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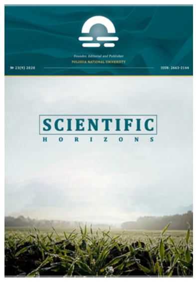

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Efficiency of organic technologies of winter rye cultivation in Ukraine's Polissya in the context of climate change adaptation

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Abstract. In the conditions of the Polissya region of Ukraine, the cultivation of winter rye in organic farming is promising, but it is constrained by low crop yields. Therefore, the urgent task is to find ways to improve the efficiency of the fertilisation system of this traditional Polissya crop. The purpose of the study was to analyse the feasibility of using liquid complex fertilisers against the background of three fertilisation systems for organic and convection cultivation of winter rye in the conditions of Ukrainian Polissya. Field, laboratory and analytical, mathematical and statistical research methods were used. The results of a stationary experiment on light grey forest soil were analysed. It was found that the highest yield of winter rye was when grown using convection technology with a mineral fertilisation system – 4.2 t/ha, which provided an increase in grain yield of 1.07 t/ha or 34.4% compared to the control option. The use of organic

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technology based on organic and organo-mineral fertilisation systems provided a significantly smaller increase – 0.6 and 0.75 t/ha or 19.3 and 24.0%, respectively. However, the level of profitability for the mineral system decreased by 0.54 thousand UAH/tonne or 39.1%, net operating profit – by 1.6 thousand UAH/tonne or 26.0% compared to the organic fertilisation system. The latter was also better from the standpoint of energy efficiency. It is proved that double foliar top dressing with liquid organo-mineral fertilisers significantly increases the efficiency of the fertilisation system. In the conditions of the experiment, this was expressed in an additional increase in productivity by 0.47-1.16 t/ha, a reduction in the cost of production by 0.14-0.36 thousand UAH/ha, an increase in profitability by 19.3-48.3%, energy efficiency – by 0.14-0.71, and the plasticity of the crop to dry conditions during the growing season. The findings can become the basis for improving the fertilisation system for organic cultivation of winter rye, which would ensure the formation of sustainable yields by minimising the impact of stress factors (dry periods during the growing season) and increase the economic efficiency of grain production in agricultural enterprises of various forms of ownership

Keywords: corganic farming; short-term crop rotation; fertilisation systems; liquid organo-mineral fertilisers; plasticity of winter rye; profitability level; energy efficiency coefficient

INTRODUCTION

The dominant soil types in Ukraine's Polissya region are those of light particle size distribution, characterised by unfavourable agrophysical and physicochemical parameters, very low nutrient supply, and low energy potential. This is a serious obstacle to the development of organic farming in Polissya. This situation forces agricultural producers to saturate crop rotations with low-margin crops that are not demanding to soil fertility. Therefore, it is important to maximise the potential of winter rye in organic farming of this agricultural soil zone, primarily by increasing the efficiency of the fertilisation system for this crop.

Rye is more tolerant to growing conditions compared to other winter cereals, which allows effectively cultivating it in the Polissya region. Research by Avramenko *et al.* (2022) found that rye is able to absorb nutrients from poorly available forms and can be successfully grown on soils with low natural fertility. Due to its high resistance to agrocenosis and plasticity to environmental conditions, this crop is often placed on poor soils due to unsuccessful predecessors, optimal sowing times are neglected, and fertilisers are not used. However, as noted by Nelson *et al.* (2011) and Hayden *et al.* (2012), the crop, even at late sowing dates, has time to accumulate enough plastic substances, is able to form a shrub well in early spring, effectively use spring moisture reserves, and develop a sufficient productive stem. One of the ways to solve the problem of increasing the yield and economic efficiency in the cultivation of winter rye is the mandatory inclusion in the technological process of foliar top dressing with complex fertilisers containing the main macro- and microelements. Goenadi *et al.* (2018) note that the requirements for the economic efficiency of the use of complex fertilisers are increasing every year. Wilier *et al.* (2020) also emphasise economic priorities when applying biological factors to the intensification of agricultural production. At the same time, studies by Karasiuk & Khomchak (2005), Martinez-Alcantara *et al.* (2016) proved that the more complex the soil and climate, and weather conditions, the more important the role of biologisation in crop cultivation technologies. According to Didiek *et al.* (2018), Bargaz *et al.* (2018), Stamenković *et al.* (2018), biological preparations are able to activate the viability of beneficial epiphytic and, especially, saprophytic microflora, which inhibit the development of pathogenic organisms by 25-30% and contribute to better assimilation of mobile phosphorus and nitrogen by plants. Mc Guire (2017) notes that liquid complex microfertilisers and biologics contribute to improving the quality of agricultural products obtained, primarily by improving the root nutrition of plants. As stated by Kysil (2005) and Gunes *et al.* (2015), there is a close correlation between plant growth and the intensity of biophilic element uptake. Therefore, it is of great importance to establish patterns of influence of various types of fertilisers and preparations on this process. The value of such research increases in the organic farming system. As noted by Jezierska-Thöle *et al.* (2017), Reganold *et al.* (2016), Muller *et al.* (2017), efficient organic production should be based on energy-efficient soil protection technologies, intensifying the circulation of substances, improving the quality of food and living conditions of people. Equally important, according to Stovolos (2014), Klonsky (2012), is the introduction of sustainable crop rotations, the widespread use of plant residues, manure and compost, perennial legumes and green manure crops. However, Seufert *et al.* (2012), Freyer *et al.* (2019) suggest that a serious deterrent to the expansion of areas under organic farming is, first of all, the widespread belief that the rejection of mineral fertilisers and chemical protection products would lead to a rapid decline in yields.

The purpose of the study was to evaluate the influence of foliar top dressing with liquid complex fertilisers on organic and convection cultivation of winter rye in Ukraine's Polissya on the formation of high and stable yields, which is relevant in the context of climate change.

MATERIALS AND METHODS

The stationary experiment "Development and evaluation of biologisation elements in the farming system in Polissya", in which the research was carried out, started in 2010 (experimental field of Polissya National University, Chernyakhivskyi district, Zhytomyr Oblast). The period of 2014-2016 was analysed. It included a 5-field crop rotation, which was deployed on light grey forest soil, characterised by a low supply of macronutrients and general humus, and a slightly acidic reaction (pH_{KCl}=4.8). The area of the sown plot was 130 m^2, and the accounting area – 110 m^2. The repetition of the experiment was threefold. Field, laboratory and analytical, mathematical and statistical research methods were used. Statistical processing of the results was performed according to Dospekhov (1985) using *Statistica* 10.0 software suite, the collection and accounting of the main and by-products was carried out in sections at full grain ripeness.

Sowing was carried out with high-yield seeds of the Khlibne variety. The technology of growing winter rye was up to the principles of organic production and was adapted for the Polissya zone. The main tillage was carried out with disk tools. The predecessor was potatoes. To assess the effectiveness of liquid organo-mineral fertilisers against the background of the use of various fertilisation systems for winter rye, the results of a two-factor stationary experiment were analysed:

Factor A Fertilisation system: 1. Biological control (without fertilisers); 2. Organic system (aftereffect of manure applied to potatoes at a rate of 50 t/ha); 3. Organo-mineral system (50% organic fertilisers and 50% fertilisers of mineral origin); 4. Mineral fertilisation system ($N_{50}P_{40}K_{70}$ directly under the crop). In the biological control variant, fertilisers were not applied, however, post-harvest residues remained in the field to simulate an agroecosystem with minimal human intervention. In the organic system, no fertilisers were applied directly to winter rye, but the aftereffect of the 1st year of applying litter manure under the predecessor was used. Notably, the fertilisation systems are balanced in terms of nutrition elements and according to the organo-mineral system, part of organic fertilisers (50% of the need for biophilic elements) was replaced with minerals of natural origin ($N_{20}P_{10}K_{30}$ directly under the crop), which are used in organic farming: nitrogen in the form of urea, phosphorous – phosphorite, and potash – kainite. Straw after harvesting grain crops remained in the field and was subsequently incorporated into the soil. The mineral fertilisation system provided for the application of fertilisers of chemical origin: simple granular superphosphate (20% a.s.), potassium chloride (51% a.s.), ammonium nitrate (34% a.s., for pre-sowing cultivation). The total need for fertilisers was determined when developing a stationary experiment scheme, considering the agrochemical characteristics of light grey forest soil, its absorption capacity, and biological features of crop rotation crops. To optimise the *C:N* ratio in the soil, nitrogen fertilisers were additionally applied at the rate of 10 kg/t of straw to accelerate the process of straw degradation.

Factor B. Liquid complex fertilisers (LCF): 1. Control; 2. Mochevyn-K No. 1 (1 l/ha); 3. Mochevyn K No. 2 (1 l/ha); 4. Organik D-2M (1 l/ha); 5. Potassium humate (2 l/ha).

Foliar top dressing of winter rye crops with liquid complex fertilisers was performed twice during the growing season (according to the experiment scheme and recommendations for their use): the first application was carried out in the phase of entering the tube, the second – after 14 days. In the control, water spraying was carried out in parallel. The studied preparations are listed in the relevant state registers (State register of pesticides…, 2022; Havran *et al.*, 2022). Mochevyn-K No. 1 (1 l/ha) is recommended by the manufacturer to improve the development of the root system, plant biomass, and improvement of the immune system. Fertiliser contains 11-13% N, 0.1-0.3% P_2O_5, 0.05-0.15% K_2O, trace elements (0.1%), and succinic acid (0.1%). Mochevyn-K No. 2 (1 l/ha) contains 9-11% N, 0.5-0.7% P_2O_5, 0.05-0.15% K_2O, 3 g/l of sodium humate, 1 g/l of potassium humate, 1 g/l of a complex of trace elements. This fertiliser is recommended to increase the resistance of plants to drought, the development of additional shoots and accelerate maturation. Organik D-2M (1 l/ha) contains 2.0-3.0% N, 1.7-2.8% P_2O_5, 1.3-2.0% K_2O, 2.0-6.0% total calcium, 65-70% organic substances (in terms of carbon) and is recommended for strengthening plant immunity to various diseases, increasing seed germination energy, reducing the conversion rate of nitrates, heavy metals and radionuclides in plants, enhancing soil microbiological activity. Potassium humate (2 l/ha) contains macronutrients (*NPK*), a complex of trace elements (0.3-2.5 g/l) and is recommended for enhancing plant resistance to frost, drought, their better growth and development (State register of pesticides…, 2022; Havran *et al.*, 2022).

RESULTS AND DISCUSSION

The analysis of crop yield in 2014 showed that the highest result was provided by the conventional mineral fertilisation system, where, on the variant without the use of preparations, the increase was 1.71 t/ha or 72.5% compared to the indicator that was achieved on biological control (2.36 t/ha). On this version of the fertilisation system, Mochevyn-K2 and Organik D-2M preparations worked best, which provided the highest yield in the experiment – 5.00 and 4.94 t/ha, respectively.

Under the conditions of the organic fertilisation system, where the crop used only the aftereffect of manure, which was applied under the predecessor, the yield on the version without the use of preparations was 3.00 t/ha. The introduction of preparations provided an increase in the yield at the level of 3.67-3.83 t/ha. The lowest rates were recorded when using the Mochevyn-K1 preparation. The organo-mineral fertilisation system on the variant without the use of preparations provided an increase in yield of 1.42 t/ha or 60.2% compared to the biological control. The use of liquid organo-mineral fertilisers significantly improved the indicator. The highest yield on this agricultural background was recorded when using Organik D-2M and Mochevyn-K2 – 4.70 and 4.98 t/ha, respectively.

The highest cost of the obtained products in the experimental conditions in 2014 was recorded for the mineral fertilisation system and the use of liquid organo-mineral fertilisers Mochevyn-K2 and Organik D-2M – 15.00 and 14.82 thousand UAH/ha, respectively. This trend was also observed in the organo-mineral system. The lowest production costs for growing winter rye were recorded on biological control and organic system (5.12 and 5.04 thousand UAH/ha, respectively), and the highest – on mineral system (8.16 thousand UAH/ha). The highest level of profitability in the cultivation of winter rye in the first year of research was with the use of the organic system. This is conditioned by the fact that the culture used the aftereffect of manure, which was introduced under the potatoes. Treatment of crops with liquid complex fertilisers has increased the efficiency of this fertilisation system. The highest level of profitability was obtained with the use of Mochevyn-K2 – 123%, Organik D-2M – 120%. Moreover, a high level of profitability of these preparations was achieved in the organo-mineral system – 124 and 111%, respectively.

In 2015, the yield level was significantly higher. On biological control, the increase was 1.23 t/ha or 52.1%. This is primarily conditioned by more favourable weather conditions during the formation of the winter rye crop. In the experiment, the highest yield was obtained under the mineral fertilisation system – 4.39 t/ha, which is 0.8 t/ha or 22.3% more than under biological control. With the use of preparations, the advantage of the fertilisation system has increased. At the same time, the best result was provided by Mochevyn-K2 and potassium humate – 5.59 t/ha and 5.67 t/ha, respectively. The organo-mineral system also provided a high yield increase relative to biological control – 0.44 t/ha or 12.3%. When using Mochevyn-K2 and Organik D-2M against the background of the organo-mineral system, the increments were 1.14 and 1.47 t/ha, respectively, or 28.3 and 36.5% relative to the control.

Analysis of the results of the economic efficiency of fertilisation systems showed that the highest cost of the products was recorded on the variants where crops were treated with Mochevyn-K2 and potassium humate against the background of the mineral system – 16.77 and 17.01 thousand UAH/ha, respectively. However, the cost of cultivation here was also the largest – 8.19 thousand UAH/ha, which is 3 thousand UAH/ha or 58.7-59.0% more than on the organic system variant. Slightly lower indicators were recorded under the conditions of the organo-mineral system with the treatment of crops by Organik D-2M and Mochevyn-K2. Net operating profit was the largest under the organic system – an increase in biological control amounted to 1.54 thousand UAH/ha, or 26.7%. Preparations also provided an improvement in the indicator. Thus, under the organic system, liquid organo-mineral fertilisers Organik D-2M and Mochevyn-K2 provided the net operating profit at the level of 9.72 and 9.81 thousand UAH/ha, which is 33.2 and 34.4% more than in the control. Under the influence of the organo-mineral system, these preparations provided an increase in net operating profit by UAH 3.28 and 4.26 thousand, or 59.1 and 76.8%, respectively. The highest level of profitability under the organic system is conditioned by the fact that rye used the aftereffect of manure to form the crop, and the cost of its application was attributed to the technological costs of the previous crop (potatoes). For the same reason, rather high profitability indicators are characteristic of the organo-mineral fertilisation system.

In 2016, the yield was lower compared to the previous year. Thus, in biological control, the indicator decreased by 0.17 t/ha or 4.7%. This is conditioned by the difficult weather conditions during the critical period of crop development, since according to the hydrothermal coefficient (HTC) in the phases of entering the tube, flowering, formation and maturation of grain, they were characterised as arid. According to the organic system, the yield increase in the control was 0.65 t/ha or 19.0%, organo-mineral – 0.39 t/ha (11.4%), and mineral – 0.71 t/ha (20.8%). The effectiveness of the preparations under different fertilisation systems was not clear. According to the organic system, foliar top dressing with Mochevyn-K No. 2 and Organik D-2M preparations was the most effective – the increase in the indicator was 0.52 t/ha (12.8%) and 0.68 t/ha (16.7%), respectively. According to the organo-mineral system, the advantage of these preparations remained – an increase relative to the control – 0.79 t/ha (20.7%) and 1.09 t/ha (28.6%), respectively. Under the mineral fertilisation system, the highest yield increase relative to the control was recorded for treatment with Mochevyn-K2 and potassium humate preparations – 1.07 t/ha (25.9%) and 1.24 t/ha (30.0%), respectively.

The highest net operating profit without the use of preparations was obtained under the organic fertilisation system – 7.18 thousand UAH/ha, which is 36.8% more than with biological control. Under foliar top dressing with Organik D-2M and Mochevyn-K2 preparations, the indicator increased by 1.43 thousand UAH/ha or 19.9% and 1.91 thousand UAH/ha or 26.6% relative to the control, respectively. For the organo-mineral system, the advantage of these preparations remained – for treatment with Organik D-2M, the increase relative to the control of the system was 3.12 thousand UAH/ha or 63.8%, and Mochevyn-K2 – 2.23 thousand UAH/ha or 45.6%. In the third year of the study, the profitability level was highest for the organic system – from 143% for the control to 176% with the use of preparations.

In general, for three years of research, the advantage of Mochevyn-K2 and Organik D-2M preparations in terms of yield was indisputable against the background of all fertilisation systems studied in the experiment (Table 1). Thus, against the background of various fertilisation systems for foliar top dressing with liquid complex fertilisers (LCF) Mochevyn-K2, the increase was 21.1-26.9%, and Organik D-2M – 19.5-29.9%.

***Table 1**. The yield of winter rye depending on fertilisation systems and preparations (average for 3 years) in the short-term crop rotation in Polissya*

Fertilisation system	Preparation	Yield, t/ha	Deviations				Variation coefficient
			by fertilisation systems		by preparations		
			±	%	±	%	
1. Biological control	Control	3.12±0.75*	–	–	–	–	21.34
2. Organic system	Control	3.73±0.71	0.60	19.3	–	–	16.90
	Mochevyn-K1	4.20±0.58	–	–	0.47	12.6	12.28
	Mochevyn-K2	4.51±0.68	–	–	0.79	21.1	13.32
	Organik D-2M	4.46±0.69	–	–	0.73	19.6	13.71
	Potassium humate	4.40±0.65	–	–	0.68	18.2	13.04
3. Organo-mineral system	Control	3.87±0.70	0.75	24.0	–	–	15.89
	Mochevyn-K1	4.54±0.70	–	–	0.67	17.2	13.70
	Mochevyn-K2	4.92±0.66	–	–	1.04	26.9	11.95
	Organik D-2M	5.03±0.75	–	–	1.16	29.9	13.23
	Potassium humate	4.62±0.54	–	–	0.74	19.2	10.41
4. Mineral system	Control	4.20±0.72	1.07	34.4	–	–	15.24
	Mochevyn-K1	4.80±0.66	–	–	0.60	14.4	12.14
	Mochevyn-K2	5.26±0.68	–	–	1.07	25.4	11.35
	Organik D-2M	5.02±0.66	–	–	0.82	19.5	11.66
	Potassium humate	5.22±0.58	–	–	1.03	24.5	9.77

***Note:** *M±m – confidence interval*
***Source:** compiled by the authors*

On average, over 3 years of research, the organic system without the use of LCF provided an increase in yield at the level of 0.6 t/ha or 19.3%, organo-mineral – 0.75 t/ha or 24.0%, and mineral – 1.07 t/ha or 34.4% relative to biological control. Foliar top dressing with Mochevyn-K2 and Organik D-2M against the background of various fertilisation systems provided an increase in yield by 0.73-1.16 t/ha or 19.5-29.9% relative to the corresponding control variants. The highest productivity was provided by agricultural technologies based on the mineral fertilisation system and foliar top dressing with Mochevyn-K2 and potassium humate – 5.27±0.68 t/ha and 5.23±0.58 t/ha, respectively.

A significant level of variation in yield in the context of years of research is conditioned by the influence of weather conditions, the share of influence of which on the indicator reached 23% (Fig. 1). For comparison, the share of exposure to fertilisation systems was 41%, and top dressing with liquid complex fertilisers was 19%. As the statistical analysis of crop yield results showed, the degree of influence of the weather factor on agricultural technologies was not the same. However, an interesting pattern can be traced. Thus, biological control recorded a strong level of variation in the yield of winter rye over the years of research (21.3%). The use of fertilisation systems with the treatment of crops with LCF significantly reduced the level of variability of the indicator. It can be assumed that improving the level of nutrition of the crop and, especially, the use of LCFs contributed to increasing the resistance of the variety to arid conditions in 2016. Although this comparison is somewhat conditional, it confirms the conclusions of researchers about the positive effect of liquid and mineral fertilisers on protecting crops from adverse weather conditions during the growing season (Semenjuk, 2017; Drobek *et al.*, 2019).

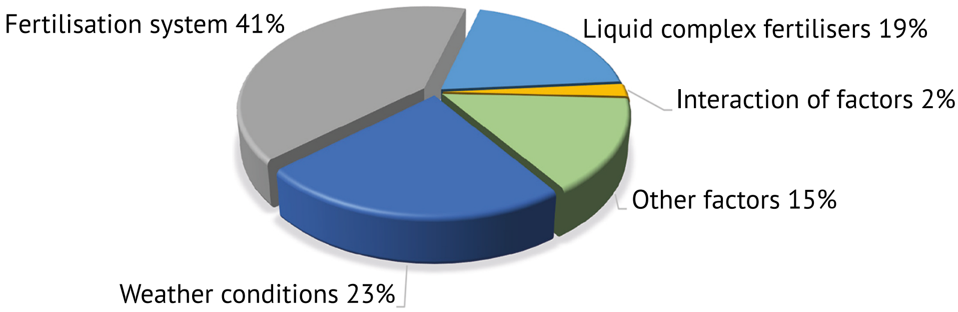

***Figure 1**. Share of influence of factors on the yield of winter rye during the observation period*
***Source:** compiled by the authors*

In general, for 3 years of research, the lowest technological costs for growing winter rye on control variants were observed for organic and organo-mineral fertilisation systems – 5.03 and 6.54 thousand UAH/ha. For the mineral system without the use of preparations, costs increased by UAH 3.03 thousand/ha, or 60.5% relative to biological control. The highest net operating profit was obtained for the organo-mineral system with the use of Organik D-2M – 8.41 thousand UAH/ha (Fig. 2).

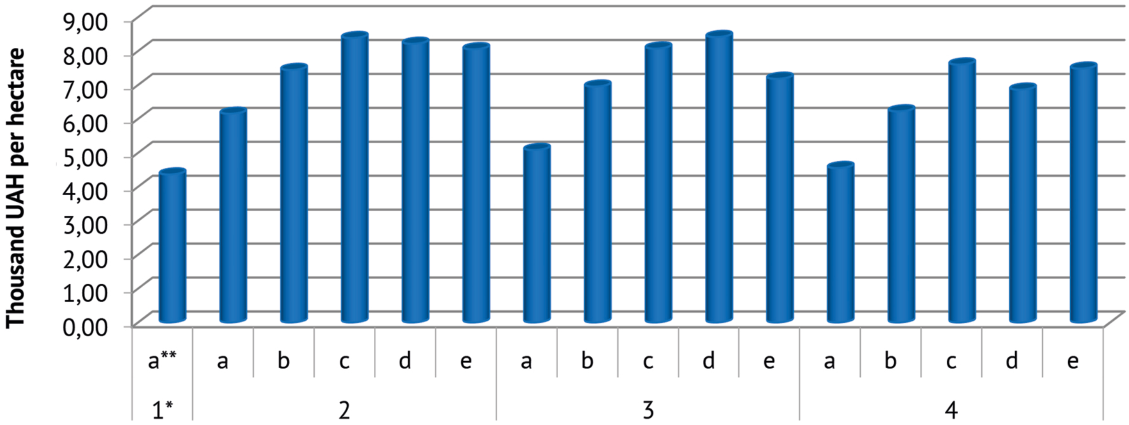

***Figure 2**. Net operating profit for growing winter rye depending on fertilisation systems and preparations (average for 3 years)*
***Note:** *Fertilisation systems: 1 – Biological control; 2 – Organic system; 3 – Organo-mineral system; 4 – Mineral system. **Liquid complex fertilisers: a – control; b – Mochevyn-K1; c – Mochevyn-K2; d – Organik D-2M; e – potassium humate*
***Source:** compiled by the authors*

The mineral fertilisation system, although it provided high productivity of the crop, but the increase in the cost of its cultivation compared to alternative organic systems significantly reduced the economic attractiveness of agricultural technologies based on it, which was manifested in a decrease in net operating profit and profitability. Thus, on the option without the use of preparations for the mineral system, the lowest level of net operating profit was recorded (4.55 thousand UAH/ha), which is 26% lower than for the organic system.

On average, for three years of research, the lowest cost of winter rye was recorded for the organic fertilisation system – 1.38 thousand UAH/t, which is 0.28 thousand UAH/t or 17% less than for biological control (Fig. 3). For the mineral system, the prime cost increased by 0.26 thousand UAH/t, or 15.5%, compared to absolute control. In general, under the organic system, the cost of winter rye grain was 0.54 thousand UAH/t, or 39.1% lower than under the mineral fertilisation system. With the foliar application of liquid organo-mineral fertilisers Mochevyn K1 and Organik D-2M, the indicator decreased, respectively, by 16.0-19.4% and 14.8-21%, depending on the system.

The use of an organic system contributed to an increase in the profitability of growing crops by 35.3% compared to the control (Fig. 4). For convection cultivation, there was a significant decrease in the indicator for all variants of the mineral fertilisation system. Without the use of liquid complex fertilisers, the profitability of grain production on this system was 65.7% lower than on the organic system. Liquid organo-mineral fertilisers significantly improved the economic efficiency of growing crops in all fertilisation systems. Thus, in particular, the use of Mochevyn-K2 and Organik D-2M provided an increase in net operating profit by 2.06-3.33 thousand UAH/ha or 33.5-67.0% relative to the control options with water treatment.

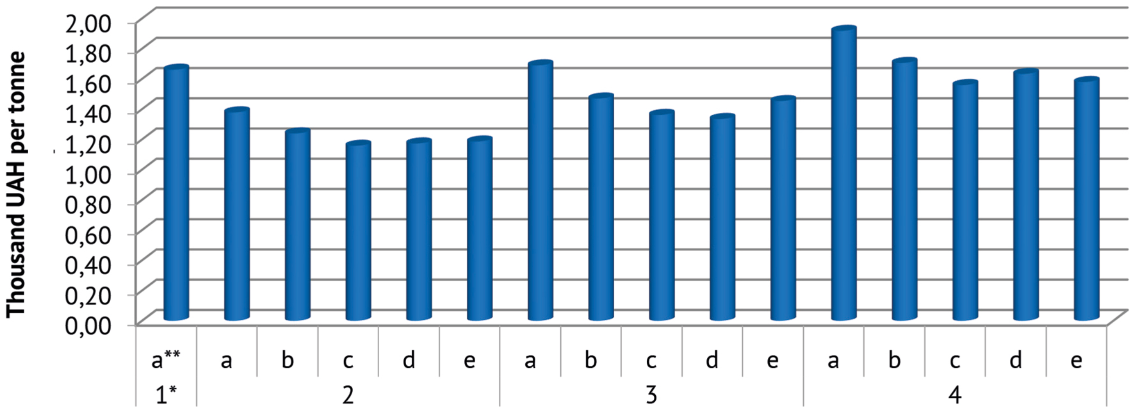

Figure 3. *Cost of winter rye depending on fertilisation systems and preparations (average for 3 years), thousand UAH/t*
Note: **Fertilisation systems: 1 – Biological control; 2 – Organic system; 3 – Organo-mineral system; 4 – Mineral system. **Liquid complex fertilisers: a – control; b – Mochevyn-K1; c – Mochevyn-K2; d – Organik D-2M; e – potassium humate*
Source: *compiled by the authors*

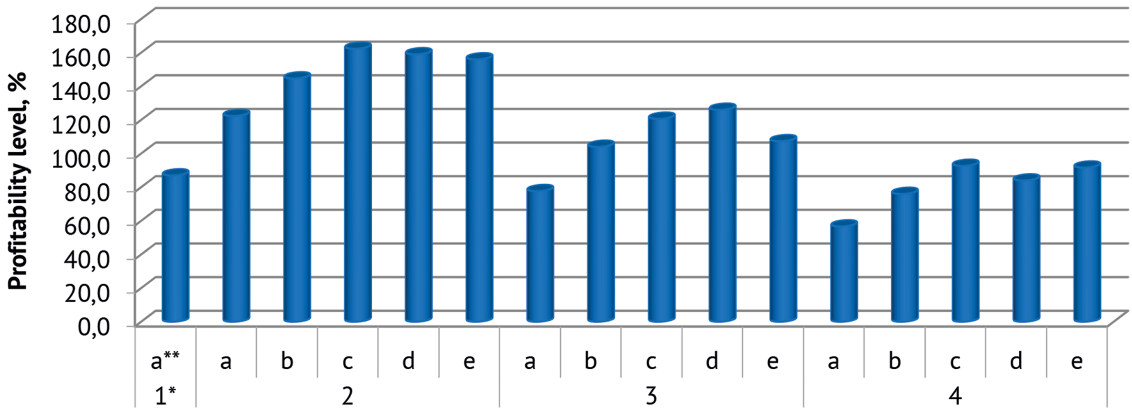

Figure 4. *Profitability level of growing winter rye depending on fertilisation systems and liquid complex fertilisers (average for 3 years), %*
Note: **Fertilisation systems: 1 – Biological control; 2 – Organic system; 3 – Organo-mineral system; 4 – Mineral system. **Liquid complex fertilisers: a – control; b – Mochevyn-K1; c – Mochevyn-K2; d – Organik D-2M; e – potassium humate*
Source: *compiled by the authors*

Along with the economic one, the energy analysis of cultivation technologies is no less important. It was found that during the research period, agricultural technologies provided a high level of energy efficiency, since the accumulation of total energy in the crop significantly exceeded the total energy costs for production (Table 2). Thus, even on biological control, the energy efficiency coefficient was 3.74±0.91. For the mineral fertilisation system in the control, the indicator improved by only 6.6%, and for the organo-mineral system – by 11.8% compared to the biological control. The organic system was the best from the standpoint of energy, providing an increase in the energy efficiency coefficient by 19.3%. Top dressing with complex preparations contributed to an increase in the indicator by 3.5-13.5% for the mineral system, 4.8-16.1% for the organo-mineral system, and 7.8-15.9% for the organic system.

Table 2. *Indicators of energy efficiency of winter rye cultivation in short-term crop rotation of Polissya*

Fertiliser variant	Liquid complex fertiliser	Energy output, GJ	Energy efficiency ratio
1. Biological control	Control	52.19±12.6	3.73±0.9
2. Organic system	Control	62.27±11.91	4.45±0.85
	Mochevyn-K1	70.13±5.97	4.8±0.41
	Mochevyn-K2	75.42±11.36	5.16±0.78
	Organik D-2M	74.47±11.55	5.09±0.79
	Potassium humate	73.58±10.86	5.03±0.74

Table 2, Continued

Fertiliser variant	Liquid complex fertiliser	Energy output, GJ	Energy efficiency ratio
3. Organo-mineral system	Control	64.72±2.58	4.17±0.17
	Mochevyn-K1	75.86±3.1	4.37±0.18
	Mochevyn-K2	82.16±5.49	4.73±0.32
	Organik D-2M	84.11±7.87	4.84±0.45
	Potassium humate	77.14±7.34	4.44±0.42
4. Mineral system	Control	70.13±3.22	3.98±0.18
	Mochevyn-K1	80.21±3.62	4.12±0.19
	Mochevyn-K2	87.95±5.67	4.52±0.29
	Organik D-2M	83.83±1.89	4.3±0.1
	Potassium humate	87.28±10.12	4.48±0.52

Source: *compiled by the authors*

The highest energy efficiency in the experiment was provided by agricultural technologies that provided for the use of an organic system and foliar top dressing of LCF Mochevyn-K No. 1 (*Kee*=5.16) and Organik D-2M (*Kee*=5.09).

Considering the characteristics of zonal and other soils common in Polissya and the recommendations of Solovei *et al.* (2018) regarding the ecological and genetic suitability of Ukrainian soils for organic production, it was found that the land fund of Polissya (except for massifs of light loamy granulometric composition) is not suitable for organic farming. Based on the study by Solovei *et al.* (2018), 50.4% of Polissya's soil cover was classified as poorly suitable, 45.5% as conditionally suitable, and only 4.1% as suitable for organic farming. The authors note that the zonal soils of Polissya are characterised by a high return on mineral fertilisers, which sharply reduces the organic coefficient. However, the approach to assessing fitness proposed by Solovei *et al.* (2018) is rather conditional. Thus, according to Grycenko (2020), the development of organic farming in the zone has significant potential, especially when growing winter rye and introducing an effective organic fertilisation system. This is confirmed by the authors of this study (Kravchuk *et al.*, 2021).

Research by Yavorskaya *et al.* (2006) substantiated the need for foliar leaf feeding of plants with microelements in the phases of intensive growth and development and, especially, in stressful situations (low temperatures, drought). Januskaitiene *et al.* (2021), Karasiuk & Khomchak (2005) note that microlements, which are part of liquid organo-mineral fertilisers, activate the course of many physiological and biochemical processes, in particular, increase the intensity of photosynthesis, activate the action of enzymes, enhance hydrocarbon metabolism, which determines the resistance of the crop to stressful situations during dry periods during the growing season. According to Bargaz *et al.* (2018), an important condition for improving the effectiveness of such fertilisers is to consider the biological characteristics of the crop, the method of their application, and the timing. Popko *et al.* (2018), Gunes *et al.* (2015), Antille *et al.* (2013) emphasise that the effectiveness of liquid complex fertilisers significantly depends on the temperature regime and moisture regime during the growing season and the state of the soil ecosystem. During the research period, it was found that the hydrothermal conditions of the growing season had a significant impact on the course of biochemical processes occurring in plants. This is confirmed by the relevant biochemical studies by Januskaitiene *et al.* (2021). Similar results were obtained by Kalenska (2004). The researcher notes that fluctuations in crop yield by year can reach 40-60%, depending on weather conditions (Kalenska, 2004).

The positive effect of organic fertilisation on increasing the resistance of cereals in critical years of moisture supply, which was recorded during the research period, was also noted by Januskaitiene *et al.* (2021). The researchers point to a significant increase in the production of enzymatic antioxidants by spring barley plants, as well as a decrease in the rate of photosynthesis in dry years with organic fertiliser than with the mineral system. In addition, as noted by Sivojiene *et al.* (2021), Zikeli & Gruber (2017) long-term mineral fertilisation significantly impoverishes the species biodiversity of soil microorganisms. This leads to the establishment of niches for the acclimatisation of pathogenic organisms and a decrease in the resistance of cultivated plants to stressful factors.

Notably, the study was carried out under a soil-saving tillage system. The expediency of using such a processing system is substantiated in the studies by Galich & Strelchenko (2004), Veremeienko & Semenko (2019), Kadžienė *et al.* (2011). This was confirmed by previous research (Kravchuk *et al.*, 2021). Moreover, previous studies (Kravchuk *et al.*, 2021) found that winter rye can be effectively grown without the use of herbicides, since it is characterised by a high tillering coefficient and an intensive increase in biomass, which causes weed suppression. The same conclusions were obtained by Reddy (2003) and Cavigelli *et al.* (2008).

Kravchuk *et al*. (2021) have found that with the long-term use of soil-protective agricultural technologies, positive changes in the agroecological state of the root layer of light grey forest soil occurred. This was manifested in a significant improvement in certain biological (humus content and biological activity of the soil), agrophysical (structure), and water and physical (supply of productive moisture) indicators. However, in terms of the impact on crop yields of crop rotation, the advantage of long-term use of no-till methods of basic cultivation in the experiment was manifested only if a fertilisation system was used.

CONCLUSIONS

For 3 years of research in short-term crop rotation, the highest productivity of winter rye was observed when growing crops using convection technology with a mineral fertilisation system – 4.2 t/ha. This fertilisation system provided a grain increase of 1.07 t/ha or 34.4% relative to the control option. When using organic cultivation technology based on an organic fertilisation system in crop rotation, the yield increase was 0.6 t/ha or 19.3%, and organo-mineral – 0.75 t/ha or 24.0%. Foliar top dressing with liquid complex fertilisers significantly increased the efficiency of these fertilisation systems, providing an additional yield increase of 0.47-1.16 t/ha or 12.6-29.9%. The highest yield gains were provided by the use of Mochevyn-K2 and Organik D-2M fertilisers.

The share of influence of weather conditions on crop yield during the research period was 23%. The variation of yields in different years of water supply significantly decreased when using fertilisation systems with treatment of crops with liquid complex fertilisers, which is especially relevant in the context of adaptation to climate change.

The most economically and energetically expedient method in the experiment was to grow crops using organic technologies based on organic (aftereffect of manure) and organo-mineral fertilisation systems (with the introduction of 5 t/ha of manure per 1 ha of crop rotation area and $N_{12}P_{10}K_{25}$, incl. $N_{20}P_{10}K_{30}$ directly under the crop) and foliar top dressing with Organik D-2M. These technologies provided net operating profit at the level of 8.21 and 8.41 thousand UAH/ha, profitability – 159 and 126%, energy efficiency coefficient – 5.09 and 4.84, respectively, which significantly exceeded the corresponding indicators for convection cultivation of winter rye.

The prospects for further research are related to the search for new effective liquid complex fertilisers and, especially, biologics for organic cultivation of winter rye, which would reduce the impact of stress factors in dry periods during the growing season, ensure stable yields, and contribute to increasing the economic efficiency of grain production in economic and production facilities of various forms of ownership.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Ефективність органічних технологій вирощування жита озимого в умовах Полісся України у контексті адаптації до змін клімату

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Анотація. В умовах Полісся України вирощування жита озимого у органічному землеробстві є перспективним, проте стримується низькими врожаями культури. Тому актуальним завданням є пошук шляхів підвищення ефективності системи удобрення цієї традиційної поліської культури. Метою досліджень було проаналізувати доцільність застосування рідких комплексних добрив на фоні трьох систем удобрення за органічного та конвекційного вирощування жита озимого в умовах Полісся України. Було використано польові, лабораторно-аналітичні, математико-статистичні методи досліджень. Було проаналізовано результати стаціонарного досліду на ясно-сірому лісовому ґрунті. Встановлено, що найвища урожайність жита озимого була за вирощування за конвекційною технологією з мінеральною системою удобрення – 4,2 т/га, яка забезпечила приріст зерна 1,07 т/га або 34,4% до контролю по досліду. Застосування органічної технології на основі органічної і органо-мінеральної систем удобрення забезпечило значно менший приріст – 0,6 і 0,75 т/га або 19,3 і 24,0%, відповідно. Однак, рівень рентабельності за мінеральної системи скоротився на 0,54 тис. грн/т або 39,1%, умовно чистий прибуток – на 1,6 тис. грн/т або 26,0% порівняно з органічною системою удобрення. Остання була кращою і з енергетичної точки зору. Доведено, що двократне позакореневе підживлення рідкими органо-мінеральними добривами суттєво підвищує ефективність системи удобрення. В умовах досліду це виражалось у додатковому прирості продуктивності на 0,47–1,16 т/га, зниженні собівартості на 0,14–0,36 тис.грн/га, підвищенні рентабельності на 19,3–48,3%, енергетичної ефективності – на 0,14–0,71 та пластичності культури до посушливих умов протягом вегетації. Наукові результати можуть стати основою для вдосконалення системи удобрення за органічного вирощування жита озимого, що забезпечить формування сталих врожаїв за рахунок мінімізації впливу стресових чинників (посушливі періоди протягом вегетації) та підвищити економічну ефективність виробництва зерна у агроформуваннях різних форм власності

Ключові слова: органічне землеробство; короткоротаційна сівозміна; системи удобрення; рідкі органо-мінеральні добрива; пластичність жита озимого; рівень рентабельності; коефіцієнт енергетичної ефективності