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RESEARCH ARTICLE

Yield and economics of foliar biofertilizer application of spring barley in organic farming on low nutrition background

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Abstract

The experiment studied the effectiveness of fertilizers in the foliar application of Rhizum, *Leanum*, and Gumisil-A in the field of barley which contain organic substances, macro- and micronutrients, amino acids, phytohormones. Of the three fertilizers, only *Leanum* contained nitrogen-fixing, phosphorus-forming, and potassium-mobilizing, lactic acid bacteria, decomposers, beneficial fungi. Soil of the experimental plot has low content of humus and nitrogen, medium content of labile phosphorus and exchangeable potassium with pH H_2O 6.7. The highest yield was obtained with *Leanum*, exceeding the control without foliar application by 10.2%. As a result, using *Leanum*, the level of profitability is 6.44%. The application of Rhizum and Gumisil-A was not profitable due to the insignificant increase in yield and the cost of preparation, transportation and applying. Expensive fuel lubricating materials currently offset farmers' profits.

Keywords: Barley, Yield, Foliar application, Biologics, Grain, Organic farming, Soil, Economic analysis, Profitability

Introduction

The economic crisis and war in Ukraine have caused radical changes in all spheres of human life, and agriculture is no exception. Rising prices for energy resources, expensive fuel lubricating materials, seeds, fertilizers, and crop protection agents negatively affect the profitability of farms from crop cultivation. Farms choose crops that can be profitable to sell despite disrupted logistic chains, resulting in high market competition. Expensiveness has led to situations where farms minimally apply mineral fertilizers, or as in 2022, some did not apply them at all due to inability to purchase. Therefore, there is a transition to minimum tillage technologies with minimal nutrient inputs, and currently, attention is focused on the application of bio-preparations, soil and plant probiotics that can help plants take up necessary nutrients from the soil. Thus, some producers are transitioning to organic farming systems, which involve using organic fertilizers, cover crops, bio-preparations, and biofertilizers. Farms wishing to trade organic products must comply with rules and certify their land or produced goods under the Organic Standard (Zakharchenko et al., 2023). However, there are producers who do not certify but nevertheless apply all measures for regenerative agriculture. The use of humates and bio-preparations based on strains of microorganisms has received positive feedback from farmers, thus various mixtures and targeted application systems are being developed by different companies for each crop they market. The application of such fertilizers or bio-preparations does not harm the environment and positively affects soil fertility indicators, stabilizing soil microbiota (Barczak et al. 2019; Marenych et al., 2020; Dindaroglu et al. 2022). Therefore, this study is dedicated to examining the effectiveness of organic fertilizer application in organic crop rotation, specifically in the cultivation of spring barley.

For cultivation on medium and low-nutrient soils, barley responds well to applied fertilizers, especially in the Forest-Steppe and Polissia zones, where the increase can reach up to 2 tons. Typically, on chernozem and podzolic soils with high and medium levels of nutrient supply, fertilizer rates of N45-60P45-60K45-60 are recommended. On soils with low fertility levels and available resources, rates can be increased to N60-90P60-90K60-90. However, currently, farms apply fertilizers at the level of NPK 30-45 in active substance.

Foliar feeding is an effective way to increase the yield and grain quality of barley, especially for feed purposes. $N_3$0-$N_4$0 can be applied in pre-sowing cultivation, followed by feeding during the tillering phase and the phase of ear emergence. That is, the first feeding contributes to an increase in protein content and grain number per ear. The second treatment on the leaf affects amino acids and the mass of 1000 grains. Thus, for feed barley, the fertilizer rate can be increased by 90 kg in active substance.

When analyzing soil for micronutrient content and identifying deficiencies in some, it is proposed to apply them during seed treatment or foliar application. Boron, copper, manganese, and zinc are proposed to be applied on more acidic soils. Boron is better applied on more neutral soils, while molybdenum on acidic ones. In cases of elevated phosphorus content, it is recommended to also apply zinc fertilizers. On peat soils, there may be a need to apply copper.
Growth regulators and bio-preparations are currently recommended for use to achieve high yields and grain quality, as well as to enhance plant immunity. Their application helps to form stronger plant stems resistant to lodging and promotes tillering (Metoui et al. 2020; Hryhoriv et al. 2021).

Research by (Horobets et al. 2020) demonstrated a positive effect of using growth regulators such as *bischofite*, *polystim*, and *zirconium* in barley cultivation in the conditions of Reshetylivsky district, Poltava region. The use of these bio-preparations during seed treatment and foliar application showed a greater effect during treatment, stimulating seed germination, but these preparations acted differently on the formation of the plant's photosynthetic apparatus.

(Masliyov et al. 2019) indicate the effectiveness of combined application of ammonium nitrate and Actibion. This fertilizer in the form of microgranules, besides NPK, also contains sulfur, calcium, magnesium, manganese, boron, and iron. The applied fertilizers stimulated branching and strengthening of the root system of spring barley, increasing grain yield by 5%-16% with simultaneous application of microgranules with ammonium nitrate.

(Lykhochvor et al. 2020) prove the effectiveness of using the fertilizer Ecolist Cereals, recommending its application in the flag leaf stage along with fungicides. In the subsequent heading phase, another application of fungicide together with Ecolist Cereals, urea, and magnesium sulfate is recommended. Ecolist contains about 4% nitrogen and a complex of micronutrients.

(Kasatkina and Gamayunova 2018) emphasize the importance of applying micronutrients and bio-preparations in spring barley cultivation in the Steppe zone. The use of the growth regulator Fresh Florida and the organo-mineral fertilizer Organic D-3 resulted in higher yields on experimental plots of MNAU compared to control plots without their application. Scientists note that growth regulators increase yield indicators by 15%-20%.

(Onufran 2013) has shown that in the conditions of dark-chestnut soils of the Steppe zone, the fertilization system should be selected according to varieties, considering their intensity, as well as sowing rate. In the study, different rates were proposed for varieties Stalker and Eney at different plant densities.

(Veremeyenko et al. 2020) found a positive response to the use of the growth regulator Vimpel-K and the microfertilizer Oracle seed with a fungicide in the conditions of dark-gray podzolized medium-loamy soils of Rivne region. Grain yield increased in fertilized variants, with an increase in the number of grains per ear and 1000 seeds in the harvest structure.

(Volkohon et al. 2015) together with colleagues established the positive effect of using Microhumus in the cultivation of spring barley in the conditions of low-fertility extracted light-loamy chernozem and weakly acidic soil environment.

This preparation contains the *Azospirillum brasilense* bacterial strain and is used for seed treatment. It is mainly produced based on peat.

(Ishchenko and Kozelets 2021) in the conditions of typical black soil with heavy loamy medium humus content, proved the positive effect of using the microbial preparation *Polymixobacterin* based on the bacterium *Paenibacillus polymyxa* , which was reflected in barley yield increase by 0.2 t ha^{-1}-0.6 t ha^{-1}. Foliar fertilization with urea, ammonium nitrate, potassium nitrate, and Reakom indicates a better effect from potassium nitrate and urea.

(Vlasyuk 2021) emphasizes the positive effect of using "Biocomplex-BTU" in barley cultivation under conditions of podzolized black soil with medium-loamy average washed with weakly acidic soil environment. It is emphasized that different barley varieties respond differently to bio-preparations. (Kovalenko et al. 2023) also emphasize that the effect of applying bio-preparations to the seeding material is obtained against the background without fertilizers and without foliar fertilization. But the highest effect is from seed treatment with the "Biocomplex BTU" against the background of mineral fertilizer, cover crops, application of straw decomposer, and urea, compared to the control variant, the increase was 1.64 tons of grain.

Gorski with other Polish colleagues (2023) proved that the highest yield of 4.5 t per hectare was obtained when treating barley seeds with preparations containing *Bacillus megaterium* var. *phosphaticum*, *Arthrobacter agilis*, *Azospirillum lipoferum Br17*, *Azotobacter chroococcum*. In organic crop rotation, the best effect was achieved with bio-preparations and cover cropping. But the authors also emphasize that different varieties of spring barley have different responses, and the peculiarities of microclimate and soil fertility also influence.

Thus, the optimal growth and development of spring barley depend on the soil fertility level, soil environment reaction, soil type, and climatic conditions. To stimulate plant development, it is recommended to apply bacterial preparations that can stimulate plant growth through better nutrient uptake (Tsvay 2008; Kokovikhin et al. 2020; Hryhoriv et al., 2020, 2023).

Due to the complication of the economic situation in Ukraine, the issue of selecting fertilizers remains relevant, namely the forms, terms, methods, and norms or doses of application that would support plant growth and restore soil fertility. The most problematic now is the supply of phosphorus fertilizers. Therefore, if we use plant and animal residues, bio-preparations, we can maintain and replenish the soil with nutrients and stimulate the activity of soil biota, which ultimately stimulates humus formation (Zanella et al., 2022).

It should be emphasized that the application of mineral and organic fertilizers may not work in full, and up to half of the applied fertilizers may leach from the soil profile or nutrients may be bound by the soil-adsorption complex. Therefore, there are currently many different humates on the market, which, in addition to humic and fulvic acids, contain macro- and microelements, chelating compounds. Nutrients in the humates sold are in chelated form, so they are available to plants immediately, therefore they are not leached and are effectively used by plants. Currently, there are proposals for potassium humate, sodium humate, and various additives to them, but already under other names of fertilizers. Thus, it has been proven that humates stimulate plant growth and development, especially where the soil is of low fertility.

Materials and Methods

The experiment was conducted during 2022-2023. The field of 2 hectares has an organic plot certificate, and since 2016, no mineral fertilizers or pesticides have been applied to the field. This plot of crop rotation with spring barley is located near the buildings of Sumy NAU, Sumy city. The area of the accounting plot was 24 m^2, with a threefold repetition. The Sebastian variety of barley was sown. The seeding rate was 5 million seeds per hectare, as this is an organic plot, with a seeding depth of 4 cm.

In the soil layer of 0 cm-20 cm, the content of organic carbon is 1.7%. The soil on the experimental plots is typical chernozem low-humus slightly leached light loam on a loess, with pHH2O 6.7. Nitrogen content according to Kornfield at the beginning of the growing season was 15.1 mg-eq per 100 g of soil, mobile phosphorus was determined according to Chirikov and was 9.3, and exchangeable potassium also according to Chirikov was 8.2 mg-eq per 100 g of soil.

Three fertilizers were used: Rhizum, *Leanum*, and Gumisil-A. Rhizum contains 60 g/l of total nitrogen, 48 g/l of water-soluble forms of phosphorus and potassium, as well as free amino acids, phytohormones, organic substances 360 g/l, including humic and fulvic acids 180 g/l, trace amounts of copper and zinc, pH of the solution 7. *Leanum* differs in the presence of nitrogen-fixing, phosphorus-forming, and potassium-mobilizing, lactic acid bacteria, decomposers, beneficial fungi, content of fulvic and humic acids 75.4 g/l, also contains 18 amino acids, vitamins, lignin, total nitrogen 30 g/l, phosphorus 3.1 g/l, potassium 0.5 g/l, magnesium 100 g/l, iron 100 mg/l, manganese 13.3 mg/l, zinc 8 mg/l, copper 1.0 mg/l, cobalt 0.7, boron 0.5, molybdenum 0.2, magnesium 0.5 g/l. GumiSil-A also contains humic and fulvic acids 30 g/l, nitrogen 90 g/l, phosphorus oxide 40 g/l, potassium oxide 95 g/l, magnesium 0.5 g/l, sulfur 10.0 g/l, microelements present: silicon 15 g/l, manganese 0.5 g/l, zinc 0.5 g/l, copper 0.4 g/l, cobalt 0.3 g/l, molybdenum 0.4 g/l, boron 0.5 g/l.

The fertilizers are in liquid form and were applied at the tillering stage of spring barley at a rate of 1.5 l ha^{-1} diluted with water at a rate of 150 l ha^{-1}. Plant treatment was carried out early in the morning with a backpack sprayer. Microplots of 10 m2 were laid out. When the full ripeness phase was reached, sheaves were collected from a square meter in triplicate from the plot.

The agronomy of spring barley cultivation differs from traditional intensive farming in that non-natural fertilizers cannot be used in organic fields, and even organic fertilizers such as manure, compost from intensive animal husbandry cannot be used unless the livestock farm is also organic and has a certificate from Organic Standard. Mineral fertilizers have also not been applied for a long time; by-products of crop farming and cover crops are used instead. Thus, in our field, mustard was used as a cover crop, which was sown after buckwheat. Biofungicides and bioinsecticides were used during the growing season. Field processing - minimal to a depth of 6 cm-8 cm with disks. In spring, harrowing and pre-sowing cultivation are carried out.

Results and Discussion

The tillering coefficient when using *Leanum* was the highest - 1.7 (Tab. 1). The use of Rhizum and GumiSil-A also affected tillering compared to the control, increasing the indicator by 0.3.

Table 1. Crop structure

Variant	Tillering coefficient	Productive stems, pcs.	Ear length, cm	Straw weight, 1 m^2, g	Sheaf weight 1 m^2, g	Grains in the ear, pcs	Grain weight in the ear, g	Corn grain yield, t ha^1
Control	1.2	392	44.7	310.2	655.6	18	8.7	2.55
Leanum	1.7	454	53.8	370.5	780.3	19	10.3	2.81
Rhizum	1.5	430	47.5	339.8	749.3	18	8.7	2.74
GumiSil-A	1.5	396	46.2	325.8	675.4	19	9.6	2.62
LSD_{05}	0.1	20	1.01	12.2	17.3	1	0.5	0.28

As for the number of productive stems, the difference between the first and fourth variants is within the smallest significant difference. Compared to the control variant with treatment only with water, the use of *Leanum* with beneficial organisms resulted in an increase in productive stems by 62 pieces. The use of Rhizum also affected the number of productive stems, but less than *Leanum*. The increase is at the level of 38 pieces. The explanation for this effect may be that indigenous organisms taken from chernozem soil were used in creating *Leanum*. Also, this fertilizer contains Trichoderma fungus, which suppresses pathogens and secretes antibiotics, enhances the process of converting molecular nitrogen into ammonium and nitrates, mobilizes phosphorus and potassium forms, thereby enriching them. And since pesticides have not been used on the plot for a long time, biofungicides of biological origin are extremely necessary, but it is difficult to find truly effective ones.

In the control variant, the length of the ear was measured at 44.7 cm. When plants were sprayed with *Leanum* at the tillering stage, the length increased by 9.1%. The use of Rhizum extended the stem length by 2.85 cm, and GumiSil-A by 1.3 cm.

The weight of the sheaf exceeds the weight of the straw in the control variant by 2.11 times, when using *Leanum* - by 2.10, Rhizum - by 2.2, GumiSil-A - by 2.07. The greatest increase in straw weight was determined in the second variant when using *Leanum* - 60.3 g. The smallest increase was found in the variant with the use of GumiSil-A - an increase in straw weight by 15.6 g. As for the total weight of the sheaf, a significant increase was also obtained in the second variant. There is no significant difference in the number of grains in the ear by variants.

As for the grain weight in the ear, there is no difference between the control plot and the data for the variant with Rhizum. But when using *Leanum*, the grain weight in the ear increased by 1.6 g, with GumiSil-A - by 0.9, which is higher than LSD05 (Least Significant Difference). That is, not all biofertilizers affect this parameter.

In our experimental plots, the yield of spring barley grain ranged from 2,55 t ha^{-1} to 2,81 t ha^{-1}. Thus, the maximum yield increase was obtained when using *Leanum*, exceeding the control by 10.2%. A slightly smaller increase when using Rhizum - 8.5% and when using GumiSil-A - the smallest yield increase was obtained at 0.07 t ha^{-1}, which is 1.03%.

All expenses must be taken into account when growing agricultural crops, including soil preparation for the crop after the predecessor. Farmers calculate possible expenses for purchasing seeds, plant protection products, fuel and lubricants, create technical maps and fill them out, and calculate expenses for workers' salaries, social costs, depreciation, direct and indirect costs. Typically, this work is done by agronomists together with economists, and in research institutions, scientists calculate with economists or accountants.

The grain market is developing, but currently it is unstable due to military actions along the entire front line. It is difficult to predict prices now, but they are still rising since the beginning of the war. The exchange rate of the dollar and the euro is unstable, there are problems with ports and product implementation, trucks are being blocked at the borders with Poland and Slovakia. Strengthening the material and technical base is also difficult.

To assess the effectiveness of using biofertilizers in spring barley cultivation, it is necessary to analyze the cost of the fertilizers themselves, the expenses for their application, and in the end, calculate how much money is spent on harvesting additional grain production if we have an increase in yield compared to the control.

Mineral fertilizers are currently very expensive; Ukraine supplies farmers with a minimal amount, again, due to partially destroyed infrastructure, including ports. Moreover, previously, before 2014, purchases were made from Russia, then from Belarus, but now these channels are blocked. The port infrastructure is in poor condition. Therefore, Ukrainian farmers can buy mineral fertilizers from abroad and transport them by rail and trucks.

Therefore, the use of biofertilizers, especially in organic farming, is a cheap way to regulate plant growth and development, influencing crop yields. Moreover, if the farm has switched to organic farming but does not have animal husbandry. Tab. 2 shows the calculation of the economic evaluation of the investigated variants.

Table 2. Economic efficiency of using biofertilizers in spring barley cultivation

Parameters	Variants 2-4		
	Leanum	*Rhizum*	*GumiSil-A*
Increase in yield comparing with control without biofertilizers, t ha^{-1}	0,26	0,19	0,07
Sale price of 1 ton of seeds, $	158.7		
Cost of additional products, $	41.3	30.1	6.3
Costs for the purchase of biofertilizers, $	14.3	23.9	11.7
Costs for refueling, transportation and applying of fertilizers, $	8.6		
Costs for collecting and selling additional yield, $	15.9	11.6	4.3
Other costs, $	3.3	3	2
Total additional costs, $	38.8	44	26.6
Additional profit, $	2.5	-	-
Profitability of the using of biofertilizers, %	6,44	-	-

Thus, to make calculations, we need to know the selling price of grain, which is around 158.7 $, according to the currency rate for October 2023. The cost of *Leanum* was 9.52 $ per liter, and 1.5 liters were used, so it is 14.28 $. The cost of Rhizum is 15.87 $ per liter, 1.5 liters is 23.8 $. The cost of GumiSil-A is 7.8 $ per liter, 1.5 liters is 11.7 $.

As seen from Table 2, profit was obtained only in the variant with the application of *Leanum*, the level of profitability was 6.44%. Expensive fuel lubricating materials currently offset farmers' profits.

Conclusions

The maximum yield of grain increase was obtained when using *Leanum*, exceeding the control by 10.2%. A slightly smaller increase was observed when using Rhizum - 8.5%, and when using GumiSil-A, the smallest yield increase was obtained at 0.7 t ha^{-1}, which is 1.03%. So additional applying of such fertilizers in the cultivation of summer barley strongly depend on yields and only 2.5 $ profit was get applying *Leanum*.

Proposals

When growing winter barley using organic technology on low nutrition background typical chernozem soil, it is recommended to use the biofertilizer *Leanum* at a rate of 1.5 l ha^{-1} for foliar feeding during the tillering phase.

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