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The use of biologization elements in the cultivation of spring barley in the conditions of the Southern Steppe of Ukraine

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ABSTRACT

The research aimed to assess the effectiveness of implementing biotechnological elements in the cultivation technology of modern varieties of spring barley. The study evaluated not only the potential for increasing grain yields but also the improvement of key soil fertility characteristics with a reduction in the application rate of mineral fertilizers. The use of stubble decomposers and modern biopreparations for fertilizing spring barley plants positively affected the grain yield of all studied varieties of this crop. This approach was comparable in terms of grain productivity to the variants applying the recommended dose of mineral fertilizer. It is substantiated that the Southern Steppe zone of Ukraine must preserve and restore soil quality, as well as its water absorption and retention capacity, by enriching it with organic matter. Improving key soil fertility characteristics, particularly by enriching them with fresh organic matter, contributes to the activation of microbiological processes. At the same time, implementing optimization elements in nutrition ensures an increase in the grain productivity of spring barley. All varieties studied showed significantly higher grain yields when combining the use of Eco-Stubble for decomposing post-harvest root residues of the preceding crop, winter wheat, along with nutrition optimization. It was established that with the application of the recommended dose of mineral fertilizer $N_{30}P_{30}$ and $N_{15}P_{15}K_{15}$ for the zone, along with foliar feeding using modern biopreparations (Organic Balance 0.5 l/ha + Azotofit 0.3 l/ha + Liposam 0.25 l/ha), the grain yield of the studied spring barley varieties was formed at an equal level. The highest grain yield was recorded for the spring barley variety Troyan, followed closely by the variety Myrny, while the lowest yield was observed for the variety Aristey. On average, across all variants from 2022 to 2024, the grain yields for the respective varieties were: 5.25; 4.88; and 3.63 t/ha.

Keywords: spring barley, varieties, stubble decomposers, biopreparations, soil fertility, biological methods in crop production, grain yield.

INTRODUCTION

In recent decades, due to violations of cultivation technology elements, the practical absence of justified crop rotation in crop systems, a reduction in the use of fertilizers, especially organic ones, and other deviations from the requirements of precision agriculture, the main indicators of soil fertility have gradually deteriorated, and climate changes have occurred (Jones et al., 2021; Anderson and Lee, 2021; Williams & Green, 2020). We have also pointed out these negative phenomena and highlighted them in publications (Gamayunova et al., 2025; Gamayunova et al., 2020). Moreover, military actions have impacted the loss of key soil fertility indicators and their degradation processes in Ukraine (Nasibov et al., 2024). Harmful emissions, including heavy metals and CO_2, also further contaminate soils and the environment, and lead to climate change

(Shebanin et al., 2024). The mentioned issues require immediate resolution. Soil is the foundation of the agricultural sector; the state of its fertility affects not only the level of yields and the quality of the produced goods but also the preservation of the environment.

For the Southern Steppe region of Ukraine and other arid regions, a key characteristic of fertility indicators is the soil's ability to accumulate and retain moisture from precipitation, which occurs extremely unevenly and in insufficient quantities. Soils that have adequate organic matter content are distinguished by optimal water absorption capacity. Conversely, in the absence of organic matter, soils exhibit unsatisfactory water-physical properties; they become compacted, and microbiological processes are hindered and slowed down.

A living and fertile soil must contain a sufficient amount of organic matter, which serves as a substrate for feeding, reproducing, and activating soil microorganisms. The activity of these microorganisms, in turn, ensures the decomposition of organic residues. In recent years, biodestructors of stubble have been successfully used to accelerate the mineralization of fresh organic matter. (Panfilova et al., 2019; Sydiakina, 2021).

The significance of the content and systematic replenishment of soils with organic matter is extremely important for the biologicalization of agriculture. The most appropriate and cost-free measure in this regard is crop rotation. After all, soil fertility is an indicator that quantitatively determines its ability to perform essential functions: to accumulate and retain water, to resist erosion processes, to absorb carbon compounds, to convert them into organic forms, to preserve and ensure the active functioning of soil microbiota, biodiversity, and to provide plants with all the necessary nutrients. The main driving force behind the nutrient cycle, the regulator of the dynamics of soil organic matter, the factor influencing carbon absorption capacity, greenhouse gas emissions, changes in the water-physical properties of soil structure, water regime, and so on, is precisely the biological component – crop rotation (Boinchian and Dent, 2020; Pacheco et al., 2023; 2023; Miller and Thompson, 2022. Justified alternation of agricultural crops with different biological characteristics, including root system depth and placement, varying levels of moisture and nutrient utilization, and the amount of organic biomass left after harvesting, etc. (Wegner, 2022; Allam et al., 2022). In modern farming, the ability to restore soil fertility characteristics effectively and at no cost is primarily attributed to the root systems of plants. Crops with a robust root system can penetrate compacted layers of soil, thereby facilitating the access of water and air for plants. They structure and loosen the soil, making it more aerated. The stronger the root system, the more post-harvest root residues remain in the soil, which in turn leads to a greater accumulation of organic matter. Additionally, the biomass of agricultural plants, which is left in the soil and incorporated after the main product – grain - is harvested, can significantly enrich the soil (Ovcharuk, 2020a; Ovcharuk, 2020b). Scientists have reported this in recent years and is well-known and has been implemented for quite some time.

However, previously there were practically no significant amounts of biopreparations and biodestructors for stubble. Straw and plant residues were primarily used for irrigation with the addition of nitrogen. In dryland agriculture, such organic fertilizers could decompose over a period of 2–7 years, depending on the amount of precipitation. Nowadays, even under arid conditions, biodestructors significantly accelerate the decomposition of fresh organic matter, including that with a high cellulose content – such as straw from cereal crops (Panfilova and Belov, 2022; Kovalenko et al., 2020; Ivanov et al., 2022; Hrytsenko, 2023; Petrenko and Kovalenko, 2023). Researchers have determined the effectiveness of biodestructors in irrigated rice crop rotation through soybean cultivation (Dudchenko et al., 2021). Many authors point out the importance of using biodestructors from an economic perspective as well (Tsentilo and Sendetskyi, 2014; Espolov et al., 2023). Researchers who studied the significance of biodestructors in agriculture identified their exclusively positive impact on activating soil microbiological activity and their ability to improve soil fertility (Smith et al., 2020; Thompson et al., 2022; Garcia et al., 2021; Miller and Thompson, 2022. The intensification of microbial activity contributes to the effective transformation of fresh organic substances into new compounds, releasing macro- and microelements from them, which allows for a reduction in the costs of mineral fertilizers and pesticides. Moreover, the presence of organic matter and microbiota in the soil can reduce greenhouse gas emissions, various other emissions, and prevent climate change (Khanam et al., 2024).

In turn, the improvement of key indicators of soil fertility and the enrichment of accessible nutrients due to their release from organic substances contribute to increased productivity of agricultural crops. This is particularly relevant for spring barley, which responds very strongly to improved nutritional backgrounds as well as to variety selection (Panfilova et al., 2021; Hanhur et al., 2021). Under the arid conditions of the Southern Steppe of Ukraine, varietal characteristics of this cereal crop and climate conditions have also been identified as extremely important elements in the technology of winter wheat cultivation (Korkhova 2023; Korkhova et al., 2022). Optimizing nutrition through the application of biopreparations in foliar feeding of several varieties of winter barley significantly increases grain productivity, yield, and grain qualityc-and the economic efficiency of their use as an element of technology (Gamayunova and Kuvshinova, 2023).

Research has shown that by combining the use of biodestructors in the stubble cultivation technology (after incorporating the predecessor residues) and conducting foliar feeding with biopreparations for the main crop, plants utilize moisture much more efficiently. This is evidenced by a significant reduction in the water consumption coefficient, especially during the most unfavorable years for moisture conditions.

RESEARCH METHODOLOGY

The experiments with three varieties of spring barley were conducted from 2022 to 2024 in the fields of the Educational and Scientific Practical Center of Mykolaiv National Agrarian University. The soil type of the experimental farm is represented by southern chernozem. The availability of nutrients in the soil (0–30 cm layer) is as follows: the content of available forms of nitrogen is average, while mobile phosphorus and exchangeable potassium are at an elevated level.

The soil-absorbing complex is predominantly saturated with calcium and magnesium. The reaction of the soil solution is close to neutral, with a pH of 6.8–7.2. According to the provided characteristics, the soil of the experimental plots is typical for southern chernozem and is fully suitable for growing most agricultural crops.

The experimental design for studying the grain productivity of spring barley varieties included the following factors and variants:

1) Factor A (variety):
   - Myrnyi,
   - Aristey,
   - Troyan.
2) Factor B (treatment with a biodestructor of post-harvest root residues of the preceding crop – winter wheat):
   - without destructor – treated with water, control,
   - application of Ekostern Classic at 2.0 l/ha.
3) Factor C (plant nutrition system):
   - without fertilizers, control;
   - recommended dose for the zone $N_{30}P_{30}$;
   - optimized nutrition system – $N_{15}P_{15}K_{15}$ + foliar feeding with biopreparations.

The total area of the plot is 80 m², the accounting area is 36 m², and the experiment was repeated four times.

The agrotechniques for growing spring barley in the experiment were generally accepted for the Southern Steppe zone of Ukraine. The preceding crop for spring barley in the experiment was winter wheat, and the straw and post-harvest plant residues (averaging 5.3 t/ha over 3 years of research) were chopped and incorporated into the soil to a depth of 5–6 cm.

After the temperature decreased at the end of September, according to the experimental scheme, the stubble destructor Ekostern Classic at 2.0 l/ha was applied along with 30 kg/ha of active substance of ammonium nitrate (with a working solution consumption of 200 l/ha), and plowing was carried out at a depth of 20–25 cm for quality distribution of post-harvest residues throughout the soil profile. In the control, N30 (ammonium nitrate) was also applied with an equivalent amount of aqueous solution without the biodestructor.

In early spring of the following year (during the first decade of March), pre-sowing cultivation was carried out to a depth of 5–7 cm, during which mineral fertilizers were applied according to the treatment scheme, followed by the sowing of the studied varieties of spring barley. During the sowing period and at the time of harvesting spring barley, soil samples (0–30 cm layer) were taken to determine the decomposition percentage of straw and the content of organic matter. During the vegetation period (at the heading phase), samples were taken to assess the quantity of soil microbiota. Crop care was performed according to regional methodological recommendations

(Ushkarenko et al., 2014). Specifically, at the end of the tillering phase, the herbicide Granstar was applied at a rate of 25 g/ha along with foliar feeding of spring barley plants using a mixture of biopreparations: Organic Balance at 0.5 l/ha + Azotophyt at 0.3 l/ha + Liposam at 0.25 l/ha. Harvesting was carried out at the phase of full grain ripeness using a Sampo 130 combine harvester over the accounting area of all plots. Soil quality was determined according to DSTU ISO-4289: 2004, which outlines the method for determining organic matter in soil. The analysis of the microbiota in soil samples was conducted according to DSTU 7847:2015 "Determination of the number of microorganisms in soil by the method of inoculation on solid (agarized) nutrient medium" (2016).

RESEARCH RESULTS

We determined the grain yield of the studied varieties of spring barley (Table 1). As a result of field studies conducted in 2022–2024, we established a significant impact of varietal characteristics, nutrient systems, and methods of post-harvest residue management on the grain yield levels of spring barley. The research covered three varieties – Myrnyi, Aristey, and Troyan – under different combinations of agrotechnical measures.

The most pronounced influence on yield levels was attributed to the barley variety. In particular, the Troyan variety consistently provided the highest grain yield levels regardless of the year of cultivation and technology elements. This indicates its high genetic potential for productivity and stable adaptive capacity to agro-climatic

Table 1. Grain yield of spring barley varieties under the influence of technology elements, t/ha

Feeding system (factor C)	Residue treatment with biodestructor (factor B)	Years of research			
		2022	2023	2024	2022–2024
Myrnyi variety (factor A)					
Without fertilizers (control)	Water treatment	5.21	4.84	3.69	4.58
	Ecostern classic	5.32	4.97	3.78	4.69
Recommended – $N_{30}P_{30}$	Water treatment	5.78	5.12	3.93	4.94
	Ecostern classic	5.94	5.31	4.09	5.11
Optimized $N_{15}P_{15}K_{15}$ + fertilization with biopreparations	Water treatment	5.72	5.08	3.91	4.90
	Ecostern classic	5.91	5.27	4.07	5.08
Aristey variety (factor A)					
Without fertilizers (control)	Water treatment	3.97	3.08	2.97	3.34
	Ecostern classic	4.16	3.17	3.10	3.48
Recommended – $N_{30}P_{30}$	Water treatment	4.38	3.49	3.17	3.68
	Ecostern classic	4.46	3.62	3.38	3.82
Optimized $N_{15}P_{15}K_{15}$ + fertilization with biopreparations	Water treatment	4.27	3.47	3.17	3.64
	Ecostern classic	4.40	3.60	3.40	3.80
Troyan variety (factor A)					
Without fertilizers (control)	Water treatment	5.48	5.12	3.93	4.84
	Ecostern classic	5.61	5.24	4.07	4.97
Recommended – $N_{30}P_{30}$	Water treatment	6.04	5.76	4.32	5.37
	Ecostern classic	6.15	5.93	4.44	5.51
Optimized $N_{15}P_{15}K_{15}$ + fertilization with biopreparations	Water treatment	6.03	5.72	4.30	5.35
	Ecostern classic	6.12	5.90	4.43	5.48
HIP_{05}	by factor A	0.12	0.13	0.10	
	by factor B	0.04	0.04	0.03	
	by factor C	0.10	0.11	0.08	
	by factor AB	0.13	0.12	0.09	
	by factor AC	0.11	0.11	0.09	
	by factor BC	0.09	0.08	0.06	
	by factor ABC	0.14	0.13	0.10	

changes. The Myrnyi variety of spring barley achieved an average yield level, while Aristey, on the contrary, yielded the lowest. At the same time, even the least productive variety, Aristey, responded positively to the application of mineral fertilizers, a bio-destructor, and foliar feeding with biopreparations, indicating the potential for increasing its productivity through improvements in cultivation technology elements.

The method of post-harvest residue management also demonstrated a statistically significant impact on yield levels. Treatment with the bio-destructor Ekostern Classic resulted in slightly higher yield levels compared to the control (water treatment). The positive effect of the bio-destructor was most clearly observed in the Myrnyi and Troyan varieties, especially when combined with recommended or reduced (optimized) fertilizer doses. This underscores the appropriateness of using biological preparations in sustainable organic farming systems, as established in cultivating spring barley varieties.

The nutrition system significantly influenced grain yield. All varieties showed the lowest yield in the control group (without fertilizers), confirming mineral nutrition's importance for forming high grain productivity in barley. The recommended fertilizer dose ($N_{30}P_{30}$) increased yield by an average of 0.36–0.79 t/ha, which is economically and agronomically justified. The optimized fertilization option ($N_{15}P_{15}K_{15}$ + biopreparations) mainly provided equivalent or close to the recommended fertilizer dose levels of yield. This indicates the promise of using resource-saving approaches to plant nutrition with the involvement of biological components when growing spring barley, allowing for a reduction in the amount of mineral fertilizers without a significant difference in yield levels.

Differences were observed between the years of growing spring barley varieties due to weather conditions. The year 2022 had the highest yield, 2023 had a moderate yield, and 2024 had the lowest. Such fluctuations in grain yield levels confirm the significant impact of weather factors and indicate the need to adapt cultivation technologies to climate change.

The analysis of the reliability of the experimental results established that all studied factors and their interactions had a statistically significant impact on the yield levels of the varieties. The greatest variability in yield was determined by the interaction of all three factors (ABC), indicating a positive response of the crop to the combination of varietal characteristics, nutritional conditions, and measures regarding post-harvest residue management.

The results obtained from three years of field studies have practical value for improving the cultivation technology of spring barley in Southern Ukraine's conditions, especially regarding agro-ecological adaptation and the possibility of implementing resource-saving farming practices. This is particularly important for sustainable grain production under the limited economic capacity of farms. Throughout three years of research, a clear varietal differentiation

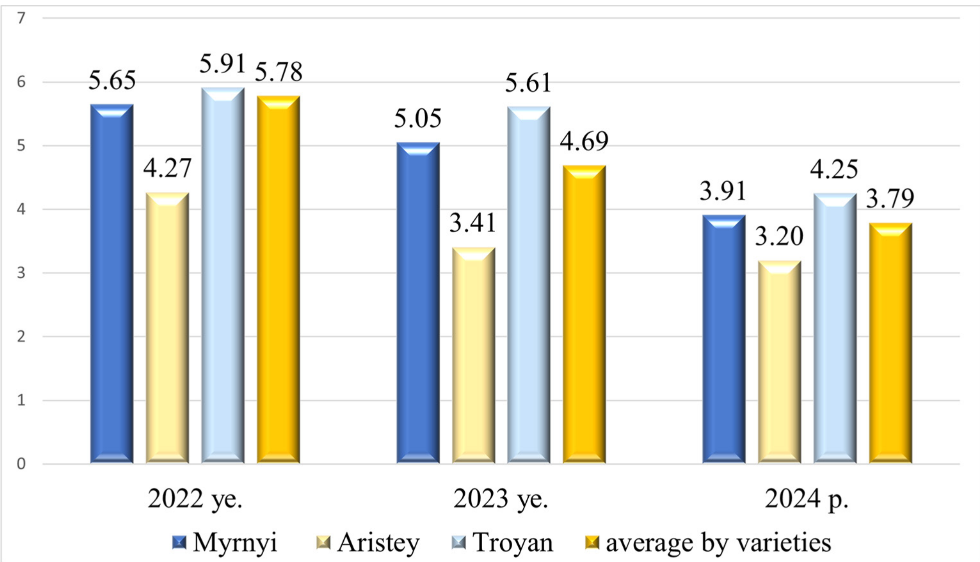

Figure 1. Average weighted grain yield of the studied spring barley varieties by years of cultivation (across all experimental variants), t/ha

was observed regarding the average weighted grain yield of spring barley (Figure 1). The Troyan variety consistently produced the highest grain yield regardless of the year of cultivation, indicating its high productivity potential and fairly stable adaptive capacity to changing growing conditions. In 2022, the grain yield of this variety was 5.91 t/ha, in 2023 it was 5.61 t/ha, and in 2024 it was 4.25 t/ha.

The Myrnyi variety consistently formed average yield indicators that were lower compared to the Troyan variety. Over the three-year period, the grain yield of this variety decreased from 5.65 t/ha in 2022 to 3.91 t/ha in 2024, which we believe is related to abiotic stresses, particularly insufficient rainfall during critical periods of crop development. The Aristey variety exhibited the lowest grain yield throughout all years of the study: from 4.27 t/ha in 2022 to 3.20 t/ha in 2024. Nevertheless, despite this, the decrease in yield for this variety was less pronounced (sharp) compared to the other two varieties, which clearly indicates its drought resistance or some ability to compensate for productivity through other morpho-physiological traits.

The overall dynamics of the average weighted grain yield levels of all studied varieties indicate a decline in spring barley productivity over the years of cultivation: from 5.78 t/ha in 2022 to 3.79 t/ha in 2024. This is likely due to the complication of agro-climatic conditions, specifically, the increase in temperature and the decrease in atmospheric precipitation during the growing season.

The results we obtained also highlight the importance of selecting varieties with high ecological plasticity and stress resistance, as well as the necessity to adapt cultivation technology elements to systematically changing conditions.

Figure 2 illustrates the grain yield of spring barley across the varieties Myrnyi, Aristey, and Troyan, averaged over the years 2022–2024, depending on the nutrition variants. The data clearly shows a comparison of controls (without fertilizers), average grain yield levels across all variants, as well as the highest values achieved within the experiment.

Analysis of the presented data indicates a positive reaction of all varieties to the application of a biodestructor and the optimization of nutrient elements. The greatest yield increase was provided by the cultivation of the Troyan variety, which reached a maximum yield level of 5.51 t/ha, exceeding the control by 0.67 t/ha. The Myrnyi variety also demonstrated a steady increase in yield – from 4.58 t/ha in the control to 5.11 t/ha in the most optimal variant. The Aristey variety produced the lowest, yet significant increase, from 3.34 to 3.82 t/ha.

Overall, the Troyan variety was identified as the most productive in both average and maximum levels, indicating its high potential response to improvements in technology elements, particularly in enhancing nutritional conditions.

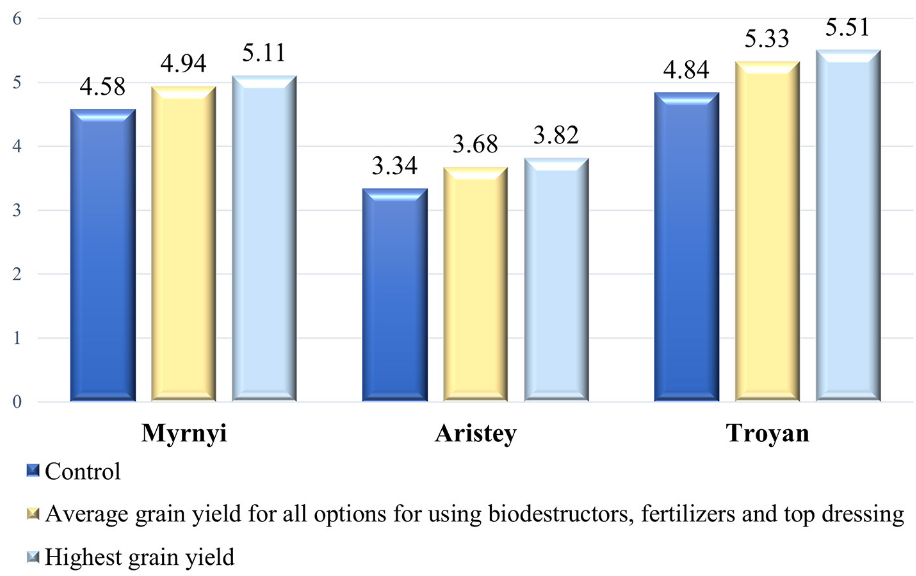

Figure 2. The reaction of the studied varieties of spring barley to the optimization of nutrition (average grain yield for 2022–2024)

Table 2. Decomposition of post-harvest root residues of winter wheat and organic matter content in the soil under spring barley crops under the influence of a biodestructor (average for 2022–2024), %

Variant	Decomposition of straw and post-harvest root residues		Content of organic matter	
	1	2	1	2
Control (without biodestructor) water treatment	37.8	51.4	4.17	4.48
Ecostern Classic, 2 l/ha	42.3	60.7	4.44	4.82

Note: 1 – sowing period of barley (1st decade of March), 2 – full maturity of grain (1st decade of July).

The data from the figure illustrate the high effectiveness of the optimized nutrition system, which is based on a combination of biological and resource-saving elements, and confirm the appropriateness of selecting a variety and adapting it to agricultural technologies. Considering the reaction of spring barley plants to optimized nutritional backgrounds, as well as the inclusion of predecessor residues and biodestructor usage in the experimental scheme, we investigated the effectiveness of applying a biodestructor on the process of mineralization of post-harvest root residues of winter wheat and changes in organic matter content in the soil under spring barley crops. The obtained results indicate a positive effect of the biodestructor on accelerating the decomposition rates of straw and its root residues, as well as changes in soil organic matter content (Table 2).

In the variants without the use of a biodestructor (control), the decomposition of straw and its residues at the time of barley sowing was 37.8%, and by the end of the growing season, it reached 51.4%. With the application of Ecostern Classic at a rate of 2 l/ha, the degree of residue decomposition was higher, reaching 42.3 and 60.7%, which exceeded the control by 4.5 and 9.3%, respectively. This indicates an enhancement in the activation of soil microbiological activity and an acceleration in the transformation of organic residues.

The content of organic matter in the soil also varied depending on the experimental variant. In the control variant, this indicator was 4.17% at the beginning of the barley growing season and increased to 4.48% at its completion (harvest). The use of the biodestructor contributed to an increase in organic matter content to 4.44 and 4.82%, respectively. Thus, the biodestructor not only accelerates the decomposition of crop residues but also improves the humus state of the soil, which is an important prerequisite for both enhancing its fertility and the sustainability of agroecosystems.

CONCLUSIONS

As a result of field experiments conducted from 2022 to 2024, it was established that one of the main factors determining grain yield levels is the variety of spring barley. The highest grain productivity was formed by the Troyan variety, which significantly surpassed the Myrnyi and Aristey varieties regardless of the year of cultivation and the studied technological elements. The application of the biodestructor Ecostern Classic positively influenced the decomposition of post-harvest residues of winter wheat (the predecessor), increased organic matter content in the soil, and improved grain yield levels of spring barley. The highest effectiveness of the preparation was determined when combined with recommended or optimized doses of mineral fertilizers, especially for the Troyan and Myrnyi varieties. The resource-saving system of mineral nutrition significantly affected the productivity of spring barley. The recommended fertilization ($N_{30}P_{30}$) provided somewhat higher yield levels; however, the optimized system ($N_{15}P_{15}K_{15}$ + biopreparations) achieved similar results, indicating its effectiveness as a resource-saving alternative.

Analysis of grain yields over the years of research revealed a significant decrease in productivity for all varieties of spring barley cultivated due to unfavorable agro-climatic conditions, primarily water scarcity. This underscores the need to adapt technologies to changing climatic conditions. All studied factors (variety, nutrition system, post-harvest residue treatment) and their interactions statistically significantly influenced grain yield levels. The greatest variability in yield was observed with the interaction of three factors (ABC), highlighting the importance and relevance of a comprehensive approach to elements of spring barley cultivation technology.

The findings of this study have important practical significance for grain producers in southern Ukraine, particularly in terms of resource conservation, biological practices, improving fertilizer efficiency, optimizing nutrition, and selecting varieties with high adaptive potential to environmental stress factors that have manifested in recent decades.

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