Chapter 11

THE PRODUCTIVITY OF BUCKWHEAT IN THE NORTHERN STEPPE OF UKRAINE

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INTRODUCTION

Buckwheat (Fagopyrum esculentum) is one of the most important agricultural crops grown in many countries around the world due to its nutritional properties and resilience to adverse conditions[1,2]. In the context of modern agriculture, the issue of increasing buckwheat yields is becoming increasingly relevant, as the growing demand for this crop necessitates new approaches to its cultivation. One of the key factors influencing plant productivity is the fertilization system, which determines not only the quantity but also the quality of nutrients available to plants.

Research on the impact of different fertilization systems on buckwheat yield allows for the assessment of the effectiveness of agronomic practices and the identification of changes in soil fertility, which is critically important for ensuring sustainable agricultural development[3,4] In addition to positively affecting plant growth and development processes, enhancing resistance to diseases and stresses, and improving photosynthesis efficiency, fertilizers can also improve soil structure and regulate soil acidity or alkalinity, which affects nutrient availability for plants[5].

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In conditions of intensive land resource use and increasing environmental challenges, understanding the relationship between fertilization and soil fertility becomes extremely important for developing effective agronomic strategies.

Considering that fertilizers play a significant role in regulating the nutrient elements of crops, there remains a question of their interaction with biopreparations and the impact of the latter on buckwheat productivity. The effectiveness of the combined use of microbial preparations and fertilizers depends on the degree of alignment with the biological requirements of the variety in specific soil and climatic conditions[6].

Recently, there has been increasing attention paid to the use of biopreparations for seed inoculation, which can significantly enhance plant growth efficiency and their resilience to stress conditions[7,8,9]. Biopreparations containing beneficial microorganisms are capable of improving nutrient availability, stimulating root system development, and increasing the overall resistance of plants to diseases. This makes them an important tool in modern agronomic practices.

In this section, we will analyze the impact of various fertilization systems and biopreparations on the yield and productivity of buckwheat grown under conditions of insufficient moisture in the Northern Steppe of Ukraine, and we will draw conclusions regarding changes in soil fertility indicators that have occurred over the past 10 years.

The results presented in this study may serve as a foundation for improving the elements of buckwheat cultivation technology and contribute not only to increasing the efficiency of modern agricultural production but also to preserving soil fertility.

Thus, in the context of intensive land resource use and growing environmental challenges, understanding the relationship between fertilization, seed inoculation, and soil fertility becomes extremely important for developing effective agronomic strategies.

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1. The emergence of prerequisites and the formulation of the problem regarding buckwheat cultivation in the conditions of the Northern Steppe of Ukraine with the aim of increasing its productivity

Buckwheat's high demand for nutrients is associated with the intensive growth of vegetative mass, rapid entry into the generative period, the formation of a large number of flowers, and a prolonged flowering period[10]. To produce 1 ton of grain and the corresponding amount of vegetative mass, buckwheat requires 30-34 kg of nitrogen, 15-20 kg of phosphorus, and 4.0-5.0 kg of potassium[11].

The choice of fertilization system is determined by the soil and climatic conditions of the crop's growing zone, which affect the effectiveness of fertilizers, taking into account varietal characteristics and the economic capability of the farm.

After good preceding crops, it is recommended to apply $N_{20}P_{30\text{-}40}K_{30\text{-}40}$; after poorer preceding crops and on poor soils, it is advisable to increase the norm to $N_{30\text{-}60}P_{45\text{-}60}$. The positive effect of the split application method for nitrogen as a main fertilizer and for top-dressing has been confirmed[12].

In the conditions of the Western Forest-Steppe of Ukraine, research on the fertilization system for buckwheat confirms that the application of mineral fertilizers at rates of $N_{30}P_{30}K_{30}$ and $N_{45}P_{45}K_{45}$ increased buckwheat yields by 0.42 and 1.50 t/ha, respectively, compared to the control, where 0.97 t/ha of buckwheat grain was obtained. The maximum yield was achieved with a norm of $N_{60}P_{45}K_{45}$ – 1.87 t/ha. Additionally, it was noted that increasing phosphorus and potassium to 60 t/ha led to a decrease in yield to 1.76 t/ha and 1.62 t/ha, respectively[13].

The study of the impact of fertilizer norms on buckwheat yield has been conducted by scientists from the Institute of Grain Crops of NAAS in the languages of the Northern Steppe region (administratively within Dnipropetrovsk Oblast)[14]. The results of their research indicate that the highest buckwheat yield (1.20-1.25 t/ha) was obtained with the application of $N_{90}P_{60}$, which is 0.35-0.37 t/ha more compared to the variants without fertilizers. However, considering the indicators of economic efficiency, the

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optimal norms were $N_{60}P_{30}$ and $N_{60}P_{60}$. Compared to the control, production costs decreased by 9.8-12.6%, while energy intensity reduced from 3.5 to 7.3%.

In the conditions of the Western Forest-Steppe, studying the impact of mineral and biological fertilization on buckwheat productivity, it was concluded that the comprehensive application of mineral fertilizers at a rate of $N_{60}P_{60}K_{60}$ and nitrogen-fixing and phosphorus-mobilizing agents contributes to an increase in leaf area by 71%, net photosynthetic productivity by 20%, and yield growth by 18% (up to 2.59 t/ha) compared to the control. The share of the fertilization factor in yield formation was 88%[15].

The issue of using scientifically justified fertilizer norms when growing buckwheat attracts the attention of researchers from many countries around the world. Studying nitrogen fertilization systems in China, it was concluded that a higher level of buckwheat yield was achieved with the application of N_{30}, while increasing the rate to N90 resulted in a decrease in yield indicators[16].

Björkman T.[17] suggests differentiating buckwheat fertilization levels based on soil pH, specifically: at pH ≥ 6, apply fertilizers at a rate of $N_{15\text{-}30}P_{25\text{-}35}K_{20\text{-}25}$, and at pH ≤ 6 – $N_{20\text{-}35}P_{30\text{-}40}K_{20\text{-}35}$. Wang Yan[18] highlights the relationship between the degree of buckwheat lodging and nitrogen fertilizer rates in Japan. He concluded that as nitrogen fertilizer rates increased, the lodging index also increased.

Research conducted at the Institute of the Agricultural Research in Arak (Iran) studied the impact of mineral fertilizers on buckwheat productivity. The experimental variants included nitrogen application rates of N_{50}, N_{100}, and N_{150}. The highest yield, 2.4 t/ha, was obtained at a rate of 100 kg/ha, with the protein content in the grain also being the highest at 15.24%[19].

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Podolska G.[20] conducted research at the experimental station IUNG-PIB in Osiny from 2004 to 2006, where the buckwheat variety Kora was sown in three replications. The nitrogen application rates were 0, 30 kg/ha, and 60 kg/ha with a background of $P_{26}K_{50}$. These studies confirm that the hydrothermal conditions for buckwheat cultivation had a greater impact on yield and the elements of yield structure than the nitrogen application rates. For optimal yield, buckwheat does not require nitrogen at a rate higher than 30 kg/ha.

Research by Liszewski M. and his team using the same buckwheat variety Kora in Poland was conducted with nitrogen applications of 20 and 40 kg/ha in combination with foliar feeding of plants with micronutrients during the budding phase. A significant increase in buckwheat yield was noted with N_{40} (without micronutrient feeding), which was 9.6% higher than in the control variant. The highest buckwheat yield (3.67 t/ha) was achieved in combination with foliar feeding of plants with copper[21].

The implementation of nutrient use in agricultural practice is aimed not only at increasing the yield of cultivated crops but also at improving the qualitative composition of soils[22,23]. The efficiency of using residues from the previous crop can be enhanced by applying mineral fertilizers, but the requirements for them may be significantly lower[24].

Post-harvest residues primarily consist of agricultural leftovers after harvesting. The return of post-harvest residues positively affects the physical and chemical properties of the soil, including soil moisture content, overall porosity, aggregate stability, and cation exchange capacity. Furthermore, post-harvest residues play a crucial role in soil reclamation; they somewhat mitigate the impact of heavy metals, organic pollutants, and pathogens, and can reduce osmotic pressure in saline soils, which are soils with alkaline reactions. The incorporation of post-harvest residues is a sustainable method

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for improving soil quality without disrupting its biological balance. The decomposition of these residues can increase the content of organic carbon and available phosphorus and potassium in the soil, which can provide nutrients for microorganisms and agricultural crops[25,26].

Research conducted at the University of Peleforo Gon Coulibaly in Korhogo (Ivory Coast) demonstrates that corn stalks, millet straw, rice straw, and sorghum stalks with high nitrogen and phosphorus content have the potential to supply greater amounts of these nutrients. Millet straw and rice straw can be beneficial for fast-growing and early crops. In contrast, corn stalks and sorghum stalks release nutrients slowly, which would be advantageous for longer nutrient availability. Additionally, buckwheat residues may help combat weeds in wheat crops; however, no reliable impact on wheat yield has been established, necessitating further research to study the selective effects of buckwheat straw on weediness in subsequent crops and their productivity[27].

The results of studies on the impact of the biological component of fertilization systems on buckwheat yield and the quality of its produce are insufficient for definitive conclusions or recommendations, making further investigation into this issue relevant.

Based on the Institute of Agriculture of the Steppe of the National Academy of Agrarian Sciences of Ukraine, a stationary field experiment was established, in which various fertilization systems with elements of biologicalization in crop rotations, including buckwheat, have been studied for 14 years. The results of the analysis of changes in soil quality and chemical composition will be presented in the following sections.

The quality of grain and seeds depends on a significant number of factors, the main ones being: the genetic characteristics of the variety or hybrid being grown, adherence to agronomic technology, climatic and geographical conditions of cultivation, soil composition and condition, as well as the timing and methods of harvest. The set of quality indicators of products (grain, flour, groats) – their technological properties – determines the suitability of the raw material for a specific type of processing or use.

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Protein constitutes approximately 15% of the mass of buckwheat grain. Compared to soybean protein, protein products from buckwheat are considered more effective in preventing the formation of stones in the gallbladder and reducing the level of colorectal carcinogenesis[28]. It has also been found that buckwheat protein can be used as an edible film for food packaging and that the properties of the protein affect the food quality of these products[29]. Nitrogen is essential for the growth and development of agricultural crops, and appropriate application of nitrogen fertilizers improves the quality of the produced goods and yields[30]. Adequate nitrogen application promotes the synthesis and accumulation of proteins in the grain, thus altering their physicochemical properties. In recent years, there has been active research into the influence of fertilization on the content of protein components in the grains of many crops, including buckwheat. However, the norms for nitrogen application depending on the soil-climatic conditions for growing this crop have been studied limitedly.

According to research by Chenxi Wan and his colleagues, optimal nitrogen fertilizer application (180 kg/ha) improved buckwheat yield and agronomic properties, as well as facilitated nitrogen transport and protein accumulation, which aligns with results from corn studies[31]. This also contributed to the accumulation of albumin, globulin, and glutenin in the grains but had little effect on the content of prolamin. Such studies may serve as a basis for high-quality selection and practical use of optimal nitrogen fertilizer application rates for buckwheat.

2. Analysis of existing methods and tasks for optimizing elements of buckwheat cultivation technology and addressing issues to increase crop productivity in the northern Steppe of Ukraine

Field studies were conducted from 2011 to 2024 at the Laboratory of Institute of Agriculture of the Steppe, National Academy of Agrarian Sciences of Ukraine, based on stationary experiments with short rotation crop rotations.

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The establishment and conduct of experiments were carried out according to the methodology for field research. Buckwheat was grown in a five-field crop rotation over three rotations, with corn as the preceding crop. In the first rotation, from 2011 to 2015, the Elena variety was sown (a high-yielding buckwheat variety of medium maturity group developed at the Research Institute of Grain Crops of the Podilsk State Agrarian Technical Academy; it is resistant to lodging, has a compact plant with a strong stem, and is characterized by high grain quality). The seeds were treated before sowing with the microbial preparation Polimiksobakterin (150 ml/t), designed to improve the phosphorus nutrition of plants.

During the second rotation, from 2016 to 2020, the Kpupinka variety was used (a determinate variety developed by the Sumy State Agricultural Station, belonging to the medium maturity group, known for its resistance to shattering and diseases, and not prone to lodging even under adverse weather conditions). The seed inoculation was carried out with the Organic Balance preparation (1.5 l/t), a biological preparation with systemic action consisting of beneficial microorganisms that are nitrogen fixers and phosphorus stabilizers.

In the third rotation, from 2021 to 2025, the Yuveleyna 100 variety was used in the experiments (a medium-maturing determinate type variety bred by the Sumy State Agricultural Station, relatively resistant to lodging, shattering, and drought, and resistant to powdery mildew and downy mildew). The buckwheat seeds were treated with the biopreparation Mikofrend (2.0 l/t), a mycorrhiza-forming biopreparation created based on mycorrhizal fungi *Glomus* VS and *Trichoderma Harzianum*.

The technology for growing buckwheat is generally accepted for the Steppe zone, except for the practices that are under study. The experiment was repeated three times. The sown area of the experimental plot was 72 m², and the accounting area was 36 m².

Buckwheat was sown using a wide-row method with row spacing of 0.45 m in the first decade of May at a seeding rate of 2.25 million seeds/ha, against the background of three fertilization systems:

1. Without fertilizers;
2. Mineral fertilization system ($N_{20}P_{20}K_{20}$);
3. Organic-mineral ($N_{20}P_{20}K_{20}$ and by-products of the preceding crop).

The determination of the chemical properties of the soil was conducted using the following methods:

– Humus content according to DSTU 4289-2004 «Methods for Determining Organic Matter» (by Tyurin);

– Ammonium and nitrate nitrogen content according to DSTU 44729:2007 (in the modification of O.N. Sokolovsky);

– Content of mobile compounds of phosphorus and potassium according to DSTU 4115-2002, Chirikov method.

The qualitative indicators of buckwheat fruits were determined as follows:

– Fat content in the fruits according to DSTU 7577:2014 «By extraction method in a Soxhlet apparatus»;

– Protein content in the fruits according to DSTU 7169:2010 «By the method of determining crude nitrogen and protein»;

– Starch content in the fruits according to GOST 10845-98 «By the method of determining starch».

General technology for buckwheat cultivation: the primary soil cultivation began with the shredding of stubble, followed by moldboard plowing to a depth of 22-25 cm. The pre-sowing soil preparation consisted of cultivation to a depth of 5 to 8 cm. Care for the crops included post-sowing rolling and inter-row cultivation at the beginning of the budding phase of the buckwheat plants. Pest and disease control was carried out according to the existing recommendations in the area. Harvesting was done in a two-phase method, with mowing into windrows when 70-75% of the seeds had turned brown and the leaf-stem mass was no more than 35%. After the windrows dried (3-5 days after mowing), they were collected for threshing the grain.

Buckwheat is a moisture-loving crop. It is most demanding for moisture during the interphase period of mass flowering and fruit formation. In the conditions of the Northern Steppe, this often occurs under prolonged dry spells with high temperatures, especially in the last 5-6 years. During this period, the plants absorb 50-60% of the water from the soil relative to their total needs. When moisture is insufficient, plant growth stops, but development continues. This leads to the formation of low-yielding dwarf plants, which, as we will note later, negatively affects their yield and productivity.

The flowering and fruit filling period for buckwheat is the most critical and largely depends on meteorological conditions. In unfavorable conditions, the number of ovaries sharply decreases, resulting in reduced plant productivity. Rain, fog, heat, drought, winds, and sharp temperature fluctuations disrupt pollination of flowers and seed filling, significantly reducing yield.

Buckwheat is sensitive to air drought. Relative humidity below 30-40%, accompanied by winds, causes wilting of plants, death of flowers, ovaries, and even fruits. The combined effect of air and soil drought has a particularly negative impact on buckwheat when temperatures rise to 30 °C and humidity drops to 40%. Under such conditions, ovaries die on the plants within 2-3 days. Prolonged dry winds and absence of precipitation for 30-40 days were noted during the research, especially in such unfavorable years as 2012, 2017, and 2024.

Considering the above, weather conditions significantly influenced buckwheat productivity during the research period. Overall analysis indicated that these conditions were dry, conditionally favorable, and unfavorable for achieving high productivity indicators for buckwheat.

Weather conditions during the research periods of 2011, 2013, 2014, 2019, 2020, and 2023, characterized by favorable temperature regimes and sufficient, and in certain periods (April-May), excessive amounts of precipitation, had a positive impact on the formation of high buckwheat yields. However, they were not sufficiently favorable during critical water consumption periods (flowering). The maturation and completion of the vegetative phase of buckwheat plants occurred under good thermal conditions but with limited moisture reserves in the soil due to the absence of precipitation. In other words, the weather conditions during the growing season of the specified years initially contributed to establishing the maximum yield potential of buckwheat, but due to a significant moisture deficit during the fruit filling period, it was not possible to realize the potentially high biological yield established in the early stages of development.

The conditions of the years 2015, 2016, 2018, 2021, 2022, and 2023 were conditionally favorable for the growth and development of buckwheat plants; moderately warm air temperatures with sufficient amounts of precipitation during the vegetation period had a positive effect on buckwheat yield formation.

Unfavorable conditions for achieving high yield levels were noted during the growing seasons of 2012, 2017, and 2024.

3. Analysis of Buckwheat Yield Depending on Fertilization Systems and Seed Inoculation with Biopreparations in the Conditions of Northern Steppe of Ukraine

The yield of buckwheat is determined by the amount of grain harvested and depends on the number of plants per unit area, their branching, the number and mass of seeds per plant, etc.[32]. Various environmental factors influence yield levels: water, temperature, and nutrient regimes of the soil, which are recognized as determinants of plant productivity

The availability of fertilizers and their effectiveness are closely related to the moisture supply for plants. In this regard, plants that are insufficiently provided with moisture utilize fertilizers less effectively than under conditions of adequate moisture. As several authors assert, under conditions of

[32] Bavec F., Punik S., Rajèan I. Yield performance of two buckwheat genotypes grownas a full-season and stubble-crop. *Rostlinna Vyroba*. 2002. 48(8): 351–355. https://doi.org/10.17221/4379-PSE

insufficient moisture, climatic conditions come to the forefront, significantly affecting buckwheat productivity[33].

During our research period, there were years with both low moisture availability for crops and excessive moisture, leading to significant growth of above-ground plant mass and the formation of empty flowers, as well as observed empty seeds and lodging of plants. The variation in yield indicators for buckwheat varieties under the influence of weather conditions during the years of research was significant.

We observed a significant decrease in buckwheat yield every five years, especially during the period from 2011 to 2020, with a reduction of 0.33-0.35 t/ha over ten years against the background of natural plant nutrition and the use of a mineral fertilization system. In the last four years, we noted a trend towards a slowdown in the rate of yield decline, with the difference between the indicators of the second and third rotations being 0.16-0.28 t/ha. The application of mineral fertilizers somewhat mitigated the impact of negative environmental factors, especially during the period from 2021 to 2024 (Table 1).

Table 1

Buckwheat yield (2011-2024)

Fertilizer system, Factor A	**Biopreparations, Factor B**	**Average for 1st rotations, 2011-2015**	**Average for 2nd rotations, 2016-2020**	**Average for 3rd rotations, 2021-2024**	**Average for 2011-2024**
Without fertilizers	Without biopreparations	1.53	1.18	0.90	1.22
	With biopreparations	1.72	1.29	1.11	1.39
Mineral	Without biopreparations	1.76	1.43	1.27	1.50
	With biopreparations	1.97	1.65	1.41	1.69
Organo-mineral	Without biopreparations	1.88	1.76	1.54	1.74
	With biopreparations	2.05	1.86	1.65	1.87
LSD_{05}	Factor A	0.08	0.14	0.15	0.07
	Factor B	0.07	0.12	0.12	0.06
	Factors AB	0.12	0.20	0.21	0.10

[33] Писаренко В.М., Писаренко В.В., Писаренко П.В. Управління агротехнологіями в умовах посухи. Монографія. Полтава. 2020. 161 р.

The use of an organic-mineral fertilization system, specifically the incorporation of residues from the previous crop during primary soil cultivation, not only allowed for achieving the highest yield indicators in the experiment but, importantly, also preserved the potential of the crop. The reduction in yield over 14 years was 0.34 t/ha, whereas the application of only mineral fertilizers in buckwheat cultivation led to a yield decrease of 0.65 t/ha, and without fertilizers, it was 0.63 t/ha.

An analysis of buckwheat yield over the last 14 years allows us to conclude that changes in weather conditions had the most critical impact on plants during the years 2011-2020. Stressful growing conditions, which caused prolonged periods of drought, high daytime temperatures above 30 °C – especially during flowering – and frequent dry winds hindered growth or development processes in plants, affecting their yield. The weather conditions from 2021 to 2024 were not more favorable for buckwheat; on the contrary, heat and a dry period lasting over 30 days, along with significant rainfall deficits throughout the entire growing season in 2024, led to a record low yield level for the entire research period. It can be assumed that adaptive properties became an important element in preserving the biological potential of the crop. However, this issue requires further research.

On average, over the years of research, the positive impact on buckwheat yield was attributed to elements of the cultivation technology such as fertilization systems and the use of biopreparations. In the absence of fertilizers and inoculants in the conditions of the northern Steppe of Ukraine, the yield of buckwheat grain did not exceed 1.22 t/ha.

Only through seed inoculation before sowing did this figure increase to 1.39 t/ha (+0.17 t/ha), confirming the validity of the factor's influence. When applying mineral fertilizers at a rate of $N_{20}P_{20}K_{20}$, a yield of 1.50 t/ha of grain was obtained, with a significant yield increase of 0.28 t/ha.

Higher yield indicators for buckwheat were observed when using an organo-mineral fertilization system, achieving 1.74 t/ha. When combined with seed inoculation using biopreparations, this indicator increased to 1.87 t/ha, which was the maximum in the experiment.

The analysis of the data presented in Table 1 confirms the validity of the influence of the factors we studied on buckwheat yield, but it is equally important to determine the degree of their impact.

When using a mineral fertilization system, the yield increase of buckwheat compared to the control was 0.28 t/ha or 23%, while combining the same rate of mineral fertilizers with a biological component, such as crop residues, increased the yield by 0.52 t/ha. Thus, the organo-mineral fertilization system had a higher degree of influence, providing an increase in buckwheat yield by almost one and a half times, or 42.3% (Figure 1).

The variability of yield indicators under the influence of biopreparations had somewhat narrower limits, ranging from 0.13 to 1.19 t/ha. It should also be noted that against the background of the organo-mineral fertilization system, the degree of influence of the biological factor was the lowest, at +0.13 t/ha or 7.3% (Figure 2).

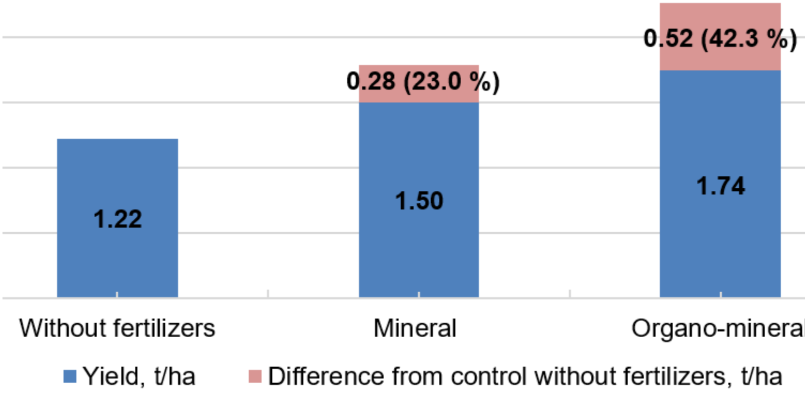

Fig. 1. The degree of influence of fertilization systems (Factor A) on buckwheat yield, 2011-2024

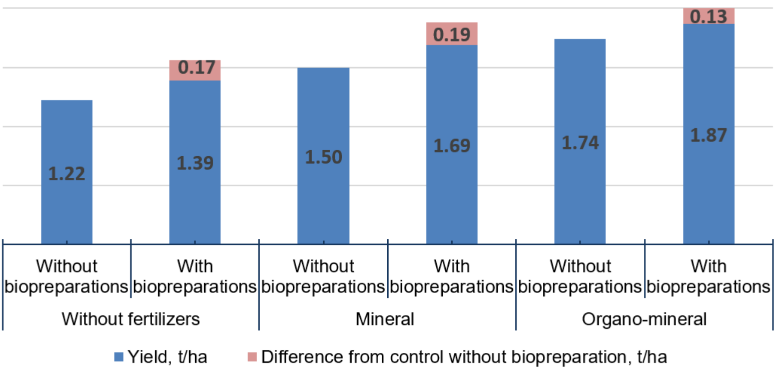

Fig. 2. The degree of influence of biopreparations (Factor B) on buckwheat yield

The greatest positive effect from seed inoculation before sowing was observed in our experiments under conditions of natural plant nutrition, i.e., when growing buckwheat without fertilizers, where the yield increase was 13.9%.

Thus, the degree of influence of biologically active preparations was determined by the level of nutrient supply to the plants; the more nutrients the plants received from the soil, the less effective the action of the biopreparations was.

4. The influence of fertilization systems and biopreparations on the quality indicators of buckwheat fruits in the conditions of the northern Steppe of Ukraine

Among the indicators that determine the quality of produced goods for the food industry, where buckwheat is predominantly used, the leading role belongs to the chemical composition of the seeds. The determination of protein, fat, starch, and ash content in the seeds is of significant importance for assessing the effectiveness of agronomic practices in buckwheat cultivation[34].

Among cereal crops, buckwheat seeds have a higher protein content than rice and millet, and their composition is of higher quality. The protein substances are similar in amino acid composition to those of leguminous plants, and in terms of valuable amino acid composition, they are comparable to animal products. In addition to protein and carbohydrates (the main substance in the carbohydrate complex is starch), buckwheat seeds contain fat, which consists of non-drying oil that oxidizes slowly during storage.

Quality indicators of agricultural products refer to the content of major organic substances that determine the purpose and feasibility of cultivating a crop (protein in wheat grain, sugar in sugar beet roots, starch in potato tubers). Several factors influence the quality indicators of agricultural products: soil-climatic conditions, varietal characteristics, sowing dates, overall farming culture, and the use of chemical means (considering optimal ratios between macro-, micro-, and ultra-microelements).

According to the results of our research, no significant effect of the fertilization system and biopreparations on the protein content in buckwheat fruits was established. In the fertilization systems using mineral fertilizers and an organo-mineral complex, the quality of the fruits in terms of protein content was somewhat higher, at 12.4 t/ha compared to the control; however, considering the LSD_{05} = 0.56 t/ha, the difference was still not significant (0.54 t/ha). Furthermore, it should be noted that in these fertilization systems, there was a slight decrease in the protein content in the fruits of plants treated with biopreparations before sowing by 0.11-0.17 t/ha (Figure 3). On average,

[34] Мащенко Ю. В., Семеняка І. М. Удосконалення технології вирощування гречки в умовах Північного Степу України. Монографія. Київ. Сільськогосподарські науки. 2018. 184 р. https://isgs-naan.com.ua/read_buckwheat

over the years of research, the protein content ranged from 11.8 to 12.4 t/ha, with the maximum value observed in the mineral and organo-mineral fertilization variants.

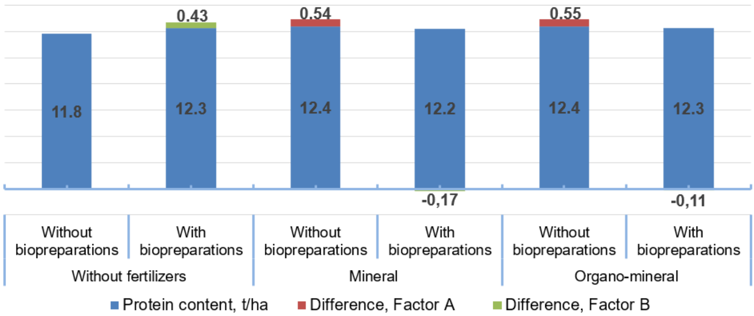

Fig. 3. Protein content in buckwheat fruits depending on fertilization systems and biopreparations, t/ha, 2011-2024. LSD_{05} t/ha: Factor A = 0.56; Factor B = 0.46; Factors AB = 0.80

It is possible that the fertilization systems presented in this work are not optimal for improving the quality of buckwheat yields, and this issue requires further study.

However, we have demonstrated that both the fertilization systems and the use of biopreparations determined the fat content in buckwheat fruits, and the effect of these nutrients had both positive and negative impacts. Thus, under mineral nutrition and the use of biopreparations, the fat content in the fruits was highest at 5.21 t/ha, which exceeded the control by 0.32 t/ha (Figure 4).

However, incorporating the crop residues of the previous culture with the same rate of mineral fertilizers and seed inoculation had a reverse effect: fat content decreased by 0.25 t/ha, making it the lowest in our experiments at 4.97 t/ha.

Growing buckwheat with mineral and organo-mineral fertilization systems without using a biopreparation did not significantly affect the quality of the fruits regarding fat content.

Chemical analysis of seeds for starch content showed that the factors we studied significantly influenced this indicator (Figure 5).

However, it was interesting to note that fertilization systems without the use of biopreparations, both mineral and organo-mineral, negatively affected the quality of buckwheat fruits, with starch content decreasing by 1.06 t/ha and 0.60 t/ha, respectively, compared to the control where this indicator was 53.0 t/ha.

Seed treatment before sowing with a biopreparation in different fertilization systems, especially without the use of fertilizers and in the mineral fertilization system, provided the greatest increase in starch content, +0.78 t/ha and +0.56 t/ha, respectively.

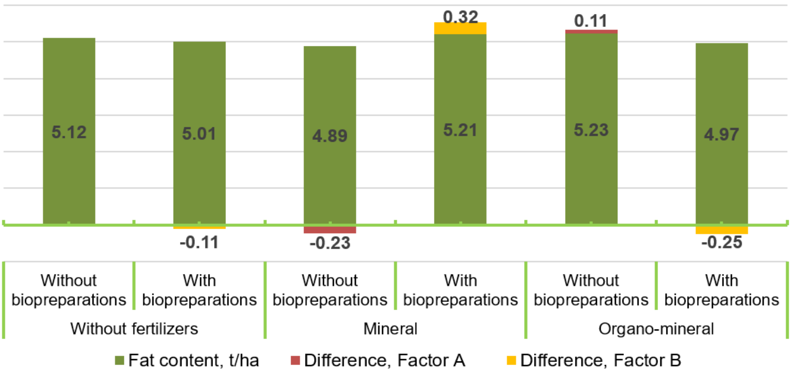

Fig. 4. Fat content in buckwheat fruits depending on fertilization systems and biopreparations, t/ha, 2011-2024. LSD_{05} t/ha: Factor A = 0.24; Factor B = 0.20; Factors AB = 0.34

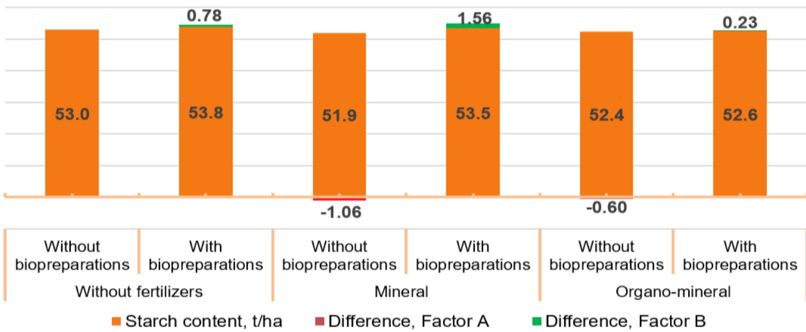

Fig. 5. Starch content in buckwheat fruits depending on fertilization systems and biopreparations, t/ha, 2011-2024. LSD_{05} t/ha: Factor A = 0.24; Factor B = 0.20; Factors AB = 0.34

Thus, the introduction of additional nutrients into the soil of mineral and biological origin, combined with the action of active microorganisms present in the biopreparations, increases the carbohydrate content, such as starch, in buckwheat fruits. No changes were established regarding protein content in the fruits under the influence of various nutrient elements. Seed treatment of buckwheat before sowing with a biopreparation when using mineral and organo-mineral fertilization systems had an opposite effect: in the first variant, there was a significant increase in fat content, while in the second, a decrease in this indicator was observed.

5. The influence of fertilization systems and biopreparations yield of grain units, feed units, and digestible protein units from main and by-products of buckwheat in the conditions of the Northern Steppe of Ukraine

The yield of grain, feed units, and digestible protein from main and additional products allows for the assessment of the effectiveness of agricultural crop cultivation. This is important for production planning and the optimization of agricultural technologies. Determining these indicators is crucial for scientific research in the field of agronomy, as it enables the study of the impact of various factors (soil, climate, cultivation technologies) on yield and product quality.

Thus, these indicators are key for managing agro-industrial production, ensuring food security, and increasing the efficiency of agriculture.

The yield of grain units from buckwheat harvest can vary depending on many factors, such as climate, sowing date, fertilization system, predecessor crop, variety, agronomic conditions during the growing season, soil cultivation, and others[35]. Typically, the yield of grain units from buckwheat fruits and leaf-stem mass is approximately 0.8-1.2 t/ha, while the yield of feed units can be around 0.9-1.0 feed unit per 1 kg of grain[36].

In our experiments, the content of grain units in the main and by-products of buckwheat averaged between 1.84-2.81 t/ha. Over 14 years of research, we also observed a trend towards a decrease in buckwheat productivity, which can be attributed to harsher weather conditions during the growing season. The highest yield of grain units was recorded in 2011-2015, ranging from 2.30 to 3.08 t/ha, while during the third rotation, these figures dropped to 1.35-2.48 t/ha (Table 2).

The organo-mineral fertilization system provided the highest yield of grain units at 2.62 t/ha, with an increase of 0.78 t/ha or 42.3% compared to the control. The largest increase in feed units with the use of biopreparations was observed in the system without fertilizers, amounting to 0.26 t/ha or 13.9%. Growing buckwheat against the background of an organo-mineral fertilization

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[35] Mashchenko O., Kriuchko L., Bordun R., Podhaietskyi A., Sobran I., Davydenko G., Toryanik V., Hnitetskyi M., Kuz'menko R. The formation of indicators of the quality of buckwheat grain depending on the elements of Technology. *Modern Phytomorphology*. 18: 12–16. https://www.phytomorphology.com/articles/the-formation-of-indicators-of-the-quality-of-buckwheat-grain-depending-on-the-elements-of-technology.pdf

[36] Mashchenko Yu.V., Sokolovska I.M. Buckwheat productivity depends on fertilizer system and seed inoculation with biopreparation. *Таврійський науковий вісник:* Сільськогосподарські науки. 2023. № 133. 54–63. https://doi.org/10.32782/2226-0099.2023.133.8

system combined with seed inoculation with biopreparations ensured the highest yield of grain units at 2.81 t/ha and contributed to maintaining crop productivity under changing climate conditions.

In our experiments, we tracked the trend regarding the influence of the factors we studied on buckwheat productivity with respect to feed unit yield (Table 3).

Table 2

The yield of grain units in the main and by-products of buckwheat depending on fertilization systems and biopreparations, t/ha, 2011-2024

Fertilizer system, Factor A	Bioprepa-rations, Factor B	Average for 1st rotations, 2011-2015	Average for 2nd rotations, 2016-2020	Average for 3rd rotations, 2021-2024	Average for 2011-2024	Difference, Factor A		Difference, Factor B	
						t/ha	%	t/ha	%
Without fertilizers	Without bioprepa-rations	2.30	1.77	1.35	1.84	–	–	–	–
	With bioprepa-rations	2.59	1.94	1.67	2.09	–	–	0.26	13.9
Mineral	Without bioprepa-rations	2.65	2.16	1.91	2.26	0.42	23.0	–	–
	With bioprepa-rations	2.96	2.48	2.12	2.55	0.45	21.6	0.29	12.7
Organo-mineral	Without bioprepa-rations	2.83	2.64	2.32	2.62	0.78	42.3	–	–
	With bioprepa-rations	3.08	2.79	2.48	2.81	0.71	34.0	0.19	7.3
LSD_{05}	Factor A	0.12	0.22	0.23	0.11	–	–	–	–
	Factor B	0.10	0.16	0.18	0.09	–	–	–	–
	Factors AB	0.18	0.31	0.32	0.15	–	–	–	–

Table 3

The yield of feed units in the main and by-products of buckwheat depending on fertilization systems and biopreparations, t/ha, 2011-2024

Fertilizer system, Factor A	Bioprepa-rations, Factor B	Average for 1st rotations, 2011-2015	Average for 2nd rotations, 2016-2020	Average for 3rd rotations, 2021-2024	Average for 2011-2024	Difference, Factor A		Difference, Factor B	
						t/ha	%	t/ha	%
Without fertilizers	Without biopreparations	2.89	2.22	1.70	2.31	–	–	–	–
	With biopreparations	3.26	2.44	2.09	2.63	–	–	0.32	13.9
Mineral	Without biopreparations	3.33	2.71	2.40	2.84	0.53	23.0	–	–
	With biopreparations	3.72	3.11	2.67	3.20	0.57	21.6	0.36	12.7
Organo-mineral	Without biopreparations	3.56	3.32	2.91	3.29	0.98	42.3	–	–
	With biopreparations	3.87	3.51	3.11	3.53	0.90	34.0	0.24	7.3
LSD_{05}	Factor A	0.16	0.27	0.28	0.13	–	–	–	–
	Factor B	0.13	0.22	0.23	0.11	–	–	–	–
	Factors AB	0.22	0.38	0.40	0.19	–	–	–	–

There is limited data on buckwheat productivity analysis, possibly because this crop is primarily used for human consumption and less for forage purposes; therefore, our results significantly differ from existing data. In our experiments, these indicators ranged from 2.31 t/ha to 3.53 t/ha, with the highest values obtained when using the organo-mineral fertilization system combined with biopreparation seed treatment.

The yield of digestible protein units in buckwheat products ranged on average from 0.18 t/ha to 0.28 t/ha. As with the analysis of previous indicators, we observed a decrease in the yield of digestible protein over the years of research, with higher levels also observed when using the organo-mineral fertilization system and biopreparations. The fertilization system had the greatest influence on the yield of digestible protein (+23.0% and +42.3%) (Table 4).

Table 4

The yield of digestible protein in the main and by-products of buckwheat depending on fertilization systems and biopreparations, t/ha, 2011-2024

Fertilizer system, Factor A	Bioprepa-rations, Factor B	Average for 1st rotations, 2011-2015	Average for 2nd rotations, 2016-2020	Average for 3rd rotations, 2021-2024	Average for 2011-2024	Difference, Factor A		Difference, Factor B	
						t/ha	%	t/ha	%
Without fertilizers	Without bioprepa-rations	0.23	0.18	0.13	0.18	–	–	–	–
	With bioprepa-rations	0.26	0.19	0.17	0.21	–	–	0.03	13.9
Mineral	Without bioprepa-rations	0.26	0.21	0.19	0.23	0.04	23.0	–	–
	With bioprepa-rations	0.29	0.25	0.21	0.25	0.05	21.6	0.03	12.7
Organo-mineral	Without bioprepa-rations	0.28	0.26	0.23	0.26	0.08	42.3	–	–
	With bioprepa-rations	0.31	0.28	0.25	0.28	0.07	34.0	0.02	7.3
LSD_{05}	Factor A	0.01	0.02	0.02	0.01	–	–	–	–
	Factor B	0.01	0.02	0.02	0.01	–	–	–	–
	Factors AB	0.02	0.03	0.03	0.02	–	–	–	–

Thus, based on the results of fourteen years of research, we established a systematic decrease in buckwheat productivity from 2011 to 2024, regardless of agronomic elements. The most significant reductions in yields of grains, feed units, and digestible protein units occurred when growing the crop without fertilizers. The application of an organo-mineral fertilization system combined with seed inoculation with biologically active preparations allowed us to mitigate the negative impact of environmental factors and achieve an average of 2.81 t/ha yields of grain units, 3.53 t/ha of feed units, and 0.28 t/ha of digestible protein units over three rotations.

6. Analysis of the chemical composition of soil in crop rotations with different sets of crops depending on fertilization systems in the conditions of the Northern Steppe of Ukraine

The relevance of the issue of utilizing by-products of crop production to enhance and maintain soil fertility in modern agriculture in Ukraine is beyond doubt. In recent years, the question of organic matter and the humus state of soils has gained global significance[37]. It raises particular concern in Ukraine under conditions of a global economic crisis.

The total amount of nutrients lost and not returned to the soil amounts to 4 million tons of nitrogen alone, which is equivalent to 12 million tons of ammonium nitrate or nearly 67 billion cubic meters of gas. By the way, municipal services (with the population) use 32 billion cubic meters of gas, of which the population consumes 22-23 billion[38]. Therefore, an important question arises regarding the preservation of the chemical and organic composition in the soil and ensuring that plants receive nutrients to enhance their productivity.

The main feature of the soil cover in the area of the research is ordinary chernozem transitioning to deep chernozem, which lies on plateaus and gentle slopes of various exposures and predominantly has a heavy clay mechanical composition.

According to the soil monitoring data from the Kirovohrad branch of the State Soil Protection Service of Ukraine, the arable layer of soil contains an average of 3.70% humus, 117 mg of easily hydrolyzable nitrogen, 92 mg of mobile phosphorus, and 137 mg of exchangeable potassium per 1 kg of soil, as well as mobile forms of manganese, zinc, and boron at 9.6, 0.65, and 1.51 mg per kilogram of soil, respectively. Chernozem soils are primarily characterized by a neutral to near-neutral reaction of the soil solution and do not require chemical amelioration[39].

In our experiments, buckwheat was grown in a five-field grain-row rotation with a 40% soybean saturation, alternating crops as follows: soybean, winter wheat, soybean, maize for grain, and buckwheat. Considering the

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[37] Bot A. The importance of soil organic matter. Food and agriculture organization of the United Nations. *Rome*. 2005. 80 p. https://www.fao.org/4/a0100e/a0100e.pdf

[38] Дегодюк С. Е., Дегодюк Е. Г., Проненко М. М., Ігнатенко Ю. О., Пипчук Н. М., Мулярчук А. О. Ефективність застосування відновлюваних місцевих ресурсів за органічного землеробства: науково-методичні рекомендації. Вінниця: ТОВ «ТВОРИ». 2020. 48 p. https://zemlerobstvo.com/wp-content/uploads/2021/04/30-renewable-local-resources.pdf

[39] Матеріали моніторингу ґрунтів зі Степового інституту сільського господарства НААН, 2021. 48 p.

biological and physiological characteristics of the crops, their nutrient requirements, and the structure of the crop rotation, we conducted an analysis of the impact of fertilization systems on the chemical composition of the soil in different crop rotations. For comparison the crop rotation that included buckwheat, we chose a classic five-field grain-fallow-crop rotation typical for the northern Steppe of Ukraine with a 20% soybean saturation and alternating crops: clean and occupied fallow, winter wheat, soybean, maize for grain, and sunflower.

Domestic and foreign studies have convincingly demonstrated and substantiated that nitrogen plays a key role in increasing the yield of agricultural crops. Among all the elements required for plants in mineral nutrition, nitrogen occupies a dominant position. No nutrient element limits food supplies on our planet as much as nitrogen does. In agronomic practice, nitrogen is referred to as the growth element. This is because all growth processes, photosynthesis, and metabolism would be impossible without nitrogen, as it forms the yield and improves the biochemical indicators of its quality.

The main role of nitrogen lies in its being a structural component of nitrogen-containing organic compounds and actively participating in all vital metabolic processes that occur in plants throughout their entire growing period. The exclusion of nitrogen from the nutrient environment leads to a significant deficiency in raw and dry plant mass[40].

The content of ammonium and nitrate nitrogen is a dynamic indicator that constantly changes and largely depends on weather conditions, air and water regimes of soils, as well as microbiological activity.

Nitrate nitrogen is very accessible to plants and is used for photosynthesis and growth. Nitrates exist in the soil as water-soluble salts. Nitrate ions are not adsorbed by soil colloids; therefore, remaining in a constantly dissolved state, they move through the soil profile along with water. This process is influenced by the amount of precipitation, the timing and form of applied nitrogen fertilizers, as well as soil properties related to its granulometric composition (permeability and water-holding capacity). Nitrogen in nitrate form is easily absorbed by plants; therefore, this indicator characterizes the soil's supply of mineral nitrogen[41].

Our research has established that over ten years, in both studied crop rotations, in variants without fertilizers and with a mineral fertilization system have led to a decrease in the content of nitrate nitrogen in the soil. The greatest losses were observed in variant without fertilizers in the intensive classical grain-fallow-crop rotation, amounting to 2.67 mg/kg of soil over two

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[40] Крамарьов С. М., Крамарьов О. С., Демиденко В. Г., Хорошун К. О., Пісоцький С. С., Бондарь В. Ю., Рубан С. М., Цуркан К. П. Роль азоту в живленні рослин. *Агроном*. 2024. https://www.agronom.com.ua/rol-azotu-v-zhyvlenni-roslyn/

[41] Форми азоту в ґрунті: нітратна, амонійна та легкогідролізована. *Farmer.ua*. https://farmer.ua/publications/formi-azotu-v-grunti-nitratnij-amonijnij-ta-legkogidrolizovanij/

rotations. In the grain-row rotation with an organo-mineral fertilization system, the increase in nitrate nitrogen content was 0.06 mg/kg of soil. In the grain-fallow-crop rotation, under the organo-mineral fertilization system, there was the highest increase in nitrate nitrogen, which amounted to 0.69 mg/kg of soil, and compared to the grain-row rotation, it increased by 0.63 mg/kg of soil (Table 5).

Ammonium nitrogen in the soil is represented in the form of water-soluble salts, exchangeable ammonium, and non-exchangeable ammonium as part of the soil-absorbing complex (SAC). Gradually, ammonium is oxidized by microorganisms to nitrates. Ammonium ions (NH4) enter the soil along with fertilizers or are formed as a result of ammonification during the decomposition of organic compounds. Due to its composition characteristics, it is gradually assimilated by plants, including at low air temperatures[42].

Conducting a chemical analysis of soil for ammonium nitrogen content indicates that over ten years, there has been an increase in this indicator in both studied crop rotations and all fertilization systems, including the treatment without fertilizers. It should be noted that this migratory form of nitrogen in the grain-fallow-crop rotation increased the most when using mineral and organo-mineral fertilization systems by 2.05 and 2.07 mg/kg of soil, respectively. In the grain-row rotation, the highest increase in ammonium nitrogen content over two rotations was observed in the treatment without fertilizers, amounting to 2.51 mg/kg of soil. Comparing the ammonium nitrogen content in different crop rotations, we found that the greatest increase occurred in the variant without fertilizers (0.74 mg/kg of soil) and when used the mineral fertilization system (0.01 mg/kg of soil) compared to the grain-crop rotation. The use of additional crop residues (leaf-stem mass of sugar corn and pea straw in occupied fallow) and mineral fertilizers in the grain-fallow-crop rotation contributed to obtaining a greater increase in ammonium nitrogen; specifically, comparing organo-mineral fertilization systems between crop rotations, the increase amounted to 0.27 mg/kg of soil (Table 5).

One of the main factors affecting soil fertility is phosphorus management. Phosphorus is essential for plant nutrition and development – it participates in all physiological processes and ensures the effective use of other nutrients. Due to its chemical properties, phosphorus has a complex nature of interaction with various soil components, resulting in a large number of different forms, reactions, compounds, and complexes in which it can exist in the soil. This significantly complicates the assessment of phosphorus availability in soils for plant nutrition[43].

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[42] Фандалюк А. Вміст гумусу в ґрунтах низької зони закарпатської області. Рослинництво (Садівництво, Виноградарство, Насінництво). 2023. 1–2: 24–27. https://doi.org/10.47279/Plantscience_2023-01-5

[43] Балюк С. А., Носко Б. С., Шимель В. В., Єтеревська Л. В., Момот Г. Ф. Оптимізація живлення рослин у системі факторів ефективної родючості ґрунтів. *Вісник аграрної науки*. 2019, 3(792): 12–19, https://agrovisnyk.com/pdf/ua_2019_03_02.pdf

Chemical analyses of phosphorus in the soil obtained after the completion of the second rotation indicate that in the grain-fallow-crop rotation, a positive balance of P_2O_5 was achieved over 10 years on various nutritional backgrounds, with the maximum increase in P_2O_5 content in the soil observed on the mineral fertilization system, amounting to +4.72 mg/100 g of soil (Table 5). In the crop rotation where sunflower was replaced with buckwheat and the fallow field with soybean, the changes in phosphorus content in the soil were somewhat different. Under natural plant nutrition, the balance of P_2O_5 was negative, decreasing by 2.06 mg/100 g of soil over 10 years, while the application of fertilizers had a positive effect. However, it should be noted that under mineral fertilization, the content of P_2O_5 increased by only 0.48 mg/100 g of soil; incorporating crop residues allowed for an increase of this substance to 2.24 mg/100 g of soil. Thus, it can be concluded that the introduction of short-rotation crop rotations, which include buckwheat, may contribute to improving the chemical composition of the soil, specifically increasing the content of P_2O_5 when using an organo-mineral fertilization system. However, this issue requires further research.

The multifaceted positive role of potassium fertilizers in producing high-quality food products and maintaining soil fertility is noted in the works of many researchers. Its total content in the soil significantly exceeds that of nitrogen and phosphorus. Therefore, the application of potassium fertilizers is sometimes given secondary importance. However, with a significant deficiency of potassium balance in the soil, we inherit increased soil absorption capacity, and in some cases, there arises a need to substantially increase fertilizer doses to create a sufficient level of potassium nutrition for plants[44,45].

The analysis of the chemical composition of soil samples for potassium content (Table 5), conducted by us in two crop rotations, allows us to highlight the advantages of the rotation that includes buckwheat. Over two rotations, the potassium content in the soil increased by 10.23 mg/100 g of soil with the use of mineral and organo-mineral fertilization systems, and by 3.21 mg/100 g of soil, respectively. A positive balance of K2O was also noted in the fertilization system without fertilizers, at +9.69 mg/100 g of soil, but this variant was inferior to the crop rotation without buckwheat in its structure (11.42 mg/100 g of soil). As a result, we see that growing buckwheat in a five-field crop rotation contributes to improving the chemical composition of the soil in the conditions of Northern Steppe Ukraine when using mineral and

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organo-mineral fertilization systems; K2O content increases by 2.78 mg/100 g of soil and by 0.54 mg/100 g of soil, respectively.

One of the more important indicators characterizing the level and conditions for reproducing fertility is the humus content in the soil[46]. The increase in humus content is a long-term process, while its decrease occurs extremely quickly. The issue of humus is extremely relevant worldwide since prolonged rains or drought periods and meager norms of organic fertilizers due to reduced livestock numbers do not compensate for the loss of humus from the soil[47]. Therefore, organizational-territorial conditions for land use created during intra-farm land management should promote not only an increase in crop yields and production intensification but also a steady increase in soil fertility, maintaining a positive humus balance within it and preserving its productive capacity.

Ten-year monitoring results on soil quality in the conditions of Northern Steppe Ukraine confirm the general problem of decreasing humus content in the arable layer. Our research indicates that this trend is observed in crop rotations of varying structure and crop saturation, and no specific pattern was established between the decrease in this indicator and fertilization systems (Table 5). It may be necessary to increase the share of biological components in fertilization systems or make changes to the structure of crop rotations with short rotation periods to enhance humus balance.

Table 5

Changes in the chemical composition and humus content in the soil depending on crop rotation and fertilization system, 2010-2020

Crop rotation	Fertilizer system	NO_3, mg/kg of soil			NH_4, mg/100 g of soil			P_2O_5, mg/100 g of soil			K_2O, mg/100 g of soil			Humus, %		
		2010	2020	Difference 2020-2010	2010	2020	Difference 2020-2010	2010	2020	Difference 2020-2010	2010	2020	Difference 2020-2010	2010	2020	Difference 2020-2010
Grain-fallow-row, soy saturation 20%	Without fertilizer	4.35	1.68	-2.67	0.45	2.22	1.77	14.57	15.68	1.11	11.41	22.82	11.42	5.43	3.61	-1.82
	Mineral	4.97	3.01	-1.96	0.55	2.60	2.05	17.37	22.09	4.72	12.92	20.36	7.44	5.45	4.01	-1.44
	Organic-mineral	3.86	4.55	0.69	0.54	2.61	2.07	17.68	18.96	1.28	13.45	16.12	2.67	5.53	4.04	-1.49
Grain-row. soy saturation 40% (with buckwheat)	Without fertilizer	4.61	3.00	-1.61	0.53	3.04	2.51	17.60	15.54	-2.06	11.63	21.32	9.69	5.33	3.63	-1.70
	Mineral	4.82	3.74	-1.08	0.57	2.63	2.06	20.45	20.92	0.48	13.80	24.02	10.23	5.36	3.66	-1.70
	Organic-mineral	5.02	5.08	0.06	0.75	2.55	1.80	19.36	21.60	2.24	13.77	16.98	3.21	5.37	3.81	-1.56
Difference between grain-fallow-row and grain-row crop rotations	Without fertilizer	0.26	1.32	1.06	0.08	0.82	0.74	3.03	-0.14	-3.17	0.22	-1.50	-1.72	-0.10	0.02	0.12
	Mineral	-0.15	0.73	0.88	0.02	0.03	0.01	3.07	-1.17	-4.24	0.88	3.66	2.78	-0.10	-0.35	-0.25
	Organic-mineral	1.16	0.53	-0.63	0.21	-0.06	-0.27	1.68	2.64	0.96	0.32	0.86	0.54	-0.16	-0.23	-0.07

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CONCLUSIONS

A decrease in buckwheat yield was observed every five years, especially during the period of 2011-2020 (by 0.33-0.35 t/ha). From 2011 to 2024, the difference in yield indicators between the second and third rotations was 0.16-0.28 t/ha.

With the use of a mineral fertilization system, grain yield increased by 0.28 t/ha or 23.0%, while with the organo-mineral system, it increased by 0.52 t/ha or 42.3%. The degree of influence of biopreparations was lower than that of fertilization systems: without fertilizers, the yield increase was 13.9%, with the mineral system it was 12.7%, and with the organo-mineral system it was 7.3%. The highest yield was obtained when growing buckwheat under the organo-mineral fertilization system combined with seed inoculation with a biopreparation, reaching 1.87 t/ha.

A significant impact of the fertilization systems and biopreparations on the protein content in buckwheat grains was established. On average, this indicator ranged from 11.8 to 12.4 t/ha. The factors we studied had both positive and negative effects on the fat content in buckwheat grains: with the use of a mineral fertilization system, a significant decrease in fat content was noted, -0.23 t/ha compared to the system without fertilizers (5.12 t/ha); under the organo-mineral system, this indicator increased to 5.23 t/ha and was maximum in the experiment. A higher positive degree of influence of the biopreparation on fat content in grains was noted in the mineral fertilization system, +0.32 t/ha of fat, while in the organo-mineral system, an opposite effect was observed, 0.25 t/ha. A significant increase in starch was noted with the use of biopreparations without fertilizers and in the mineral fertilization system, 58.3 t/ha (+0.78 t/ha) and 53.5 t/ha (+1.56 t/ha), respectively. Without seed inoculation, fat content in grains was 0.6-1.06 t/ha lower.

A trend towards a decrease in buckwheat productivity, as well as yield, was observed over the 14 years of research. At the same time, higher average indicators were found when using the organo-mineral fertilization system and with biopreparations: 2.81 t/ha yield of grain units, 3.53 t/ha yield of feed units, and 0.28 t/ha yield of digestible protein units.

Over two rotations of five-field crop rotations, the use of an organo-mineral fertilization system contributed to an increase in nitrate nitrogen content in the soil in the crop rotations we studied. The highest increase was obtained in the grain-fallow-row crop rotation, which amounted to 0.69 mg/kg of soil; in the rotation where sunflower was replaced with buckwheat, this indicator decreased by 0.63 mg/kg of soil. The use of a grain-row crop rotation contributed to an increase in ammonium nitrogen content without fertilizers by 2.51 mg/100 g of soil over ten years.

Growing buckwheat in five-field short-rotation crop rotations may contribute to improving the chemical composition of the soil, specifically increasing P_2O_5 content with the use of an organo-mineral fertilization system (+0.96 mg/100 g of soil). The use of mineral and organo-mineral fertilization systems contributed to an increase in K_2O content by 2.78 mg/100 g of soil and by 0.54 mg/100 g of soil, respectively.

The results of a decade-long study confirm the trend towards a decrease in humus content in crop rotations of varying structure and crop saturation; moreover, no specific pattern was established between the decrease in this indicator and fertilization systems.

SUMMARY

The research results demonstrate a trend towards a decrease in the yield and productivity of buckwheat over the fourteen years. Growing buckwheat under the mineral fertilization system contributed to a higher yield of 0.28 t/ha or 23.0%, while under the organo-mineral system, it increased by 0.52 t/ha or 42.3%. The degree of influence of biopreparations was lower than that of fertilization systems, ranging from 7.3% to 13.9%. The highest yield was obtained when growing buckwheat with the organo-mineral fertilization system combined with seed inoculation before sowing with a biopreparation, reaching 1.87 t/ha.

Higher average productivity indicators were observed with the organo-mineral fertilization system and the use of biopreparations: 2.81 t/ha yield of grain units, 3.53 t/ha yield of feed units, and 0.28 t/ha yield of digestible protein units.

No significant impact of the fertilization systems and biopreparation on the protein content in buckwheat grains was established. A higher positive degree of influence of the biopreparation on fat content in the grains was noted in the mineral fertilization system, with an increase of +0.32 t/ha of fat. A significant increase in starch content in buckwheat grains was observed only with the use of biopreparations without fertilizers and under the mineral fertilization system, measuring 58.3 t/ha (+0.78 t/ha) and 53.5 t/ha (+1.56 t/ha), respectively.

The highest increase in nitrate nitrogen was found in the grain-fallow-cultivated crop rotation, amounting to 0.69 mg/kg of soil; ammonium nitrogen in the crop rotation with buckwheat amounted to 2.51 mg/100 g of soil without fertilizers. An increase in P_2O_5 content was noted in the fertilized variants in both crop rotations, as well as K_2O across all fertilization systems. The results of the decade-long studies confirm the trend towards a decrease in humus content in crop rotations of varying structure and crop saturation; moreover, no specific pattern was established between the decrease in this indicator and fertilization systems.

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