themselves do not increase plant productivity, but they can influence the processes, direction and intensity that cannot be corrected by agronomic measures (Blandino et al., 2009; Macholdt et al., 2021). The mechanism of action of growth-regulating preparations is to activate biological processes of plants and increase the permeability of intercellular membranes. This contributes to the fuller disclosure of their biological productivity potential (Arikan et al., 2022). The analysis of weather conditions in 2020–2024 allows us to classify them as medium-dry typical for this growing zone. The main average long-term weather data of the research sites are shown in Figure 2.

The average annual air temperature during the research years was almost the same 11.0–2.2 °C, but the average monthly temperature of the growing season of winter wheat fluctuated within 8.8–10.1 °C. A somewhat higher temperature period was noted for the growing season of the crop in 2022–2023. The amount of precipitation that fell during the growing season of winter wheat was the largest in 2022–2023 – 411.7 mm, which exceeded the indicators of other years of the study by 16.7–136.7 mm.

A characteristic biological feature of cereals is the ability to bush. There are general and productive bushiness. The main factors that form a productive stem are the genetic characteristics of the variety, the supply of plants with nutrients and the hydrothermal conditions of the growing season. Of the winter wheat varieties studied by us, on average over the years of research and by the nutrition factor, on the variants without irrigation, a slightly higher density of productive stems was formed by plants of the Anatolia variety – 685.6 pcs./m^2 and plants of the Duma Odeska variety – 677.3 pcs./m^2. The smallest number of productive stems on average over the years of research on the variant without irrigation was in plants of the Ovidii variety – 636.9 pcs./m^2.

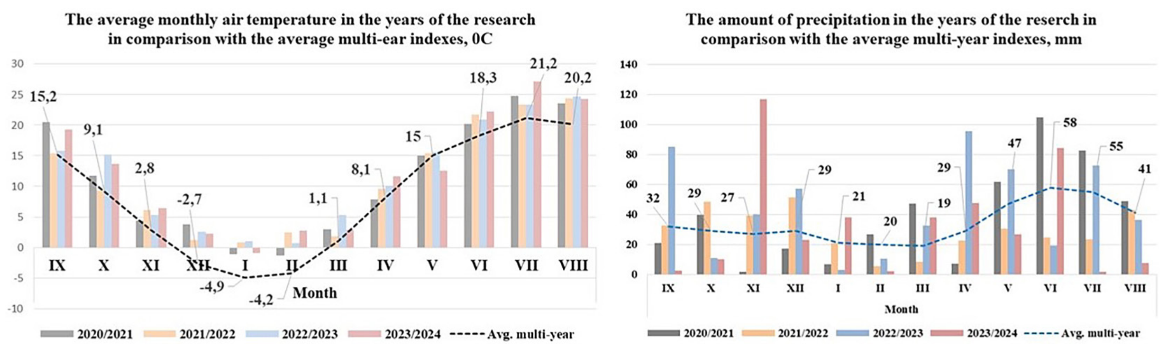

Figure 2. Weather conditions at the research site for 2020–2024

When growing winter wheat under irrigation, the plants of the Ozerna and Duma Odeska varieties formed the largest number of productive stems, 835.7 and 873.9 pcs./m^2. In the variant without irrigation, the largest number of productive winter wheat stems was formed in the variant of pre-sowing seed treatment with Azotophyt-r 684–689 pcs./m^2, depending on the use of foliar feeding (Fig. 3).

At the same time, on average over the years of research, the largest number of productive stems of winter wheat plants was formed with foliar feeding with the drug Helprost – 648–684 pcs./m^2, depending on the option of pre-sowing seed treatment. The same trend was observed in the options for using irrigation (Fig. 4).

On average, over the years of research, the number of productive stalks of winter wheat under irrigation conditions was the largest in the application options of seed treatment with Azotophyt-r and Mikofriend – 839–851 and 851–856 pcs./m^2.

It should be noted that under the conditions of irrigation, the highest number of productive stems was formed on the variant of the combined use of the biological preparation Mikofriend and Helprost – 856 pcs./m^2 on average according to the variety factor and over the years of research,

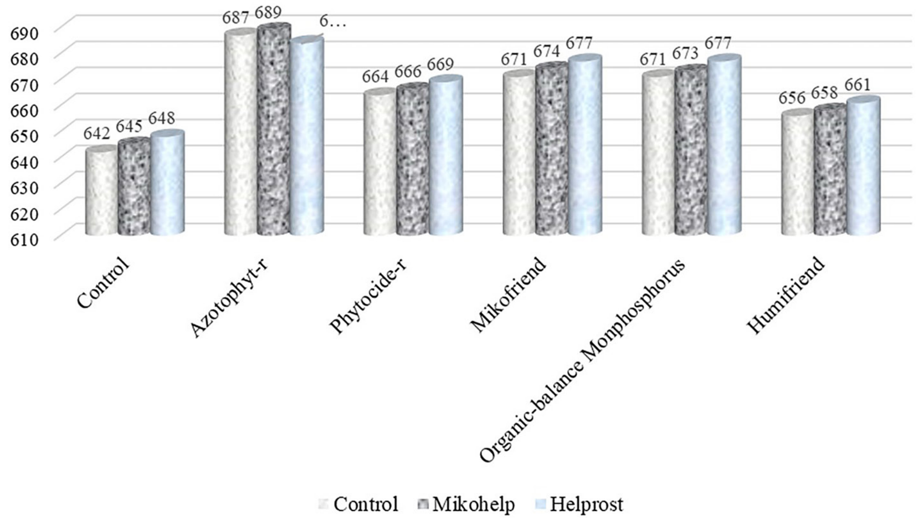

Figure 3. Number of productive stems formed by winter wheat plants depending on pre-sowing seed treatment with biological products and foliar feeding without irrigation (average for 2021–2023 and by variety factor), pcs./m^2

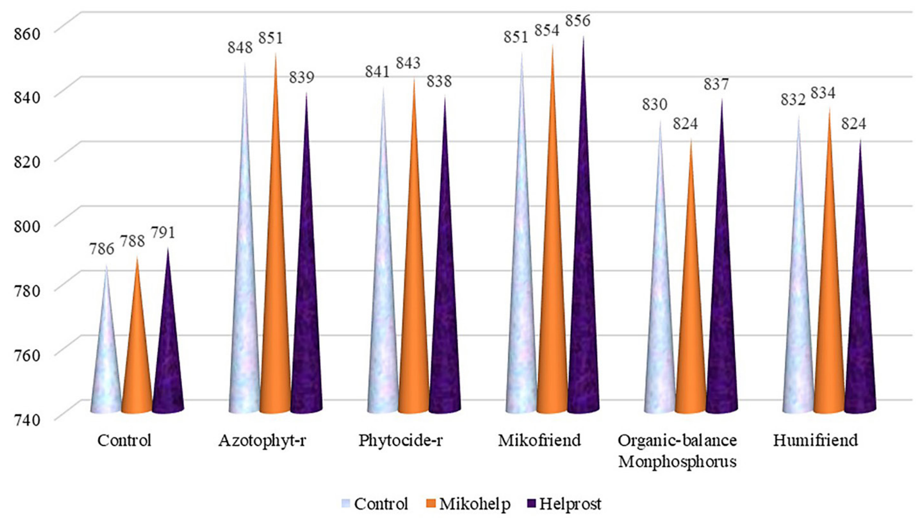

Figure 4. The effect of biological products on the number of productive stalks of winter wheat under irrigation conditions (average for 2021–2023 and by variety factor), pcs./m^2

which exceeded the indicators of the control variant of the experiment by 8.2%.

The research showed that the grain yield of winter wheat cultivars depended on biological products for seed and plant treatment, as well as moisture conditions.

On average, over the years of research (2020–2023), a higher grain yield (6.79 t/ha) on the bogar was formed by winter wheat plants of the Duma Odeska cultivar under pre-sowing seed treatment with the biological product Azotophyt-r in combination with foliar feeding of plants with the biological product Helprost (Table 1).

The lowest grain yield (5.63 t/ha) was formed by plants of the Ovidii variety in the control variant when seeds and plants were treated with water under non-irrigated conditions.

It was determined that under non-irrigated conditions the studied winter wheat varieties had a higher grain yield: 6.38 t/ha (Ovidii), 6.57 t/ha (Ozerna), 6.69 t/ha (Anatolia) and 6.79 t/ha (Duma Odeska) were formed by plants in variants with pre-sowing seed treatment with the biological product Azotophyt-r in combination with foliar feeding of plants with the biological product Helprost.

The cultivar response to the formation of winter wheat grain yield depending on biological products under bog conditions was established. Thus, higher grain yields were recorded in plants of the Anatolia cultivar in the control variant (water treatment) (6.48 t/ha) and in the variant with foliar treatment with the Mikohelp biopreparation (6.60 t/ha), while in the variant with foliar treatment using the Helprost biopreparation, higher grain yields (6.79 t/ha) were recorded in plants of the winter wheat cultivar Duma Odeska.

When growing winter wheat under irrigation, the highest grain yield (8.43 t/ha) was formed by plants of the Duma Odeska cultivar in the variant with pre-sowing seed treatment with the biological product Mycofriend in combination with

Table 1. Influence of biological products on grain yield of winter wheat cultivars without irrigation (average for 2021–2023), t/ha

No.	Factor B	Factor A			
		Ovidii	Anatolia	Ozerna	Duma Odeska
Factor C - control					
1	Control	5.63	5.75	5.92	6.10
2	Azotophyt-r	6.13	6.48	6.43	6.46
3	Phytocide-r	5.81	6.30	6.23	6.22
4	Mikofriend	5.99	6.32	6.35	6.28
5	Organic-balance Monphosphorus	6.06	6.27	6.47	6.24
6	Humifriend	5.73	5.97	6.02	6.11
Factor C – Mikohelp					
1	Control	5.70	5.84	5.98	6.06
2	Azotophyt-r	6.30	6.60	6.50	6.57
3	Phytocide-r	5.90	6.45	6.33	6.30
4	Mikofriend	6.09	6.20	6.40	6.32
5	Organic-balance Monphosphorus	6.18	6.44	6.53	6.26
6	Humifriend	5.79	6.03	6.08	6.17
Factor C – Helprost					
1	Control	5.81	6.02	6.08	6.10
2	Azotophyt-r	6.38	6.69	6.57	6.79
3	Phytocide-r	5.99	6.47	6.40	6.37
4	Mikofriend	6.14	6.59	6.46	6.47
5	Organic-balance Monphosphorus	6.24	6.58	6.33	6.38
6	Humifriend	5.87	6.20	6.45	6.22
LSD_{05} (t/ha) by factor A : 2021 – 0.14; 2022 – 0.14; 2023 – 0.14					
LSD_{05} (t/ha) by factor B : 2021 – 0.22; 2022 – 0.28; 2023 – 0.21					
LSD_{05} (t/ha) by factor C : 2021 – 0.16; 2022 – 0.16; 2023 – 0.16					

foliar feeding with the Helprost biopreparation (Table 2). The lowest yield of winter wheat grain (6.73 t/ha) was observed in plants of Ovidii cultivar in the control variant (water treatment).

It was determined that a higher grain yield in the variant with water treatment (control) – 8.05 t/ha was observed in the Duma Odeska cultivar in combination with pre-sowing seed treatment with the Phytocide-r biopreparation.

In the variant with foliar feeding of plants with the Mycohelp biological product, a higher grain yield (8.21 t/ha) was formed by the Duma Odeska variety in the variant with pre-sowing seed treatment with the Azotofit-r biological product, while in the variant with the Helprost biological product, a higher grain yield (8.43 t/ha) was formed by plants of the same variety with the combined use of the Mycofriend biological product.

On average, according to the cultivars (factor A), a higher grain yield (6.61 t/ha) was formed by winter wheat plants in the variant with pre-sowing seed treatment with Azotophyt-r biological product in combination with foliar fertilization with Helprost biopreparation when grown on a dry land (Figure 5).

The lowest grain yield (5.85 t/ha) was observed in the control variant (pre-sowing treatment of seeds and plants). When growing winter wheat under conditions of modern sprinkler irrigation, a higher average yield (8.02 t/ha) was formed by plants in the variant with pre-sowing seed treatment with the biological product Azotophyt-r in combination with foliar feeding with the Mycohelp biopreparation (Figure 6).

With the combined use of most of the studied biopreparations for pre-sowing seed treatment along with biopreparations for foliar feeding, it was found that the higher grain yield was formed in the variant of feeding with the Mycohelp biopreparation, and only in the case of seed treatment with Organic-balance

Table 2. Effect of biopreparations on grain yield of winter wheat cultivars under irrigation (average for 2021–2023), t/ha

No. п/п	Factor B	Factor A			
		Ovidii	Anatolia	Ozerna	Duma Odeska
Factor C - control					
1	Control	6.73	6.97	7.10	7.51
2	Azotophyt-r	7.72	7.80	7.97	7.96
3	Phytocide-r	7.37	7.44	7.48	8.05
4	Mikofriend	7.94	7.59	7.70	8.03
5	Organic-balance Monphosphorus	7.21	7.32	7.58	7.86
6	Humifriend	6.99	7.07	7.23	7.60
Factor C – Mikohelp					
1	Control	6.79	6.99	7.14	7.55
2	Azotophyt-r	7.76	7.93	8.13	8.27
3	Phytocide-r	7.43	7.47	7.65	8.25
4	Mikofriend	7.98	7.51	7.96	8.26
5	Organic-balance Monphosphorus	7.26	7.46	6.53	8.09
6	Humifriend	7,01	7.22	7.39	7.76
Factor C – Helprost					
1	Control	6.84	6.58	7.23	7.57
2	Azotophyt-r	7.96	7.52	8.21	6.79
3	Phytocide-r	7.47	6.47	7.77	8.42
4	Mikofriend	7.98	7.27	8.20	8.43
5	Organic-balance Monphosphorus	7.31	7.03	7.78	8.25
6	Humifriend	7.05	6.20	7,41	7,94
LSD_{05} (t/ha) by factor A : 2021 – 0.14; 2022 – 0.14; 2023 – 0.14					
LSD_{05} (t/ha) by factor B : 2021 – 0.16; 2022 – 0.28; 2023 – 0.20					
LSD_{05} (t/ha) by factor C : 2021 – 0.16; 2022 – 0.16; 2023 – 0.16					

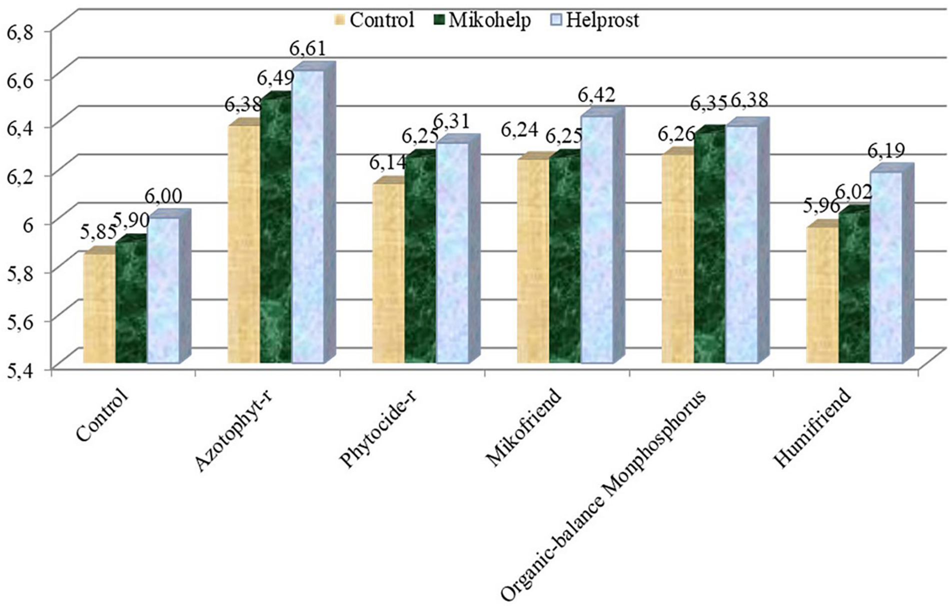

Figure 5. Winter wheat yield (t/ha) depending on pre-sowing seed treatment with biopreparations and foliar feeding without irrigation (average for factor A – cultivars)

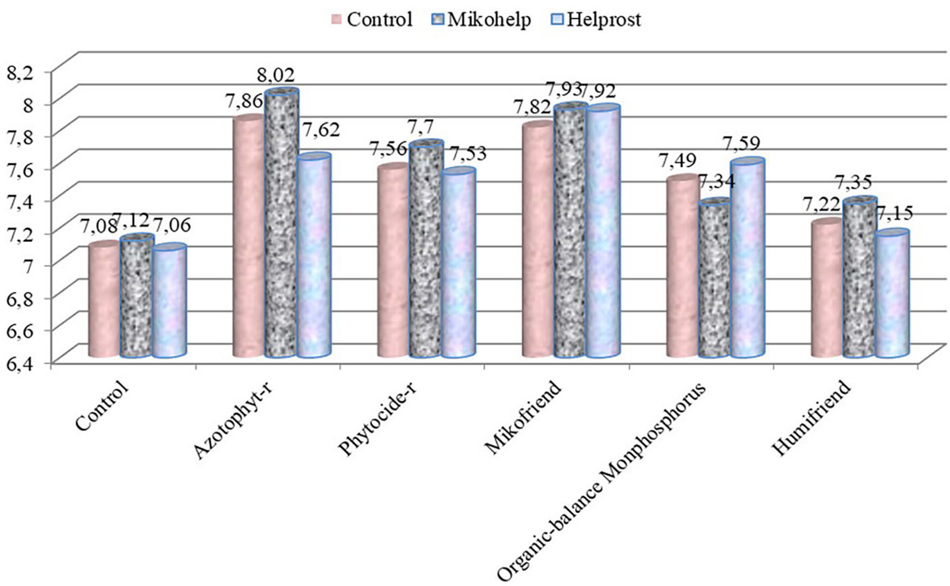

Figure 6. Winter wheat yield (t/ha) depending on pre-sowing seed treatment with biopreparations and foliar feeding on irrigation (average for factor A - cultivars)

Monophosphorus the best variant in terms of yield was in feeding with Helprost.

Studies conducted in 2021–2024 on the cultivation of the variety Perlyna Odesa also revealed a positive effect of biopreparations on plant growth and development, as well as their productivity. Thus, the use of pre-sowing seed treatment and foliar feeding of plants during the growing season contributed to an increase in grain yield by an average of 0.43–0.54 t/ha or 7.1–8.8% over the years of research compared to the control variant of the experiment (Table 3). The highest yield of winter wheat grain was formed during pre-sowing seed treatment with the biological product Azotophyt-r in combination with foliar application of Helprost and amounted to 6.17 t/ha, which exceeded the control variant of the experiment by 0.54 t/ha or 8.8%, and the variant of using the biological product Organic-Balance for seed treatment and foliar application of Helprost – by 0.11 t/ha or 1.8%.

Table 3. Influence of biopreparations on the yield of winter wheat variety Perlyna Odesska, t/ha

Variety	Years			Average for 2022–2024
	2022	2023	2024	
Control	6.35	6.38	4.17	5.63
Azotophyt-r + Helprost	6.85	6.94	4.72	6.17
Organic-balance + Helprost	6.73	6.80	4.65	6.06
LSD_{05}, t/ha	0.14	0.10	0.05	

CONCLUSIONS

Thus, on average, during three years of research (2020–2023), the highest yield among the four studied winter wheat cultivars was formed in the Duma Odeska cultivar (8.43 t/ha) under irrigation conditions in the variant with pre-sowing seed treatment with the Mycofriend biopreparation in combination with foliar feeding with the Helprost biopreparation.

In the cultivation of winter wheat on dry land, the best option for most of the studied cultivars was the pre-sowing seed treatment with the Azotophyt-r biopreparation in combination with foliar feeding with the Helprost biopreparation.

On average, for the years 2022–2024, the highest grain yield of sorghum Perlyna Odeska was obtained with pre-sowing seed treatment with Azotophyt-r and plant nutrition with Helprost – 6.17 t/ha.

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