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Evaluation of the Effectiveness of Leanum Biofertilizer in the Management of Organic Crop Rotation and Buckwheat Productivity

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Abstract: This article examines the effectiveness of the Leanum biofertilizers in cultivating the "Yaroslava" buckwheat (*Fagopyrum esculentum*) variety. Four application variants of the biofertilizers were tested: control (no treatment), pre-sowing seed inoculation, foliar feeding, and their combination. The analysis included each variant's biometric indicators, yield, yield structure, and economic efficiency. The research results indicate a significant increase in buckwheat productivity using biofertilizers. The highest yield increase was recorded with the combined application of inoculation and foliar feeding (I + F), which led to an increase in grain mass per plant and a higher weight of 1000 grains. The results demonstrate biofertilizers' potential for increasing buckwheat productivity and promoting the sustainable development of agricultural production. Implementing such technologies will not only boost yields but also optimize costs and reduce environmental impact by reducing the usage of mineral fertilizers.

Keywords: organic farming, organic fertilizer-biostimulant, buckwheat, yield, ecological management, Leanum, soil fertility conservation, management of efficiency

1. Introduction

Buckwheat (*Fagopyrum esculentum*) is a valuable grain crop that plays an important role in agriculture due to its nutritional properties, low soil requirements, and high ecological value (Moisiienko et al. 2023). In modern conditions, increasing the productivity of any crop is crucial. Still, it is particularly important for buckwheat, as it is one of Ukraine's most consumed grain crops, yet its cultivation area has significantly declined. Specifically, in the 2000s, buckwheat cultivation covered 574 thousand hectares, gradually decreasing to 69 thousand hectares by 2019, before increasing again to 121 thousand hectares by 2022 (Agriculture of Ukraine 2023). The reduction in buckwheat cultivation areas may be attributed to several factors, including changes in the structure of agricultural production, market instability, and declining global demand (Averchev 2021). Additionally, climate change, rising costs of fertilizers, and plant protection products have significantly impacted the production volumes of this crop.

Given these challenges, implementing modern cultivation technologies that enhance crop yields while reducing production costs is necessary. One promising approach is the use of biofertilizers, which not only improve plant growth and development but also contribute to the rational use of soil resources – an aspect of particular importance in modern agriculture (Pocienė & Šlinkšienė 2024, Datsko et al. 2025). The use of biofertilizers can positively affect soil biological activity by increasing beneficial microbial populations and improving soil structure. The term "biofertilizers" refers to beneficial microorganisms and their metabolic byproducts that can enhance crop productivity (such as phytohormones, enzymes, organic acids, and vitamins).

The effectiveness of biofertilizers has been demonstrated in multiple aspects, particularly in improving nutrient uptake from the soil, which leads to increased crop yields and enhanced agricultural product quality, as well as in improving soil properties (Litvinov et al. 2024, Datsko et al. 2024). However, this statement is not always universally valid. For instance, a study by Jastrzębska et al. (2024) found that the use of biofertilizers and mineral fertilizers had no significant effect on grain quality improvement in wheat under the conditions of northeastern Poland. Conversely, researchers in Iran determined that *Azospirillum lipoferum*, in combination with atrazine, increased protein content in wheat grain (Tykhonova et al. 2024, Nasiri et al. 2025). A positive effect on grain quality and yield was also observed in crops such as sunflower. Specifically, Dasgupta et al. (2024) demonstrated that applying 75% of the nitrogen norm combined with Azospirillum and Azotobacter strains improved biometric parameters, including head size, increased the weight of 1000 grains and the overall yield. The effectiveness of biofertilizers has also been confirmed in maize cultivation; for example, Zinati et al. (2025) showed that arbuscular mycorrhiza reduced stress and enhanced crop nutrition, which is particularly important in regions with adverse climatic conditions.

In light of the above, this study aims to evaluate the effectiveness of biofertilizers in buckwheat cultivation to increase yield, improve grain quality, and ensure the sustainable development of agricultural production. The research focuses on identifying optimal technological approaches to applying biofertilizers in agroecosystems and analyzing the economic feasibility of their use in buckwheat production.

2. Materials and Methods

Studies were conducted at the experimental field of the Institute of Agriculture of the North-East of the National Academy of Agrarian Sciences of Ukraine. The field is situated in the Sumy region (Ukraine) with geolocation coordinates of 50°53'22.3"N latitude and 34°42'34.1"E. The experiments were carried out from 2022 to 2024. The soil of the experimental plots was classified as Loamic Profondic Chernozem, with the following characteristics: humus content ranging from 4.1% to 4.3% (according to I. V. Tyurin), salt pH between 6.2 and 6.5. The average nutrient content was nitrogen (by Kornfield) – 128.5 mg/kg of soil; phosphorus and potassium (by Chirikov) – 211.6 mg/kg and 81.1 mg/kg of soil, respectively.

In 2022, the total precipitation during the spring durum wheat growing season amounted to 370 mm, exceeding the long-term average (237 mm) by 133 mm. The monthly distribution was as follows: April – 107 mm, May – 26 mm, June – 155 mm, and July – 82 mm. In 2023, the total precipitation during the growing season reached 222 mm, 15 mm below the long-term average of 237 mm. The monthly distribution was: April – 54 mm, May – 17 mm, June – 71 mm, and July – 80 mm. In 2024, the total precipitation during the growing season was 150 mm, falling 87 mm short of the long-term average (237 mm). The monthly distribution was: April – 48 mm, May – 34 mm, June – 51 mm, and July – 17 mm (Figure 1).

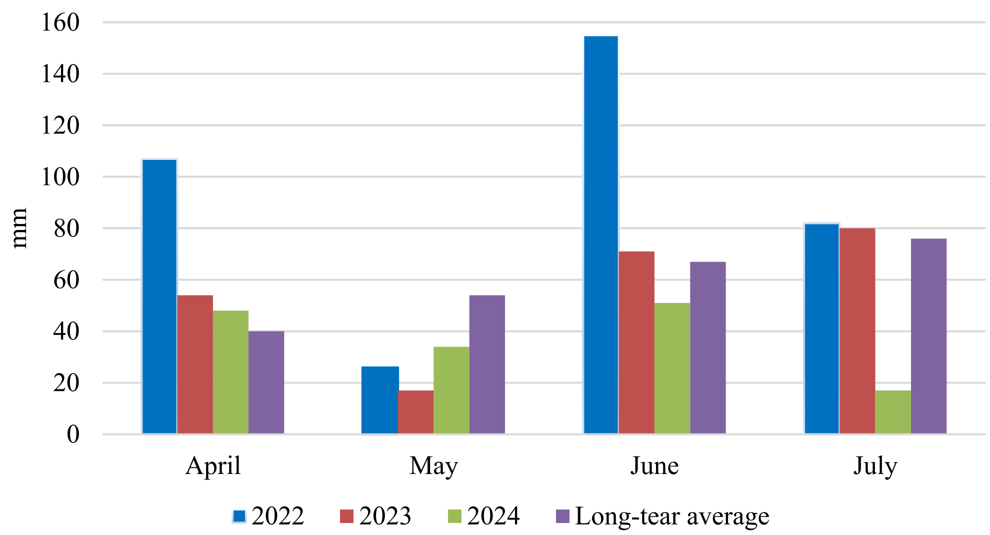

Fig. 1. Amount of atmospheric precipitation during the growing season of 2022-2024

In 2022, the average daily temperature during the spring durum wheat growing season was 16.0°C, which was 0.2°C above the long-term average of 15.8°C. The monthly temperature distribution was: April – 8.3°C, May – 13.3°C, June – 21.0°C, and July – 21.3°C. In 2023, the average daily temperature reached 16.6°C, exceeding the long-term average by 0.8°C. The monthly distribution was: April – 9.8°C, May – 15.5°C, June – 19.3°C, and July – 21.6°C. In 2024, the average daily temperature was 19.2°C, surpassing the long-term average by 3.4°C. The monthly temperature distribution was: April – 12.9°C, May – 16.0°C, June – 22.4°C, and July – 25.4°C (Figure 2).

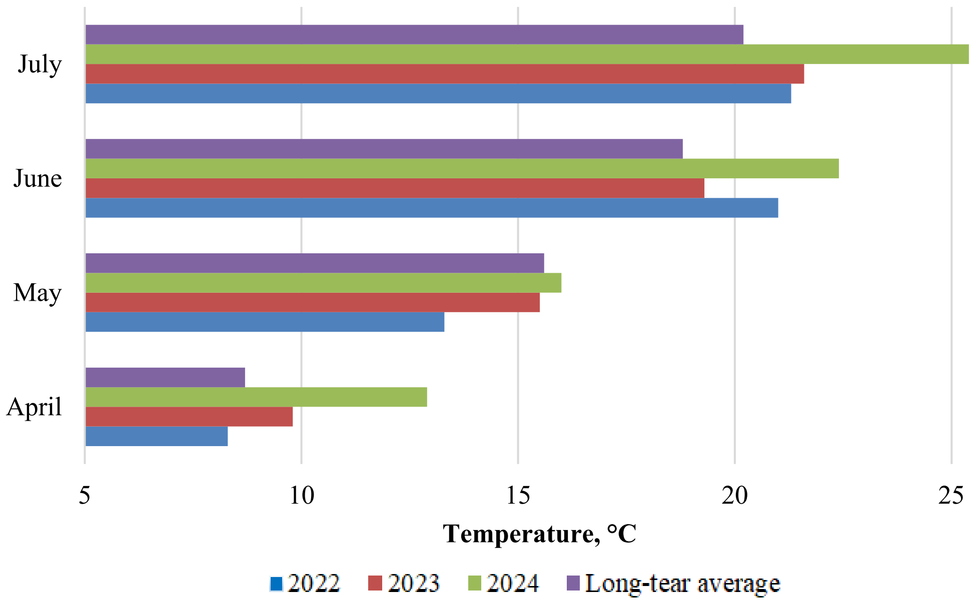

Fig. 2. Dynamics of the average daily air temperature during the growing season of 2022-2024

The most favourable years for crop yield formation were 2022 and 2023. Dry conditions prevailed in 2024, characterized by low precipitation and extreme deviations in air temperature during the vegetation period. The study is a single-factor experiment examining the effect of the biofertilizer Leanum according to the following scheme: control (C); seed inoculation with Leanum before sowing – 2 L/t (I); foliar application – 2 L/ha (F); combined application: inoculation + foliar treatment – 2 L/t + 2 L/ha (I + F). The composition of Leanum includes a complex of beneficial soil microorganisms combined with organic substances from fertile soils – humic and fulvic acids, amino acids, and vitamins. The studied determinant buckwheat variety is Yaroslavna. Replication of the experiment was tripled. The experimental plot size is 30 m^2, and the size of the accounting area is 25 m^2. The buckwheat yield in the experimental field was determined by the method of continuous harvesting of the accounting area by variants and then recalculated into tons per hectare, considering grain moisture.

A simplified cost-benefit analysis was performed to assess the economic efficiency of biofertilizer application. Growing costs included expenditures for seed, tillage, sowing, crop protection, harvesting, and the biofertilizer Leanum, calculated at the market rate of €9.5/L. The average buckwheat grain selling price was €502.2 per ton. Sales revenue was determined by multiplying the yield by the sales price for each treatment. Net profit was calculated as the difference between sales revenue and total growing costs. Economic efficiency was evaluated by calculating profitability, expressed as a percentage of net profit to growing costs.

Mathematical processing of primary data and reliability assessment were performed using Microsoft Excel. Descriptive statistics were conducted in Statistica 10.0 (StatSoft Inc., Tulsa, USA). The Duncan's Multiple Range Test was used in the study to assess the significance of differences between treatment means at a 5% probability level. This allowed us to statistically group the experimental variants and determine which treatments significantly affected buckwheat productivity.

3. Results and Discussion

The obtained results provide new insights into the impact of the studied factor on yield formation. One of the key components affecting crop yield is biometric indicators. For buckwheat, these include plant height, the number of nodes, primary branches, and inflorescences, as presented in Table 1.

The tallest plants were observed in variant I, which suggests a pronounced effect of the corresponding treatment on vegetative growth. However, both the control (C) and the I + F combination showed noticeably reduced plant height, with the lowest variance in F, indicating uniformity in response. Although the F-test for plant height did not reach statistical significance ($F = 1.6$, $p = 0.2$), the visible differences suggest potential physiological effects that warrant further investigation.

The number of nodes displayed a clear increasing trend across the treatment variants, peaking in variant F. The high F-test value ($F = 13.5$, $p = 0.00$) confirms the statistical significance of these differences, highlighting this trait as particularly sensitive to the applied treatments.

Regarding the development of branching, a modest yet consistent increase in the number of primary branches was recorded, with the highest mean value in the I + F variant. Although the range of variation was minimal, statistical analysis confirmed the significance of these differences ($F = 9.9$, $p = 0.00$), which may reflect enhanced morphogenesis under combined treatment conditions.

In terms of reproductive development, the highest number of inflorescences was registered in variant I, suggesting a strong generative response to the individual treatment. Conversely, a notable decline in inflorescence number was observed in the I + F variant, which may imply a trade-off effect or possible antagonism when both factors are applied simultaneously. Despite the relatively high variability ($s^2 = 19.5$ in I + F), the F-test result ($F = 2.4$, $p = 1.3$) did not confirm statistical significance, possibly due to inconsistent plant responses within this group.

These observations underscore the complex nature of buckwheat's morphological responses to different treatments and highlight the importance of targeted application strategies to optimize both vegetative and reproductive traits for yield improvement.

Table 1. Biometric indicators of Yaroslava buckwheat plants

Variant	Height, cm		Nodes, pcs		Branches of the 1st order, pcs		Inflorescences, pcs	
	Mean ± SD	s^2	Mean ± SD	s^2	Mean ± SD	s^2	Mean ± SD	s^2
C	121.7±9.8	96.2	7.1±0.8	0.8	1.5±0.1	0.02	15.9±1.3	1.8
I	130.8±7.8	61.3	9.5±0.2	0.7	1.9±0.1	0.01	19.6±0.5	0.2
F	120.7±2.4	5.9	9.8±0.3	0.1	1.7±0.1	0.01	17.6±1.2	1.5
I + F	120.1±4.6	21.1	9.6±0.5	0.3	2.0±0.1	0.01	14.6±4.4	19.5
DMRT*	12.8		1.1		0.2		4.5	
	F = 1.6, p = 0.2		F = 13.5, p = 0.00		F = 9.9, p = 0.00		F = 2.4, p = 1.3	

*DMRT – Duncan's Multiple Range Test

Statistically significant differences identified for all three key indicators – the number of grains per plant, grain mass per plant, and the weight of 1000 grains – clearly indicate that factors I and F, especially their combined application, positively impact plant productivity.

The I + F variant is particularly noteworthy, as it demonstrated the highest average values for both the number of grains (58.1 pcs.) and grain mass (1.65 g) per plant, while also showing one of the highest values for 1000-grain weight (28.5 g). This performance was coupled with exceptionally low within-group variance, especially for grain mass ($s^2 = 0.001$), indicating consistency and stability of the treatment effect. These outcomes suggest a synergistic influence of the combined factors, providing strong justification for its potential agronomic application.

The I variant also showed consistently strong results, significantly increasing grain number and mass compared to the control, while maintaining a high 1000-grain weight. The high F-test values for all traits ($F = 7.04$ to 11.9, $p < 0.05$) confirm the statistical robustness of these observations.

In contrast, the F variant alone resulted in moderate gains, particularly in the number of grains (51.1 pcs.), yet showed the highest variability in results ($s^2 = 42.7$), suggesting less predictable outcomes. Interestingly, this variant contributed positively to the weight of individual grains, which increased to 26.9 g, though not as significantly as in the I and I + F variants.

An analysis of the 1000-grain weight further confirms the beneficial effect of factor I, especially when used in combination, as the top values were achieved in the I and I + F treatments. Given the direct correlation between grain weight and total yield, these findings underscore the relevance of grain size as a critical target in buckwheat productivity strategies.

The results of ANOVA and Duncan's multiple range test validate the observed effects, confirming significant differences among the variants and highlighting the importance of treatment choice for optimizing yield components (Table 2).

Table 2. Yield structure indicators of Yaroslava buckwheat under different biofertilizer treatment methods

Variant	Number of grains from 1 plant, pcs.		Mass of grain from plant, g		Mass of 1000 grains, g	
	Mean ± SD	s^2	Mean ± SD	s^2	Mean ± SD	s^2
C	44.5 ± 3.7	13.7	1.08 ± 0.12	0.014	24.2 ± 1.23	1.5
I	55.6 ± 1.8	3.3	1.59 ± 0.12	0.014	28.5 ± 1.3	1.7
F	51.1 ± 6.5	42.7	1.37 ± 0.19	0.038	26.9 ± 0.5	0.2
I + F	58.1 ± 1.2	1.4	1.65 ± 0.02	0.001	28.5 ± 0.8	0.5
DMRT	7.36		0.24		1.88	
	F = 7.04, p = 0.012		F = 11.7, p = 0.002		F = 11.9, p = 0.002	

At the same time, the impact of different biofertilizer treatment options on buckwheat yield is quite significant. It has to be noted that in Figure 3, the lower and upper limits of crop yield are marked with whiskers. In particular, the control variant has the lowest yield, whereas the application of inoculation significantly increases it. Fertilization also contributes to yield growth, but to a lesser extent than inoculation. The combined variant demonstrates the highest yield, indicating a synergistic effect of inoculation and fertilization. However, the yield obtained in variant I was nearly equivalent to that of the combined treatment (I + F), indicating that seed inoculation is the primary contributing factor to yield enhancement in the I + F variant.

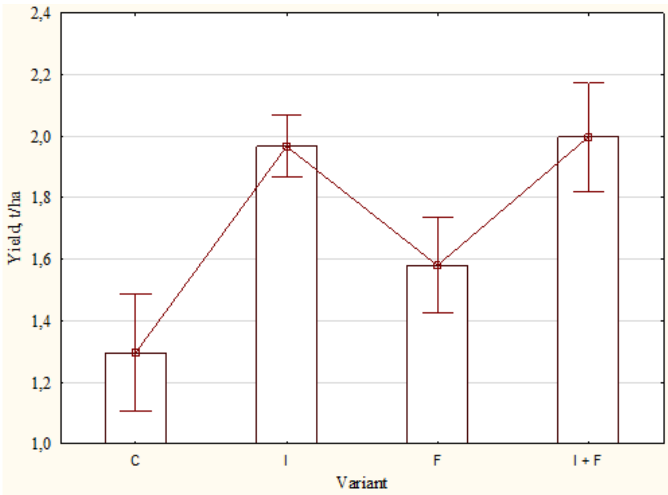

Fig. 3. Impact of biofertilizer treatment options on the yield of the Yaroslavna buckwheat variety

Table 3 confirms the use of biofertilizers in the cultivation of the Yaroslavna buckwheat variety. The control variant (C) shows the lowest yield (1.29 t/ha) and, accordingly, the lowest revenue from sales (647.8 €/ha). However, due to low production costs (352.6 €/ha), its profit amounts to 295.2 €/ha, with a profitability level of 83.7%. The I variant has a significantly higher yield (1.97 t/ha), contributing to an increase in gross revenue to 989.3 €/ha. The cultivation costs for this variant amount to 357.5 €/ha, allowing for a profit of 631.8 €/ha. The profitability reaches 176.7%, which is a significant improvement compared to the control variant. The F variant is characterized by a yield of 1.58 t/ha and a gross revenue of 793.4 €/ha. At the same time, cultivation costs remain at 357.5 €/ha, ensuring a profit of 435.9 €/ha. The profitability level for this variant is 121.9%, which is lower than that of variant I but higher than the control variant. The combination of methods in variant I + F ensures the highest yield (1.99 t/ha) and maximum revenue from sales (999.4 €/ha). Despite slightly higher production costs (362.5 €/ha), the profit reaches 636.9 €/ha. This results in a profitability of 175.7%, which is slightly lower than variant I but higher than the control and F variants. Although the highest yield was recorded in the I + F variant, the greatest profitability was achieved with variant I, indicating it as the most cost-effective approach. Moreover, seed inoculation requires less labor input and is less energy-intensive than foliar treatments, further reinforcing its efficiency and practical value in agricultural production.

Table 3. Economic efficiency indicators of Yaroslavna buckwheat cultivation using biofertilizers

Variant	Yield, t/ha	Sales price €*/t	Growing costs, €/ha	Sales revenue, €/ha	Profit, €//ha	Profitability, %
C	1.29	502.2	352.6	647.8	295.2	83.70
I	1.97		357.5	989.3	631.8	176.7
F	1.58		357.5	793.4	435.9	121.9
I + F	1.99		362.5	999.4	636.9	175.7

€* – euro exchange rate as of 01.04.2025 – 44.8 UAH per 1 euro

The obtained results allow for a deeper understanding of the impact of the studied factors on the productivity of the Yaroslavna buckwheat variety and open up prospects for their further practical application. Statistically significant differences between the variants indicate that both individual applications of biofertilizers and their combination contribute to increased yields. The synergistic effect of variant I + F is particularly noticeable, as evidenced by the highest average values in terms of the number of grains per plant, grain mass per plant, and the weight of 1000 grains. At the same time, this variant demonstrates the lowest intra-group variability, indicating the stability of the obtained results.

Comparative analysis showed that inoculation (I) has a more pronounced positive impact on crop productivity than foliar biofertilizer application. Both yield structure indicators and economic efficiency confirm this. In particular, variant I ensures a significant increase in yield compared to the control, which is also reflected in economic indicators – the highest profitability level (176.7%). Meanwhile, although variant F has a positive effect, it shows somewhat lower yield and economic benefits.

The combination of methods (I + F) allows for the highest yield (1.99 t/ha), indicating a complementary effect of the factors. However, from an economic perspective, the variant I proved to be slightly more advantageous due to the cost-to-profit ratio. This leads to the conclusion that choosing a specific biofertilizer treatment method depends on the producer's priorities – maximizing yield or achieving the highest profitability.

Similar studies have been conducted (Mashchenko & Sokolovska 2023) but using mineral fertilizers. In particular, the highest yield was obtained under the organo-mineral system, whereas the use of a biofertilizers without fertilizers resulted in an increase of 0.19 t/ha (+17.7%). The study by Dutchak (2024) confirmed the feasibility of growing buckwheat in organic farming, which helps reduce anthropogenic pressure, preserve, and enhance soil fertility. Using the organic fertilizer-biostimulant Vermimag for seed treatment and foliar feeding reduces weed infestation, increases yield, and improves the economic efficiency of organic buckwheat cultivation.

Research by Raghavendra et al. (2015) showed that applying microbial inoculants significantly improves buckwheat growth, yield, and quality, as well as the biological properties of the soil. Combining inoculation with Azotobacter spp. and Azospirillum spp. was the most effective, ensuring maximum plant growth, yield, and microbial soil activity. Studies by Butenko et al. (2025) and Mashchenko et al. (2024) confirmed that applying mineral fertilizers significantly increases buckwheat yield, particularly for the Slobozhanka variety. However, excessive fertilizer application was not always economically viable due to increased costs. The best results were obtained with moderate fertilizer use, ensuring a balance between yield, profitability, and soil fertility conservation. As could be concluded from the literature review, the exact mechanism of action of biofertilizers lies in their ability to enhance nutrient availability and stimulate plant physiological processes (Gulshan et al. 2022). These bioagents, often comprising nitrogen-fixing bacteria, phosphate-solubilizing microorganisms, and growth-promoting rhizobacteria, improve nutrient uptake by producing phytohormones (e.g., auxins, gibberellins), enhancing root development, and increasing enzymatic activity in the rhizosphere (Singh, et al. 2021). For *Fagopyrum esculentum* in this research, it could be concluded the application of biofertilizers contributed to significant improvements in both vegetative and generative parameters – including increased plant height, number of nodes, grain yield, and 1000-grain weight – suggesting that these bioformulations support overall plant vigor and yield potential by optimizing nutrient efficiency and stress resilience.

4. Conclusions

This study demonstrates that biofertilizers can play a pivotal role in enhancing buckwheat's productivity and economic viability (*Fagopyrum esculentum*). Applying seed inoculation and foliar feeding, both individually and in combination, stimulated key growth parameters and improved yield outcomes. Most notably, the combined application revealed a synergistic effect, contributing to stable and high productivity and substantial economic gains. These findings support the practical value of integrating biological treatments into buckwheat cultivation as a sustainable agricultural practice. Further investigation into the long-term ecological effects and adaptability of biofertilizer use across various environmental conditions is warranted.

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