Acta fytotechn zootechn, 27, 2024(4): 321-330
http://www.acta.fapz.uniag.sk

Original Paper

Efficiency of Biologized Fertilizer System in Organic Buckwheat Production

Olha Dutchak[1,2] , Halyna Kunychak[1] , Uliana Karbivska[2] , Volodymyr Sendetskyi[1] , Volodymyr Matviiets*[1]

[1]*Carpathian State Agricultural Experimental Station of the Institute of Agriculture of the Carpathian region of NAAS, Ivano-Frankivsk, Ukraine*

[2] *Prykarpattia National University named after Vasyl Stefanyk, Ivano-Frankivsk, Ukraine*

Article Details

Received: 2024-02-11 | Accepted: 2024-06-18 | Available online: 2024-10-03

https://doi.org/10.15414/afz.2024.27.04.321-330

The article highlights the expediency of growing buckwheat, which meets the basic requirements of organic production, reducing the anthropogenic burden on the environment, preserving and increasing soil fertility. The introduction of organic buckwheat cultivation technology is relevant in modern economic conditions, which contributes to the restoration of agroecosystems and ensures the production of environmentally friendly agricultural products. According to the results of the conducted researches, the regularities of formation of buckwheat seed productivity in organic production were determined. The use of organic fertilizer-biostimulant Vermimag for buckwheat seed treatment and foliar feeding of plants helps to reduce weed infestation of crops, increase yields and increase the economic efficiency of organic buckwheat cultivation technology.

Keywords: buckwheat, weediness, organic production, organic fertilizer-biostimulant, yield

1 Introduction

Optimization of crop management and regulation is an important area of agricultural activity. Along with this, agro-environmental safety is a prerequisite for sustainable development and the basis for maintaining favorable environmental conditions and production of environmentally safe and biologically complete food products as an integral part of the national security of the state.

Due to the predicted global climate change and increased soil degradation, the importance of crop production management in agro-systems will increase in the future.

The development of organic production is a topical issue, as the demand for safe and high-quality products is constantly growing worldwide. Today, environmental safety and the quality of products produced by farmers are the main factors of internal and, above all, external competitiveness.

Research and publications by domestic scientists highlight the role of organic farming in the implementation of the main provisions of sustainable development as a food security of the state. The current economic conditions and Ukraine's integration into the international community place new demands on the quality of agricultural products, production technologies and their promotion to the market. The ever-increasing chemical load due to the intensification of agriculture disrupts the ecological balance in agricultural landscapes and affects the quality of crop production. Therefore, it is necessary to introduce elements of "biological" agriculture, the ultimate goal of which is to obtain environmentally friendly products (Dehodiuk et al., 1992).

The development of organic production is quite relevant today due to a number of clear environmental, economic and social benefits inherent in this area of activity. In general, the problem of greening agricultural production is relevant for all developed countries. Formalized in the concept of organic production, it embodies the idea of a healthy lifestyle and healthy eating (Rohach, 2019).

The problems of developing organic production in the agricultural sector have been studied by such scholars as: V. Kysil, M. Kobets, Yu. Manko, V. Mesel-Veseliak, Ye. Mylovanov, P. Pysarenko, I. Prymak, P. Sabluk. Their scientific works contributed to the creation of a solid theoretical and methodological foundation, but this topic requires further deeper and more comprehensive research.

Agricultural producers, operating on the basis of organic production, gain significant competitive advantages, the most important of which are the high quality of the products grown, their safety, and significant demand in international markets (Dankevych et al., 2018; Dankevych et al., 2017). The growth in demand for organic products, in turn, leads to a rapid increase in the production of organic products, an increase in the land area occupied by organic production (Chaikin et al., 2018). Thus, there is a trend in the world to increase the land area under organic agriculture, especially in the EU member states, which is confirmed by the analysis of statistical information of the FAO (FAO, 2018; Zeman & Hron, 2018). Accordingly, the area of organic land is increasing every year, which due to the significant demand for this product.

Today, the main trend in the global organic market is the concentration of demand: about 90% of organic food and beverages are consumed in North America and Europe. At the same time, countries in Africa, Asia, and Latin America produce organic products mainly for foreign markets. The largest markets for organic products are the United States (USD 43.1 billion), Germany (USD 10.5 billion), and France (USD 7.5 billion) (Kyrylov et al., 2018). According to the Federation of Organic Movement of Ukraine, the annual growth of organic products on the world market is 25% (Federation of organic movement, 2018).

Organic agriculture, having significant environmental advantages over conventional agriculture, provides prospects for the development of economic systems (Bezus & Antoniuk, 2011; Zinovchuk et al., 2011; Shchkuratov et al., 2015).

Organic agriculture offers an alternative food system that can increase agricultural productivity, overcome food shortages even in the poorest regions of the world, ensure social justice and preserve the environment. The FAO reports that with a 56% increase in organic farming in developing countries, by 2030 it will be possible to fully meet the food demand in these countries and overcome the effects of climate change (Federation of Organic Movement, 2021).

Another factor in the growing popularity of organic production is that it is increasingly positioned and popularized as a resource-saving agricultural production that allows for the most efficient use of the potential of different soils and agroecological systems. Organic farming technologies can be used for the production of almost all crops, including cereals, horticulture, and perennial plantations (Singh et al., 2016).

The development of cereal production is of great importance for a balanced food market. This is due to the high consumer and dietary properties of cereal products. Buckwheat is a valuable cereal crop, characterized by high nutritional and medicinal properties of cereal, and is one of the main steam-generating, insurance, mulberry, honey and profitable crops. Due to the fact that buckwheat has been gaining popularity in recent years, the area under it is growing.

Buckwheat is a crop with a zero-waste cultivation technology. It is used to produce medicines (flowers, pollen, nectar), food coloring, food (cereals, flour), processed products (film, chaff, straw), and bacterial and organic fertilizers (ash). It is also an important honey plant (Alekseieva et al., 2004). Buckwheat grain contains about 13% of protein, which consists mainly of easily soluble globulins and glutenins, which contributes to its better absorption. Buckwheat grain also contains about 67% carbohydrates, 3% oil and 13% fiber. Buckwheat groats are a valuable food product that has high taste and nutritional properties, as they are rich in vitamins B1, B2, B5, etc.

Due to its high demand in the domestic market, buckwheat is the first candidate for growing under organic farming conditions, where the use of synthetic fertilizers, pesticides, growth regulators, and GMOs is prohibited. To increase yields, it is most effective to use different methods of tillage, crop rotation, and organic fertilizers (crop residues, manure, peat, composts, green manure, etc.) (Malynska, 2003; Iutynska, 2006).

The growing interest in organic buckwheat production from both farmers and the government makes this area quite promising. The issue of organic buckwheat production, increasing its acreage and production volumes is particularly relevant.

Based on the norms of rational nutrition according to the order of the Ministry of Health of Ukraine No. 272 of 18.11.1999 and the population of the country, we can determine the optimal volumes of

buckwheat production. The population of Ukraine consuming buckwheat products needs up to 300 thousand tons of grain, including export orders.

Buckwheat belongs to ecologically oriented crops, which can ensure the profitability of production and improve its ecological environment (Trygub et al., 2022). It is known that the profitability or not of buckwheat cultivation for an agricultural producer is determined by a number of factors, among which the main ones are natural and climatic, organizational, technical, agronomic and logistical. According to scientists, the analysis of the economic efficiency of buckwheat production shows the economic feasibility of its production in modern economic conditions, which has the potential as an organic crop, the possibility of waste-free production, a valuable honey crop and the ability to fight weeds. Therefore, given the existing advantages of this crop, further development of buckwheat production is socially important and necessary (Mirzoieva, 2017).

According to experts, Ukraine is one of the world's top three buckwheat producers on the global market. For example, Ukraine annually produces 6 thousand tons of . only organic buckwheat for export (Kucher & Kucher, 2016).

Optimization of buckwheat cultivation technologies is of great scientific and practical importance, as it allows to obtain the highest level of plant productivity, increase the return on agricultural resources and economic efficiency of production, and reduce the anthropogenic impact on the environment.

In recent years, crop cultivation technologies have widely used the harvesting of precursors with grinding and spreading of by-products. This method is simple and cost-effective. The use of straw for fertilizer plays an important role in the biologization of agriculture, increasing soil fertility, and preserving the environment. According to V.F. Saiko, straw contains all the nutrients necessary for plants, which, after mineralization, become readily available to plants.

A promising direction for reducing the cost of cultivation technology with increased yield and quality is the use of modern biological products that are easy to use and relatively inexpensive. Literature data indicate a positive prospect of using biological products in buckwheat crops to increase its productivity and seed quality indicators (Furmanets & Furmanets, 2016; Suchek & Kyryliuk, 2013; Radchenko & Nikolaienko, 2014).

The research data shows the effectiveness of the use of biological products for seed treatment and foliar feeding of crops in organic buckwheat production, which allows to grow high-quality environmentally friendly products (Kunychak et al., 2021).

Therefore, much attention should be paid to the introduction of a biological farming system that uses by-products of the precursor and organic preparations. This reduces degradation processes and saves money on fertilizers.

2 Material and methods

The research was conducted by the laboratory of soil cultivation, weed control and organic crop production technology of the Carpathian State Agricultural Experimental Station of the Institute of Agriculture of the Carpathian region of NAAS.

For 12 years, no mineral fertilizers, synthetically produced pesticides or other products prohibited in organic production were used in the crop rotation. The field experiments were conducted on sod-podzolic, surface-glazed medium loamy soil. The predecessor of buckwheat was winter triticale, the straw of which was chopped during harvesting and incorporated into the soil as organic fertilizer in all variants. The soil cultivation system was common for the zone and consisted of post-harvest stubble peeling, and autumn plowing to the depth of the humus horizon (20-22 cm). The first early spring tillage was moisture closure (harrowing). Later, as the soil was compacted and weeds germinated, two cultivations were carried out. Pre-sowing tillage was carried out with a complex unit on the day of sowing. A mandatory technique is post-sowing rolling, which levels the soil, improves seed contact with the soil, and promotes friendly plant germination.

The seeds of buckwheat sowing variety Volya, which is characterized by food purpose and is recommended for cultivation in different regions of Ukraine, were used for the study.

As you know, buckwheat is sown in two ways - in a conventional row method with a row spacing of 15 cm and in a wide-row method with a row spacing of 45 cm. Therefore, in our studies, buckwheat was sown in a row method with a seeding rate of 60 kg/ha and in a wide-row method with a seeding rate of 110 kg/ha.

In case of refusal from mineral fertilizers, in organic production, to improve the growth and development of plants, the formation of buckwheat seed productivity was studied with the use of an organic fertilizer-biostimulant, in particular, buckwheat seed treatment and foliar feeding of crops. In the buckwheat fertilization system, a liquid organic fertilizer-biostimulant Vermimag was used. In particular, buckwheat seeds were treated at the rate of 6.0 liters of the product diluted in 10 liters of water per 1 ton of seeds.

During the period of research, buckwheat crops were sprayed with an organic fertilizer-biostimulant at the rate of 6.0 liters of the preparation per 1 ha of crop. The first spraying of buckwheat crops was carried out in the branching phase, the second - in the budding phase.

On wide-row crops, two inter-row loosening of the soil was carried out during the growing season in the phase of the first true leaf and budding.

Accounting, observations and analyzes in the experiments were carried out according to the following generally accepted methods.

Phenological observations of the onset of buckwheat developmental stages (germination, branching, budding, flowering, fruit formation, ripening) according to the "Method of examination of plant varieties of the leguminous and grain groups for distinction, homogeneity and stability" (2024).

Harvesting was carried out in a continuous, split-level method with a Sampo-130 harvester. The yield was adjusted to 100% purity and standard moisture content (Yeshchenko, 2024).

Plant structure was analyzed using test sheaves of 25 plants, which were selected before harvesting from two non-contiguous replications in two locations of the plot (Bochkareva, 1994).

The quality of buckwheat grain was determined by the following technological parameters: weight of 1000 grains - according to GOST 12041-80, grain nature - according to the method (Hrytsenko & Koloshyna, 1984),

Statistical processing of the research results was carried out using the methods of analysis of variance (Yeshchenko, 2024). Cost-effectiveness analysis (Zbarskyy et al., 2012).

3 Results and discussion

Weeds are the main competitors of cultivated plants in the use of soil fertility elements. Stable yields with high seed quality are possible on weed-free fields. This is especially important in organic production, where weed control is complicated by the fact that chemical pesticides are not used, so the main role is played by preventive, agrotechnical and biological measures**.** Early spring tillage plays a significant role in weed control. The cultivation creates favorable temperature, water and air conditions for maximum germination of early and late spring cereals and regrowth of perennial weeds. Cultivation prior to buckwheat sowing loosens and levels the soil and destroys weed seedlings.

In our research, the first early spring tillage - harrowing - was carried out when the soil was physically ripe. As weeds germinated, cultivation was carried out. In the early phases of buckwheat plant development, weeds must be effectively controlled to allow cultivated plants to build up sufficient biomass that will further inhibit weed growth. In order for late spring crops, including buckwheat, to drown out weeds, it is necessary to create optimal conditions for their initial growth. One of the ways to achieve this is to treat buckwheat seeds with preparations of natural origin.

The most common weeds in our studies were creeping wheatgrass, pink thistle, yellow thistle, field bindweed, rape, wild radish, field mustard, chicken millet, gray mouse, and white quinoa.

Better growth and development of buckwheat plants and, accordingly, their higher competitiveness contributed to a decrease in weed infestation during the growing season in the variants where organic fertilizer was applied. As a result of the research conducted during 2021-2023, it was found that at different periods of buckwheat plant growth and development, both the number of weeds and their species composition changed. At the beginning of the buckwheat growing season, perennial weeds, wild radish and field mustard were predominant. Weed infestation, both in row and wide-row sowing, varied within 32-36 pcs./m^2 (Table 1).

Table 1 Weediness of buckwheat crops in organic production, 2021-2023.

Variant number	Experimental design		Number of weeds, pcs./m^2			Changes in weediness before harvesting	
	Sowing methods	Fertilizers	formation of the first leaf	flowering phase	before harvesting	pcs./m^2	%
1	in-line (15 cm)	Seeds treated with water, 10 l/t (control)	33	52	92	-	-
2		Seed treatment with a biological product	34	45	78	14	15,2
3		Seed treatment with a biological product + one spraying of crops with a biological product	34	38	69	23	25,0
4		Seed treatment with a biological product + two sprayings of crops with a biological product	32	33	63	29	31,5
5	wide-row (45 cm)	The seeds are treated with water, 10 l/t	36	38	103	-	-
6		Seed treatment with a biological product	35	35	100	3	2,9
7		Seed treatment with a biological product + one spraying of crops with a biological product	34	33	97	6	5,8
8		Seed treatment with a biological product + two sprayings of crops with a biological product	33	33	95	8	7,7

During the growing season, weed infestation in all variants increased. On wide-row buckwheat crops, two inter-row treatments were carried out in the phase of the first true leaf and budding, which destroyed weeds in the aisles.
According to a number of researchers, for the normal growth and development of buckwheat plants, the crops must be free of weeds. In buckwheat crops, weeds such as white quinoa, yellow thistle, chicken millet and gray mouse-ear begin to grow intensively and quickly use up moisture and nutrients from the soil during the period of fruit formation, which is critical for plants (Alekseieva, 1987; Demydenko, 1972). Thus, the second wave of weeds causes significant damage to buckwheat crops. In our research, they were represented by pink and yellow thistles, field bindweed, bindweed, pink bitterroot, white quinoa, gray mussel and others. Wide-row crops, as the loosened row spacing facilitated the germination and development of weeds, became more weedy by the end of the growing season (Fig. 1).

Also, it should be noted the impact of weather conditions during the research on buckwheat weed infestation. A significant amount of precipitation in July, both in 2021 and 2023, contributed to the intensive growth of weeds. At the same time, weed infestation at the time of flowering in the row seeding method was lower than in wide-row crops where inter-row cultivation was carried out. There was a higher weed infestation with blue mousegrass, chicken millet, white quinoa and yellow thistle, especially in the aisles.

In the control variant, the weed infestation in the flowering phase was 52 units/m^2. The use of organic fertilizer biostimulant improved the growth and development of buckwheat plants and increased their competitiveness against weeds. Thus, the weed counts conducted during buckwheat flowering show a positive effect of the preparation both for seed treatment with organic fertilizer and for its use for spraying crops in buckwheat cultivation technology. The lowest weed infestation at the time of buckwheat flowering in the row seeding method was due to the combination of seed treatment and double spraying of buckwheat crops with Vermimag organic fertilizer, where it was 33 pcs./m^2 , which is 31.5% less than in the same sowing method without the use of these preparations. When using organic fertilizer-biostimulant on wide-row crops, a similar dependence on weediness is observed to the row seeding method.

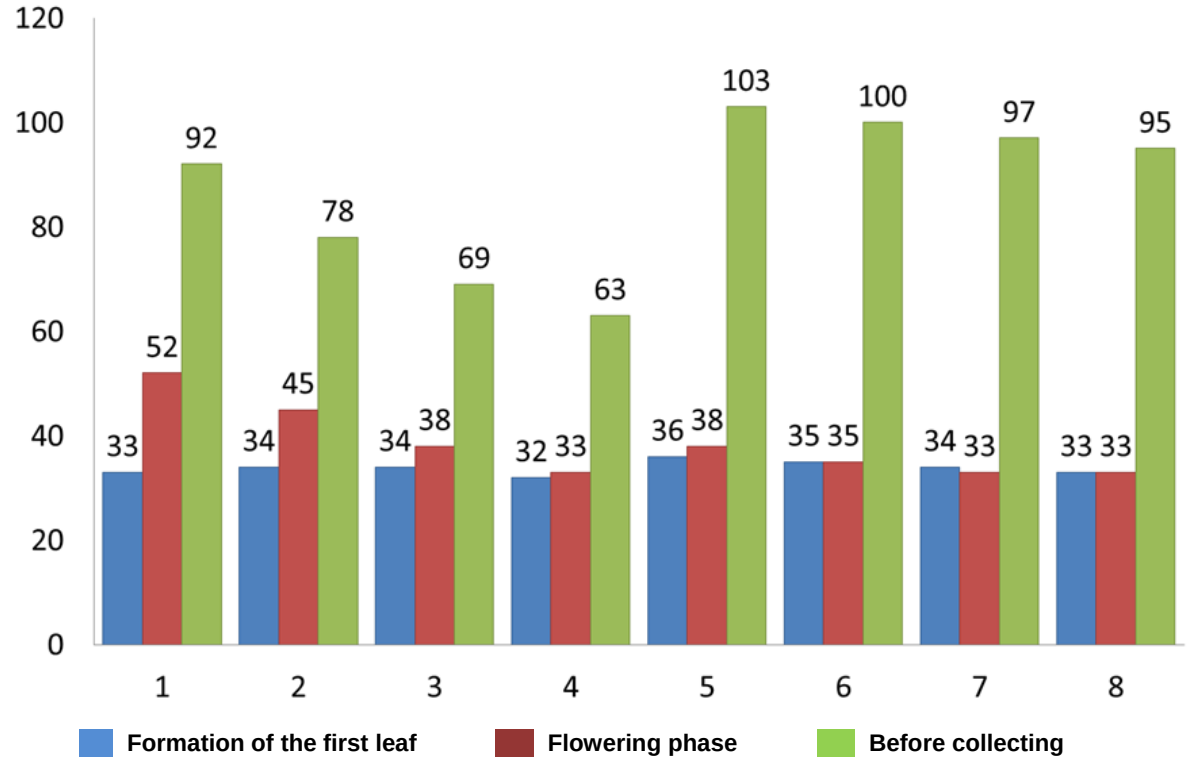

Fig. 1 Weed infestation of buckwheat crops under biological and agronomic measures, 2021-2023.

The use of the biostimulant Vermimag in the fertilizer system in 2021-2023 contributed to better growth and development of buckwheat plants and increased their competitiveness against weeds during the growing season. According to the research results, the combination of buckwheat seed treatment with crop spraying helped to reduce weed infestation before harvesting. In particular, there is a decrease in buckwheat weed infestation, both when treating seeds and combining it with a single foliar fertilization by 15.2 and 25.0%, respectively.

As already noted, the weediness of the wide-row sowing method before harvesting buckwheat was higher than that of the row method. However, there was a decrease in weediness with the use of the preparation by 2.9-7.7% compared to the wide-row sowing method, where the preparation was not used. The lowest weed infestation at the end of the growing season was observed after seed treatment and double spraying of buckwheat crops with organic fertilizer in the row seeding method - 63 pcs/m^2 , where the reduction of weed infestation was 31.5% compared to the control.

To obtain high and stable yields of high-quality buckwheat seeds, agrotechnology is important, based on measures taken for specific soil and climatic conditions, selection of the best predecessor, weed control, and increase of the seed multiplication rate. On this basis, yields are determined by many factors that affect the conditions of plant growth and development: moisture and heat supply, nutrients, physical condition of the soil, and weed infestation.

Spraying buckwheat crops during the growing season stimulates plant growth and development at the beginning of the growing season, increases drought and heat resistance, increases yields, stimulates active plant growth, increases resistance to negative environmental factors and diseases, and increases the weight of 1000 seeds. The use of a liquid organic fertilizer-biostimulant in the technology of organic buckwheat production improved the growth and development of plants and increased the yield of buckwheat. According to the results of the research, on average for 2021-2023, the yield was 1.33 t/ha for the row seeding method, where no preparations were used (Fig. 2).

An increase in yield was observed when buckwheat seeds were treated before sowing with a row seeding method by 16.5%. With this method of sowing, the complex application of the biological product for seed treatment and one and two-time spraying of crops contributed to an increase in buckwheat yield by 36.1-57.1%, respectively.

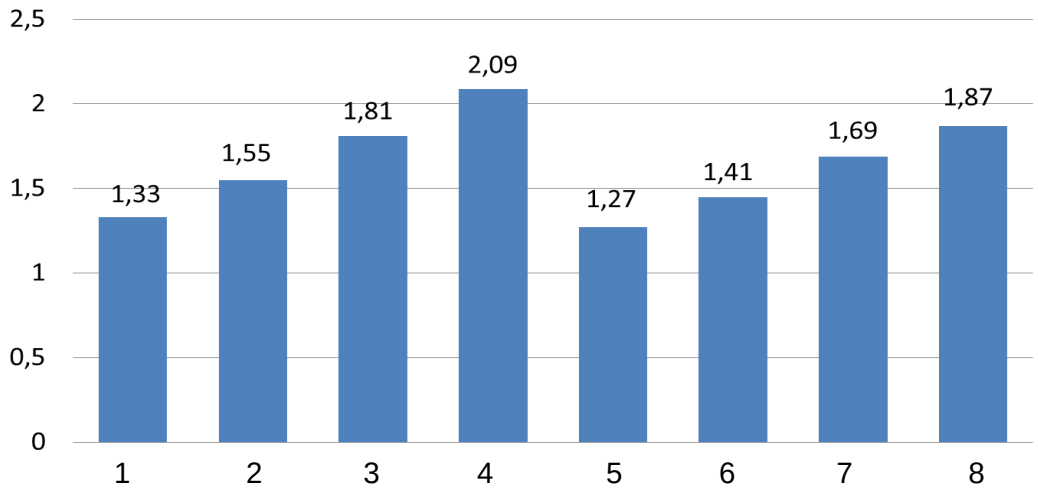

Figure 2. Buckwheat yield in organic production (t/ha) in 2021-2023.

The average yield of buckwheat with a wide-row sowing method was 1.27 t/ha. The use of the biological product for seed treatment with this sowing method increased the yield by 14.1%, and in combination with one-time and two-time foliar fertilization by 33.1 and 47.2%, respectively.

Thus, the highest yield of buckwheat on average for 2021-2023 was obtained with the row seeding method and the use of organic fertilizer-biostimulant for seed treatment and double spraying of plants, where it amounted to 2.09 t/ha, which is 0.76 t/ha or 57.1% more than in the control.

The use of an organic fertilizer-biostimulant helped to improve the conditions for plant growth and development and increase productivity. On average, in 2021-2023, the height of the plant in the control was 105 cm and increased by 9-22 cm with the application of fertilizer (Table 2). The weight of 1000 seeds and the nature of the grain also increased. The highest indicators of structure were obtained by seed treatment and double spraying of crops with Vermimag organic fertilizer. Under these measures, the height of the plants was 127 cm, which is 22 cm higher than the control. The weight of 1000 seeds was also 15.4% higher. As the flowering, fruit setting and ripening of buckwheat plants were more evenly distributed, more seeds were filled, and a higher grain weight of 619 g/l was obtained, which is 20 g/l more than in the control.

Thus, the combination of buckwheat seed treatment and double spraying of crops with Vermimag liquid organic fertilizer created better conditions for plant growth and development, increased branching and number of inflorescences, and fruit formation, which increased buckwheat productivity.

The goal of production is not only to produce environmentally friendly products, but also to be economically efficient. Organic production results in low yields, but the price of products grown in compliance with organic production requirements is higher. At the same time, the costs of fuel and lubricants, mineral fertilizers, and chemical protection products are reduced.

The results of the analysis of many studies and production tests indicate the high economic efficiency of biologization products. The effect is achieved due to the increase in yields, which, together with the relatively low level of additional costs for their use, contributes to a significant reduction in production costs.

According to the results of the research, the use of an organic fertilizer-biostimulant with insignificant additional production costs allowed to increase the economic efficiency of organic buckwheat cultivation.

On average, in 2021-2023, the cost of gross production was high and increased by variant due to higher yields. Thus, in the control variant, it amounted to 526 euros/ha and increased when treating seeds with organic fertilizer, as well as combining it with spraying crops to 574-827 euros/ha (Table 3). The total costs of growing organic buckwheat were low because no mineral fertilizers and chemical protection products were applied, which currently account for a large share of costs. At the same time, the costs of organic fertilizer used in the research were low.

Table 2 Structure of buckwheat harvest, 2021-2023

variant number	Experimental design		Plant height, cm	Weight of 1000 seeds, g	Grain content, g/l
	Sowing methods	Fertilizers			
1	in-line (15 cm)	Seeds treated with water, 10 l/t (control)	105	26,2	599
2		Seed treatment with a biological product	114	26,6	610
3		Seed treatment with a biological product + one spraying of crops with a biological product	120	26,9	615
4		Seed treatment with a biological product + two sprayings of crops with a biological product	127	27,5	619
5	wide-row (45 cm)	Seeds treated with water, 10 l/t	110	26,4	586
6		Seed treatment with a biological product	117	26,7	597
7		Seed treatment with a biological product + one spraying of crops with a biological product	122	27,1	601
8		Seed treatment with a biological product + two sprayings of crops with a biological product	127	27,7	605

Despite the additional costs of seed treatment and spraying, the net profit increased in all variants due to higher yields. When buckwheat seeds were treated with a row seeding method, a yield of 1.55 t/ha was obtained, where the net profit increased by 86 euros/ha. The combination of seed treatment and one-time spraying of crops increased net profit by 181 euros/ha. Also, with these measures, it was noted its increase in wide-row crops from 61 euros/ha to 212 euros/ha.

Table 3 Economic efficiency of organic buckwheat production, 2021-2023.

No. var.	Experimental design		Yield, t/ha	Value of gross production, EUR/ha	Total costs, EUR/ha	Pro forma net profit, EUR/ha	Cost price, EUR/t	Profitability level, %.
	Sowing methods	Fertilizers						
1	in-line (15 cm)	Seeds treated with water, 10 l/t (control)	1,33	526	196	330	147	168
2		Seed treatment with a biological product	1,55	613	197	416	127	211
3		Seed treatment with a biological product + one spraying of crops with a biological product	1,81	716	205	511	113	249
4		Seed treatment with a biological product + two sprayings of crops with a biological product	2,09	827	213	614	102	288
5	wide-row (45 cm)	Seeds treated with water, 10 l/t	1,27	502	183	319	144	174
6		Seed treatment with a biological product	1,45	574	184	391	127	213
7		Seed treatment with a biological product + one spraying of crops with a biological product	1,69	668	191	477	113	249
8		Seed treatment with a biological product + two sprayings of crops with a biological product	1,87	740	198	542	106	273

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With the increase in buckwheat yields due to the use of organic fertilizer, the net profit also increases, where the highest figure of 614 euros/ha was obtained for seed treatment and double spraying of crops with a row seeding method, which is 284 euros/ha more than in the control. These measures also resulted in the lowest cost of production - 102 euros/ha, which is 45 euros/ha less than when growing buckwheat without fertilizers.

With low costs for buckwheat cultivation and high product prices, the level of profitability in the control was 168% and increased both when seed treatment was combined with spraying of crops.

Thus, according to the results of research in 2021-2023, the patterns of formation of buckwheat seed productivity in organic production were determined, where the highest yield of 2.09 t/ha, net profit of 614 euros/ha and a profitability level of 288% and the lowest cost of 102 euros/t were obtained by combining buckwheat seed treatment and two sprayings of crops with an organic fertilizer-biostimulant using a row seeding method.

4 Conclusions

Treatment of seeds with an organic fertilizer-biostimulant ensured friendly germination of buckwheat plants and better initial growth and development during all years of research.

The use of biological and agrotechnical measures in the technology of organic buckwheat cultivation increases the competitiveness of plants in relation to weeds, which improves the phytosanitary condition of crops, where the reduction of weeds by the end of the growing season was 31.5%.

The combination of buckwheat seed treatment and double spraying of crops with an organic fertilizer-biostimulant using the row seeding method increases the weight of 1000 seeds, grain weight and increases the yield of buckwheat by 0.76 t/ha, or 57.1%.

Eliminating mineral fertilizers and chemicals from the technology of growing organic buckwheat seeds, replacing them with an organic fertilizer-biostimulant for seed treatment and double spraying of crops ensured an increase in net profit by 284 euros/ha, a decrease in production costs by 45 euros/ha and an increase in profitability to 288%.

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