UDC 631.582:631.8:633.1
DOI https://doi.org/10.32848/agrar.innov.2026.35.29

INFLUENCE OF THE CROP ROTATION FACTOR AND FERTILIZATION SYSTEMS ON PRODUCTIVITY, QUALITY INDICATORS AND ECONOMIC EFFICIENCY OF WINTER WHEAT

MASHCHENKO Yu.V. – Candidate of Agricultural Sciences, Senior Researcher
orcid.org/0000-0001-7965-0193
Institute of Agriculture of the Steppe of National Academy of Agrarian Sciences of Ukraine
SOKOLOVSKA I.M. – Candidate of Agricultural Sciences, Associate Professor
orcid.org/0000-0003-4256-8852
Kherson State Agrarian and Economic University
SHEVCHENKO T.V. – Candidate of Agricultural Sciences, Senior Researcher
orcid.org/0000-0001-9488-0325
Institute of Potato Growing of National Academy of Agrarian Sciences of Ukraine

Problem Statement. Modern grain production requires increasing the productivity of winter wheat as a strategic food crop while simultaneously preserving soil fertility and ensuring the economic efficiency of agricultural production. Growing demand for grain and fluctuations in market prices highlight the need to optimize technological elements of cultivation, primarily fertilization systems and crop placement within crop rotations, which directly affect yield and grain quality [5]. Long-term field experiments demonstrate that combining organic and mineral fertilizers and optimizing crop rotation structure can significantly increase grain crop productivity, in particular providing yield gains of 35–54% compared with less effective nutrition systems [10]. At the same time, it has been established that the preceding crop in rotation and the level of fertilization can substantially alter wheat productivity: for example, after legumes, grain yields exceeded those after cereal predecessors and increased under combined fertilization [1]. Despite existing findings, the complex effects of the interaction between crop rotation factors and fertilization systems under specific soil and climatic conditions remain insufficiently studied, which necessitates further research to develop scientifically grounded cultivation technologies for winter wheat.

Analysis of Recent Research and Publications. The issue of optimizing agrotechnological elements of winter wheat cultivation occupies a leading place in modern agricultural research, since this crop is a fundamental component of food security and a strategic object of agricultural production. Scientific publications indicate that yield level and grain quality are formed under the combined influence of biological, agrochemical, and technological factors, among which the fertilization system and the crop's position in rotation are of particular importance [1, 6, 8, 10].

Studies from long-term stationary field experiments have proven that balanced mineral nutrition ensures stable increases in cereal yields and maintains soil fertility, especially with prolonged application of complete mineral fertilizers. These results confirm that agrochemical factors have long-lasting effects and determine the productivity of agroecosystems over time [1]. At the same time, it is emphasized that fertilization efficiency largely depends on crop rotation structure, since different preceding crops create unequal conditions for mineral nutrition and the phytosanitary status of the soil [11, 12].

The significant influence of preceding crops in rotation on winter wheat yield is confirmed by numerous experiments. It has been established that after legumes, perennial grasses, and row crops, grain yield and quality are higher compared with repeated cereal sowings, which is explained by improved soil nitrogen regimes, enhanced soil structure, and reduced spread of pathogens [9, 10, 17].

Researchers also note that an optimal crop rotation can partially compensate for insufficient mineral nutrition, which is particularly important under conditions of limited resources or rising fertilizer costs [10, 16].

In the works of Ukrainian scientists, considerable attention is paid to evaluating different fertilization systems – mineral, organic, and combined. It has been shown that combining organic and mineral fertilizers not only increases yield but also improves soil physicochemical properties, increases humus content, and stabilizes agroecosystem productivity in the long term [4, 6, 7]. Some studies emphasize the role of foliar feeding and micronutrient fertilizers in improving grain quality, particularly increasing protein and gluten content, which is important for the technological value of the product [13, 14, 15].

An important aspect of modern research is the economic efficiency of fertilization systems and crop rotations. Scientific studies demonstrate that optimizing fertilizer application rates not only increases yields but also ensures maximum economic return through rational resource use and reduced production costs [4, 16]. It has been established that the most economically efficient systems are those combining medium or optimal doses of mineral fertilizers with organic nutrient sources and scientifically grounded crop rotations.

Recent scientific publications also show growing interest in integrated approaches to managing agroecosystem productivity that consider not only agrochemical factors but also climate change, varietal adaptability, and technological innovations [3, 11].

The use of mathematical models and machine-learning methods to predict yields confirms the complexity of interactions between environmental factors and cultivation technology and indicates the need for a comprehensive approach to evaluating the effectiveness of agrotechnologies [2, 14].

Thus, analysis of the scientific literature shows that the crop rotation factor and fertilization system are interrelated components of winter wheat cultivation technology that jointly influence yield formation, grain quality indicators, and the economic efficiency of production. At the same time, despite the large number of studies, the issue of optimizing the combination of these factors under specific soil and climatic conditions remains insufficiently explored, which substantiates the need for further research in this direction.

Objective. The aim of the study was to determine the influence of crop rotation factors and different fertilization systems on productivity, grain quality indicators, and the economic efficiency of winter wheat cultivation, as well as to substantiate optimal agrotechnological measures to increase yield and production profitability under the conditions of the Northern Steppe of Ukraine.

Materials and methods. The main research methods were field and laboratory-field experiments. To scientifically substantiate the objective and accomplish the set tasks, as well as to generalize experimental results, the following methods were used: the hypothesis method (selection of research direction, determination of relevance, development of experimental schemes); the dialectical method (observation of crop development and yield formation processes); the synthesis method (generalization of results and formulation of conclusions); the analysis method (assessment of adaptability of the studied objects to growing conditions); the induction method (drawing conclusions based on identification of the best treatments); and mathematical statistics (determination of factor significance, experimental accuracy, and correlations).

The studies were conducted from 2016 to 2025 in a scientific crop rotation at the Institute of Agriculture of the Steppe of NAAS of Ukraine. The soil and climatic conditions of the site correspond to those of the Northern Steppe zone of Ukraine.

A two-factor field experiment was established: factor A – short-rotation crop rotations; factor B – fertilization systems.

Short-rotation crop rotations:

– Grain–row crop rotation No. 1, soybean saturation up to 60% with the following sequence: soybean, winter wheat, soybean, grain maize, soybean;

– Grain–row crop rotation No. 2, soybean saturation 40% with the sequence: soybean, winter wheat, soybean, grain maize, buckwheat;

– Grain–fallow–row crop rotation No. 3, soybean saturation up to 20 %, consisting of: clean and occupied fallow, winter wheat, soybean, grain maize, sunflower. In the occupied fallow, peas were sown with mineral fertilizers applied at a rate of $N_{30}P_{30}K_{30}$.

The fertilization system was designed so that on average over the rotation, $N_{40}P_{40}K_{40}$ was applied per crop in fertilized treatments, without exceeding recommended fertilizer rates for the study zone.

Fertilization systems:

– **biologized fertilization system** – seed **inoculation** with a biological preparation before sowing;

– **mineral fertilization system** (crop rotation No. 1 – $N_{90}P_{60}K_{60}$; crop rotation No. 2 – $N_{70}P_{40}K_{40}$; crop rotation No. 3 – $N_{50}P_{20}K_{20}$);

– **mineral-biological fertilization system** with seed **inoculation** before sowing + (crop rotation No. 1 – $N_{90}P_{60}K_{60}$; crop rotation No. 2 – $N_{70}P_{40}K_{40}$; crop rotation No. 3 – $N_{50}P_{20}K_{20}$);

– **organo-mineral system** ($N_{60}P_{30}K_{30}$ + $N_{60}P_{30}K_{30}$ applied to the crop replacing fallow + by-products of the preceding crop);

– **organo-mineral biologized system** with seed **inoculation** before sowing + ($N_{60}P_{30}K_{30}$ + $N_{60}P_{30}K_{30}$ applied to the crop replacing fallow + by-products of the preceding crop).

Weather conditions in autumn 2015 were relatively favorable for the growth and development of winter cereals. Conditions during 2016–2017 were unfavorable during critical water-consumption periods of winter wheat. Ripening and completion of vegetation occurred under good heat supply but limited soil moisture due to lack of precipitation.

Weather conditions during the 2018–2019 growing seasons were generally favorable for winter wheat. Under moderate temperatures and sufficient precipitation in the autumn–winter period, early spring vegetation recovery was observed, accompanied by gradual temperature increases and sufficient soil moisture in spring.

The winter of 2019–2020 was very warm, with a precipitation deficit and no snow cover. Summer 2020 weather in Kirovohrad region was generally dry. Despite rainy periods early in summer, total seasonal precipitation was below normal – 66 mm or 36 % of the norm. The average air temperature during the calendar summer was 22.5 °C, which is 3 °C above normal.

Weather conditions during 2020–2021 were insufficiently favorable for obtaining high productivity of winter wheat.

Conditions during the growing seasons of 2022 and 2023 were favorable, with moderate temperature increases and sufficient soil moisture reserves in spring and summer.

Weather conditions in 2024 and 2025 were favorable for obtaining high productivity indicators of winter wheat.

The seeding rate of winter wheat was 4.5 million seeds/ha.

During 2016–2018, the variety Shestopalivka (winter wheat bred by Ukrainian breeders and entered into the State Register of Plant Varieties Suitable for Dissemination in Ukraine in 2007, recommended for cultivation in central and southern regions) was sown. In 2019–2025, the variety Oranta Odeska (Ukrainian winter wheat variety entered into the register in 2017 and recommended for cultivation in the Forest-Steppe, Polissia, and Steppe zones of Ukraine) was used.

The following biological preparations were applied in the experiment: Polymyxobacterin (1 ha/portion) during 2016–2018, intended to improve phosphorus nutrition of wheat (equivalent to applying 30–60 kg of active ingredient of mineral phosphorus fertilizers); Mycofriend (1.5 L/t) during 2021–2025, developed on the basis of mycorrhiza-forming fungi and phosphate-mobilizing bacteria and containing biologically active substances such as phytohormones, vitamins, fungicidal compounds, and amino acids.

Results of the Study. Based on the results of the research conducted during 2016–2025 under the conditions of the Northern Steppe of Ukraine, it was established that the structure of crop rotations had a significant effect on winter wheat yield. The data presented in Table 1 indicate that the presence of a fallow or a fallow-replacing crop in the rotation increased winter wheat yield. Thus, the average yield in the grain–fallow–row crop rotation (No. 3) ranged from 5.68 to 6.96 t/ha, which is 0.97–1.38 t/ha higher than in grain–row crop rotations No. 1 and No. 2. It should be noted that the difference between crop rotation No. 3 and No. 1 in terms of average yield exceeds the LSD_{05} for factor A (0.32 t/ha), indicating a statistically significant effect of including a fallow in the rotation (Table 1).

It was also found that the fertilization system (factor B) determined the level of winter wheat yield. The greatest yield increase was observed with the organo-mineral system with a biologized component, where yield in the grain–row crop rotation with 60% soybean saturation was 2.09 t/ha (48.7 %) higher compared with the unfertilized control (LSD_{05} = 0.45 t/ha). In the rotation with 40 % soybean, the yield gain was +1.92 t/ha (40.9 %), which is also statistically significant. It should be noted that the effectiveness of the biological preparation decreased with decreasing soybean saturation; in the grain–fallow–row crop rotation (No. 3), the difference between treatments with and without the biological preparation was only 1.28 t/ha (22.6 %).

Based on the comparison of crop rotations No. 2 (grain–row, 40 % soybean) and No. 3 (grain–fallow–row), it was established that the inclusion of a fallow field in the rotation provided a yield increase of 0.33–0.98 t/ha or 4.7–17.1 %, depending on the fertilization system. It should be noted that the greatest effect of introducing fallow into the rotation was observed under the organo-mineral system with a biologized component, where the yield reached 6.96 t/ha, whereas in rotation No. 2 the maximum value was 6.63 t/ha. These data indicate the high potential of the grain–fallow–row crop rotation for increasing winter wheat productivity when effective fertilization systems are applied simultaneously.

Analysis of the interaction between factors A and B showed that the maximum effect is achieved when the grain–fallow–row crop rotation (No. 3) is combined with the organo-mineral system with a biologized component, where the average winter wheat yield reached 6.96 t/ha. It should be noted that in variants with high soybean saturation (60 %), the effect of the biological component was most pronounced, providing an increase of +0.67 t/ha or 13.6 % compared with the unfertilized control.

Increasing the efficiency of winter wheat cultivation is a key task in modern agriculture, as it affects not only the total grain harvested but also the overall productivity of the crop. It is important to consider that maximum efficiency of agrotechnical measures is achieved through the simultaneous optimal selection of crop rotations and fertilization systems, ensuring fuller utilization of the biological potential of the plants. A comprehensive approach allows improving not only the biological but also the economic productivity of winter wheat.

Table 1

Winter wheat yield in different crop rotations depending on fertilization system

Crop rotation, factor A	Fertilization system, factor B	Average 2016–2025, t/ha	Difference Factor A				Difference Factor B	
			Difference of rotations No. 2 and No. 3 vs. No. 1		Difference rotation No. 3 vs. No. 2			
1. Grain–row crop rotation, 60 % soybean	Unfertilized	4.30	–	–	–	–	–	–
	Biologized	4.85	–	–	–	–	0.56	13.0
	Mineral	5.72	–	–	–	–	1.43	33.2
	Mineral biologized	6.13	–	–	–	–	1.84	42.7
	Organo-mineral	6.19	–	–	–	–	1.89	44.1
	Organo-mineral biologized	6.39	–	–	–	–	2.09	48.7
2. Grain–row crop rotation, 40 % soybean	Unfertilized	4.70	0.41	9.5	–	–	–	–
	Biologized	5.08	0.22	5.2	–	–	0.37	7.9
	Mineral	5.94	0.22	5.1	–	–	1.24	26.3
	Mineral biologized	6.24	0.11	2.7	–	–	1.54	32.7
	Organo-mineral	6.36	0.17	4.0	–	–	1.66	35.2
	Organo-mineral biologized	6.63	0.24	5.6	–	–	1.92	40.9
3. Grain–fallow–row crop rotation	Unfertilized	5.68	1.38	32.2	0.97	17.1	–	–
	Biologized	6.05	1.20	28.0	0.98	16.1	0.38	6.7
	Mineral	6.38	0.65	15.2	0.44	6.8	0.70	12.4
	Mineral biologized	6.68	0.55	12.9	0.44	6.6	1.01	17.8
	Organo-mineral	6.63	0.45	10.4	0.27	4.1	0.96	16.9
	Organo-mineral biologized	6.96	0.57	13.2	0.33	4.7	1.28	22.6
LSD_{05}, t/ha	Factor A = 0.32		Factor B = 0.45			Interaction AB = 0.78		

With the inclusion of black or occupied fallow in the rotation, a sequential increase in crop productivity was observed: the grain–fallow–row crop rotation (No. 3) demonstrated the maximum grain unit yield – 6.24–7.65 t/ha, which is 1.07–1.52 t/ha higher than the yields of grain–row crop rotations No. 1 and No. 2. The difference between rotation No. 3 and No. 1 exceeded the LSD_{05} for factor A (0.39 t/ha), confirming the reliability of the effect of including fallow field on winter wheat productivity (Table 2).

Fertilization systems (factor B) significantly modified productivity results in terms of grain unit yield. The organo-mineral system with a biologized component provided the highest increase in the grain–row crop rotation with 60 % soybean, +2.30 t/ha or 48.7 %, and in the rotation with 40% soybean – +2.11 t/ha or 40.7 %, compared to the unfertilized variants (LSD_{05} = 0.16 t/ha). It should be emphasized that the effectiveness of the biological component was more pronounced in rotations with a higher share of soybean, and when the soybean share decreased, the productivity gain remained significant, but less intensive.

The inclusion of a fallow predecessor contributed to an increase in grain unit yield by 0.36–1.08 t/ha or 4.2–17.1 %, depending on the fertilization system applied. Comparative analysis of rotations No. 2 (grain–row, 40 % soybean) and No. 3 (grain–fallow–row) showed that the integration of a fallow predecessor ensures a stable increase in crop productivity. The highest values were obtained by combining rotation No. 3 with the organo-mineral system and biologized component – 7.65 t/ha, whereas the maximum grain unit yield in rotation No. 2 was 7.29 t/ha.

The combination of the grain–fallow–row crop rotation with a comprehensive fertilization system provided optimal formation of winter wheat productivity, increasing not only the grain yield but also its economic value.

Optimization of the crop rotation contributed to an increase in the feed value of the winter wheat harvest. Analysis of data from 2016–2025 showed that the crop rotation factor (factor A) determined the level of feed unit yield accumulation and the formation of the crop's protein potential (Tables 3 and 4). Thus, the grain–fallow–row crop rotation (No. 3) provided an average feed unit yield in the experiment of 8.00–9.81 t/ha, exceeding the values of grain–row crop rotations No. 1 and No. 2 by 0.61–1.95 t/ha, which surpasses the threshold of statistical significance (LSD_{05} = 0.20 t/ha).

Fertilization systems significantly modified feed productivity. The highest values were achieved with the organo-mineral system with a biologized component, where the increase in feed unit yield in rotation No. 1 amounted to 2.95 t/ha, and in rotation No. 2 – 2.71 t/ha, compared to the unfertilized variants (LSD_{05} = 0.29 t/ha). It should be emphasized that the effect of the biological component was more pronounced in rotations with a high share of soybean, while in combinations with a lower share of soybean, the yield increase remained significant but was more moderate.

Regarding the digestible protein yield, the crop rotation structure and fertilization system show similar trends. In the grain–fallow–row crop rotation (No. 3), its average yield ranged from 0.68 to 0.83 t/ha, whereas in the grain–row crop rotations no. 1 and No. 2, this indicator varied from

Table 2

Grain unit yield of winter wheat in different crop rotations depending on fertilization system

Crop rotation, factor A	Fertilization system, factor B	Average 2016–2025, t/ha	Difference Factor A		Difference Factor B
			Difference of rotations No. 2 and No. 3 vs. No. 1	Difference rotation No. 3 vs. No. 2	
1. Grain–row crop rotation, 60 % soybean	Unfertilized	4.72	–	–	–
	Biologized	5.34	–	–	0.61
	Mineral	6.30	–	–	1.57
	Mineral biologized	6.74	–	–	2.02
	Organo-mineral	6.81	–	–	2.08
	Organo-mineral biologized	7.03	–	–	2.30
2. Grain–row crop rotation, 40 % soybean	Unfertilized	5.18	0.45	–	–
	Biologized	5.58	0.25	–	0.41
	Mineral	6.54	0.24	–	1.36
	Mineral biologized	6.87	0.13	–	1.69
	Organo-mineral	6.99	0.19	–	1.82
	Organo-mineral biologized	7.29	0.26	–	2.11
3. Grain–fallow–row crop rotation	Unfertilized	6.24	1.52	1.07	–
	Biologized	6.66	1.32	1.08	0.42
	Mineral	7.01	0.72	0.48	0.77
	Mineral biologized	7.35	0.61	0.48	1.11
	Organo-mineral	7.30	0.49	0.30	1.05
	Organo-mineral biologized	7.65	0.63	0.36	1.41
LSD_{05}, t/ha	Factor A = 0.39	Factor B = 0.16		Interaction AB = 0.22	

Table 3

Feed unit yield of winter wheat in different crop rotations depending on fertilization system

Crop rotation, factor A	Fertilization system, factor B	Average 2016–2025, t/ha	Difference Factor A		Difference Factor B
			Difference rotation No. 3 vs. No. 2	Difference rotation No. 3 vs. No. 2	
1. Grain–row crop rotation, 60 % soybean	Unfertilized	6.06	–	–	–
	Biologized	6.84	–	–	0.79
	Mineral	8.07	–	–	2.01
	Mineral biologized	8.64	–	–	2.59
	Organo-mineral	8.72	–	–	2.67
	Organo-mineral biologized	9.01	–	–	2.95
2. Grain–row crop rotation, 40 % soybean	Unfertilized	6.63	0.58	–	–
	Biologized	7.16	0.32	–	0.52
	Mineral	8.38	0.31	–	1.74
	Mineral biologized	8.81	0.16	–	2.17
	Organo-mineral	8.97	0.24	–	2.33
	Organo-mineral biologized	9.35	0.34	–	2.71
3. Grain–fallow–row crop rotation	Unfertilized	8.00	1.95	1.37	–
	Biologized	8.54	1.70	1.38	0.54
	Mineral	8.99	0.92	0.61	0.99
	Mineral biologized	9.42	0.78	0.62	1.42
	Organo-mineral	9.35	0.63	0.39	1.35
	Organo-mineral biologized	9.81	0.80	0.46	1.81
LSD_{05}, t/ha	Factor A = 0.20	Factor B = 0.29		Interaction AB = 0.50	

Table 4

Digestible protein yield of winter wheat in different crop rotations depending on fertilization system

Crop rotation, factor A	Fertilization system, factor B	Average 2016–2025, t/ha	Difference Factor A		Difference Factor B
			Difference rotation No. 3 vs. No. 2	Difference rotation No. 3 vs. No. 2	
1. Grain–row crop rotation, 60 % soybean	Unfertilized	0.51	–	–	–
	Biologized	0.58	–	–	0.07
	Mineral	0.69	–	–	0.18
	Mineral biologized	0.74	–	–	0.22
	Organo-mineral	0.74	–	–	0.23
	Organo-mineral biologized	0.77	–	–	0.25
2. Grain–row crop rotation, 40 % soybean	Unfertilized	0.56	0.05	–	–
	Biologized	0.61	0.03	–	0.05
	Mineral	0.71	0.02	–	0.15
	Mineral biologized	0.75	0.01	–	0.19
	Organo-mineral	0.76	0.02	–	0.20
	Organo-mineral biologized	0.80	0.03	–	0.24
3. Grain–fallow–row crop rotation	Unfertilized	0.68	0.16	0.11	–
	Biologized	0.73	0.14	0.12	0.05
	Mineral	0.77	0.08	0.05	0.09
	Mineral biologized	0.80	0.07	0.05	0.13
	Organo-mineral	0.80	0.05	0.03	0.12
	Organo-mineral biologized	0.83	0.07	0.04	0.16
LSD_{05}, t/ha	Factor A = 0.02	Factor B = 0.02		Interaction AB = 0.04	

0.51 to 0.80 t/ha. The use of an organo-mineral system with a biological component provided a significant increase in protein potential by 0.25 t/ha in rotation no. 1 and 0.24 t/ha in rotation no. 2 (LSD_{05} = 0.02 t/ha).

Comparison of rotations No. 2 and No. 3 shows that including a fallow field provides an additional gain in feed unit yield of 0.36–1.08 t/ha and in digestible protein yield of 0.04–0.16 t/ha, depending on the fertilization system. Maximum values were observed in the combination of rotation No. 3 with organo-mineral fertilization and a biological component – 9.81 t/ha feed units and 0.83 t/ha digestible protein.

The study of qualitative indicators of winter wheat grain shows the influence of the crop rotation factor and fertilization systems on the formation of the crop's protein and gluten potential (Table 5). The use of a biological preparation and mineral fertilizers contributed to an increase in protein and gluten content, which is critical for grain class quality.

In particular, in the grain–fallow–row crop rotation (No. 3), applying a mineral fertilization system with a biologically enhanced component provided the maximum protein content – 13.1 % and gluten – 27.7 %, corresponding to the 3rd class. In other combinations, the grain mostly fell into the 4th class, although the combination of an organo-mineral fertilization system with a biological preparation increased protein to 11.6 % in the grain–row crop rotation no. 2, allowing production of high-quality 4th class grain (Table 5).

It should be noted that the presence of a fallow predecessor and balanced fertilization contributed to the stability of gluten properties and high protein content across all crop rotations, emphasizing the effectiveness of an integrated approach to the formation of high-quality winter wheat grain. The highest gluten values were observed under mineral and combined fertilization systems, demonstrating the significant role of nutrient supply in realizing the grain quality class potential.

Thus, the optimal combination of the crop rotation factor and fertilization systems makes it possible to obtain winter wheat grain of high or first class in terms of protein and gluten composition, ensuring its competitiveness on the market and suitability for high-quality baking purposes.

Analysis of the economic efficiency of the crop rotation factor and fertilization system showed that the highest production costs in winter wheat cultivation were observed under the mineral biologized fertilization system in the grain–fallow–row crop rotation No. 3 and amounted to 42250 UAH/ha, whereas the lowest costs were recorded in the unfertilized treatment of the grain–row crop rotation No. 1, totaling 22243 UAH/ha (Table 6). The substantial increase in costs was associated with the high prices of mineral fertilizers and fuel and lubricants required for transportation and harvesting of larger yield volumes.

The value of gross output depended on the yield level of winter wheat and was highest under the organo-mineral biologized fertilization system in the grain–fallow–row crop rotation No. 3, reaching 66120 UAH/ha, while the lowest value was observed in the unfertilized treatment of the grain–row crop rotation No. 1 – 40420 UAH/ha.

Conditional net profit in winter wheat cultivation depended on both the crop rotation factor and the fertilization system. On average across rotations, an increase in this indicator was observed in the grain–fallow–row crop rotation No. 3 compared with grain–row crop rotation No. 1

Table 5

Quality indicators of winter wheat grain in different crop rotations depending on the fertilization system

Crop rotation, factor A	Fertilization system, factor B	Gluten, %	Protein, %	Gluten water absorption capacity (WAC)	Class
1. Grain–row crop rotation, 60 % soybean	Unfertilized	20.6	9.6	90.4	4
	Biologized	20.9	9.9	87.3	4
	Mineral	24.6	11.4	88.4	4
	Mineral biologized	24.1	11.4	90.4	4
	Organo-mineral	24.1	11.5	87.7	4
	Organo-mineral biologized	24.1	11.6	87.5	4
2. Grain–row crop rotation, 40 % soybean	Unfertilized	17.8	9.0	91.8	4
	Biologized	18.8	9.2	90.6	4
	Mineral	22.9	11.2	90.1	4
	Mineral biologized	23.2	11.2	88.5	4
	Organo-mineral	24.0	11.4	88.2	3
	Organo-mineral biologized	25.1	11.6	90.4	4
3. Grain–fallow–row crop rotation	Unfertilized	21.2	10.3	91.0	4
	Biologized	22.1	10.4	87.7	4
	Mineral	26.2	12.6	92.4	4
	Mineral biologized	27.7	13.1	90.3	3
	Organo-mineral	21.7	11.0	87.2	4
	Organo-mineral biologized	22.8	11.0	88.3	4

Table 6

Economic efficiency of winter wheat cultivation in different crop rotations depending on the fertilization system (2016–2025)

Crop rotation, factor A	Fertilization system, factor B	Production costs, UAH/ha	Gross output value, UAH/ha	Conditional net profit, UAH/h	Profitability, %
1. Grain–row crop rotation, 60 % soybean	Unfertilized	22243	40420	18177	81.7
	Biologized	23225	45590	22365	96.3
	Mineral	30518	54340	23822	78.1
	Mineral biologized	30629	58235	27606	90.1
	Organo-mineral	30798	58805	28007	90.9
	Organo-mineral biologized	31565	60705	29140	92.3
2. Grain–row crop rotation, 40 % soybean	Unfertilized	22481	44180	21699	96.5
	Biologized	23362	47752	24390	104.4
	Mineral	35198	56430	21232	60.3
	Mineral biologized	35377	59280	23903	67.6
	Organo-mineral	35448	60420	24972	70.4
	Organo-mineral biologized	35609	62985	27376	76.9
3. Grain–fallow–row crop rotation	Unfertilized	24360	52256	27896	114.5
	Biologized	25228	55660	30432	120.6
	Mineral	41458	59972	18514	44.7
	Mineral biologized	42250	62792	20542	48.6
	Organo-mineral	32831	62322	29491	89.8
	Organo-mineral biologized	33654	66120	32466	96.5

by 1704 UAH/ha and compared with grain–row crop rotation No. 2 by 2628 UAH/ha. However, the lowest profitability was recorded in the unfertilized treatment of the grain–row crop rotation No. 1 and amounted to 18177 UAH/ha, whereas the maximum conditional net profit was obtained when winter wheat was grown in the grain–fallow–row crop rotation No. 3 under the organo-mineral biologized fertilization system, reaching 32466 UAH/ha.

Our economic efficiency studies showed that both the lowest and the highest profitability levels were obtained in the grain–fallow–row crop rotation No. 3, amounting to 44.7 % under the mineral fertilization system and 120.6 % under the biologized fertilization system.

Thus, a high economic effect was achieved when winter wheat was cultivated in the grain–fallow–row crop rotation No. 3 under the biologized fertilization system, where conditional net profit reached 30432 UAH/ha with a profitability of 120.6 %, while the highest overall economic indicators were recorded in the same rotation under the organo-mineral biologized fertilization system, namely conditional net profit of 32466 UAH/ha with a profitability of 96.6 %.

Conclusions. The inclusion of a fallow predecessor in the crop rotation influenced the formation of winter wheat yield, ensuring additional realization of the crop's biological potential. In the grain–fallow–row crop rotation, the average grain yield over 2016–2025 reached 6.96 t/ha, exceeding that of the grain–row crop rotation with 40 % soybean saturation (6.63 t/ha) by 0.33 t/ha (4.9 %) and that of the grain–row crop rotation with 60% soybean (6.39 t/ha) by 0.57 t/ha (8.9 %). A reduction in soybean concentration in the rotation from 60% to 40 % contributed to increased winter wheat yield (6.63 t/ha and 6.39 t/ha, respectively).

Decreasing the proportion of soybean in the rotation and including a fallow predecessor increased grain unit yield by 0.24–1.08 t/ha (4.2–17.1 %). The application of an organo-mineral biologized fertilization system ensured a statistically significant increase of 0.41–2.30 t/ha. The highest grain unit yield was obtained in the grain–fallow–row crop rotation under the organo-mineral biologized fertilization system – 7.65 t/ha.

Significantly higher feed unit yield (9.81 t/ha) and digestible protein yield (0.83 t/ha) were also obtained in the grain–fallow–row crop rotation with the organo-mineral biologized fertilization system.

The combined use of an organo-mineral fertilization system with a biologized component after fallow made it possible to obtain grain of the 3rd and 4th classes, with protein content of 11.6–13.1 % and gluten of 22.8–27.7 %. Mineral and organo-mineral fertilization stabilized quality indicators in all crop rotation combinations, confirming the effectiveness of an integrated approach to producing high-yielding and high-quality winter wheat grain under the conditions of the Northern Steppe of Ukraine.

The highest economic efficiency was achieved when winter wheat was grown in the grain–fallow–row crop rotation No. 3 under the organo-mineral biologized fertilization system: gross output value – 66120 UAH/ha, conditional net profit – 32466 UAH/ha, with profitability of 96.6 %.

BIBLIOGRAPHY:

1. Babulicová M. The influence of fertilization and crop rotation on the winter wheat production. *Plant, Soil and Environment*. 2014, Vol. 60, No. 7: 297–302. https://doi.org/10.17221/3/2014-PSE
2. Bansal Y., Lillis D., Kechadi M. T. Winter wheat crop yield prediction using machine learning. *International Conference on Computational Science and Computational Intelligence* (CSCI) 2023. https://doi.org/10.1109/CSCI58124.2022.00040
3. Bocchi G., Micheletti A., Nota P. Alessandro OlperThe impact of abnormal temperatures on crop yields in Italy: a functional quantile regression approach. *Cornell University*. 2026. https://doi.org/10.48550/arXiv.2601.12864
4. Дребот О. І. Оцінка еколого-економічної ефективності систем удобрення в сівозмінах органічного виробництва Полісся: (науково-методичні рекомендації). Чернігів. Видавець Брагинець О. В. 2020. 48 с. https://ismav.com.ua/wp-content/uploads/2025/01/02.pdf
5. Гангур В., Маренич А., Сокирко Д. Вплив прецедентів та рівня удобрення на врожайність зерна озимої пшениці в умовах Лівобережного Лісостепу. *Науковий прогрес та інновації*. 2025, 28 (1), 63–67. https://doi.org/10.31210/spi2025.28.01.11
6. Hospodarenko, H., Mostoviak, I., Karpenko, V., Liubych, V., Novikov, V. Yield and quality of winter durum wheat grain depending on the fertiliser system. *Scientific Horizons*, 2022. 25(3), 16–25. https://doi.org/10.48077/scihor.25(3).2022.16-25
7. Мащенко Ю.В., Кулик Г.А., Трікіна Н.М., Малаховська В.О. Урожайність пшениці озимої у сівозмінах степу залежно від системи удобрення та біопрепарату. *Аграрні інновації*. 2023. № 18 С. 77–83. https://doi.org/10.32848/agrar.innov.2023.18.11
8. Mashchenko Yu., Sokolovska I. Growing winter wheat in various short-rotation crop rotation models adapted to the conditions of the steppe zone of Ukraine. *Acta u niversitatis agriculturae et silviculturae mendelianae brunensis*. Volume 72. Number 5– 6, 2024. P. 165м176. https://doi.org/10.11118/actaun.2024.011
9. Mashchenko Yu.V., Sokolovska I.M. Yield, productivity, and economic efficiency of winter wheat cultivation depend on crop rotation link and fertilizer systems. *Подільський вісник*: сільське господарство, техніка, економіка. 2023. Випуск 3 (40). 21– 27. https://doi.org/10.37406/2706-9052-2023-3.3
10. Пташник М., Заяць П., Ременюк Ю., Цимбал Ю., Уста В. Особливості формування врожайності та продуктивності зернових культур короткоротаційної сівозміни у відновлюваному сільському господарстві. *Сільське господарство та рослинництво: теорія та практика*. 2025. (1), 15–23. https://doi.org/10.54651/agri.2025.01.02
11. Salehi A., Salehi A., Surböck A., Freyer B., Friedel J. K. 10-Year study on the impact of organic fertilization on winter wheat yield and quality following lucerne and grain pea in a dry sub-humid region under organic cultivation in Austria. *Journal of Agriculture and Food Research*. Volume 21, June 2025, 101888. https://doi.org/10.1016/j.jafr.2025.101888
12. Щерба М. М. Вплив попередників і удобрення на продуктивність пшениці озимої. *Передгірне та гірське землеробство і тваринництво*. 2021. Вип. 69 (2). С. 137–153. https://doi.org/10.32636/01308521.2021-(69)-2-9 https://phzt-journal.isgkr.com.ua/69(2)/9.pdf
13. Silifonov T. V. Grain yield and protein content in different ripening varieties of soft winter wheat using various types and doses of fertilizers. *Plant Varieties Studying and Protection*. 2023. 19(1), 44–51. https://doi.org/10.21498/2518-1017.19.1.2023.277770
14. Srivastava A. K., Safaei N., Khaki S., Lopez G., Zeng W., Ewert F., Gaiser T., Rahimi J. Winter wheat yield prediction using convolutional neural networks from environmental and phenological data. *Scientific Reports*. 2022. Volume 12, Article number: 3215. https://www.nature.com/articles/s41598-022-06249-w
15. Силіфонов Т., Господаренко Г., Любич В., Полянецька І., Новіков В. Урожайність та якість зерна м'якої озимої пшениці на стадіях дозрівання за різних систем удобрення в сівозміні. *Агробіологія*. 2021. № 2. С. 146–156. https://doi.org/10.33245/2310-9270-2021-167-2-146-156
16. Центило Л В. Продуктивність сівозміни залежно від удобрення і обробітку ґрунту. *Вісник аграрної науки Причорномор'я*. 2019. Вип. 3. С. 52–60. https://bsagriculture.com.ua/web/uploads/pdf/Ukrainian%20Black%20Sea%20Region%20Agrarian%20Science_2019_Vol.%2023,%20No.%203-52-60.pdf
17. Umrykhin, N., Sokolovska, I., Mashchenko, Yu. Productivity and economic efficiency of winter wheat (*Triticum aestivum* L.) cultivation depending on preceding crops and sowing dates. *International Journal of Agricultural Technology*. 2024. Vol. 20(6):2589-2604. http://www.ijat-aatsea.com/pdf/v20_n6_2024_November/28_IJAT_20(6)_2024_Umrykhin,%20N.--2058.pdf

REFERENCES:

1. Babulicova M. (2014). The influence of fertilization and crop rotation on the winter wheat production. *Plant, Soil and Environment*. Vol. 60, No. 7: 297–302. https://doi.org/10.17221/3/2014-PSE
2. Bansal Y., Lillis D., Kechadi M. T. Winter wheat crop yield prediction using machine learning. *International Conference on Computational Science and Computational Intelligence* (CSCI) 2023. https://doi.org/10.1109/CSCI58124.2022.00040
3. Bocchi G., Micheletti A., Nota P. Olper A. (2026). The impact of abnormal temperatures on crop yields in Italy: a functional quantile regression approach. *Cornell University*. https://doi.org/10.48550/arXiv.2601.12864
4. Drebot, O. I. (2020). *Otsinka ekoloho-ekonomichnoi efektyvnosti system udobrennia v sivozminakh orhanichnoho vyrobnytstva Polissia: (naukovo-metodychni rekomendatsii)* [Assessment of ecological and economic efficiency of fertilization systems in crop rotations of organic production in Polissia: scientific and methodological recommendations]. Chernihiv: Vydavets Brahinets O. V., 48 s. https://ismav.com.ua/wp-content/uploads/2025/01/02.pdf [in Ukrainian].
5. Hangur V., Marenych A., Sokyrko D. (2025). *Vplyv pretsedentiv ta rivnia udobrennia na vrozhainist zerna ozymoi pshenytsi v umovakh Livoberezhnoho Lisostepu.* [Influence of precedents and fertilization level on winter wheat grain yield in the conditions of the Left-Bank Forest-Steppe]. *Naukovyi prohres ta innovatsii*. 2025, 28 (1), 63–67. https://doi.org/10.31210/spi2025.28.01 [in Ukrainian].

6. Hospodarenko H., Mostoviak I., Karpenko V., Liubych V., Novikov V. (2022). Yield and quality of winter durum wheat grain depending on the fertiliser system. *Scientific Horizons*. 25(3), 16–25. https://doi.org/10.48077/scihor.25(3).2022.16-25
7. Mashchenko Yu. V., Kulyk H. A., Trikina N. M., Malakhovska V. O. (2023). *Urozhainist pshenytsi ozymoi u sivozminakh stepu zalezhno vid systemy udobrennia ta biopreparatu*. [Yield of winter wheat in steppe crop rotations depending on fertilization system and biological preparation]. *Ahrarni innovatsii*. № 18. S. 77–83. https://doi.org/10.32848/agrar.innov.2023.18.11 [in Ukrainian].
8. Mashchenko Yu., Sokolovska I. (2024). Growing winter wheat in various short-rotation crop rotation models adapted to the conditions of the steppe zone of Ukraine. *Acta universitatis agriculturae et silviculturae mendelianae brunensis*. Volume 72. Number 5– 6. P. 165–176. https://doi.org/10.11118/actaun.2024.011
9. Mashchenko Yu. V., Sokolovska I. M. (2023). Yield, productivity, and economic efficiency of winter wheat cultivation depend on crop rotation link and fertilizer systems. *Podilskyi Visnyk: Sil'ske Hospodarstvo, Tekhnika, Ekonomika.* Issue 3 (40). P. 21–27. https://doi.org/10.37406/2706-9052-2023-3.3
10. Ptashnyk M., Zaiats P., Remeniuk Yu., Tsymbal Yu., Usta V. (2025). *Osoblyvosti formuvannia vrozhainosti ta produktyvnosti zernovykh kultur korotkorotatsiinoi sivozminy u vidnovliuvanomu silskomu hospodarstvi*. [Peculiarities of yield formation and productivity of cereal crops in short-rotation crop rotations under regenerative agriculture]. *Silske hospodarstvo ta roslynnytstvo: teoriia ta praktyka*. № 1. S. 15–23. https://doi.org/10.54651/agri.2025.01.02 [in Ukrainian].
11. Salehi A., Salehi A., Surböck A., Freyer B., Friedel J. K. (2025). 10-Year study on the impact of organic fertilization on winter wheat yield and quality following lucerne and grain pea in a dry sub-humid region under organic cultivation in Austria. *Journal of Agriculture and Food Research*. Volume 21. 101888. https://doi.org/10.1016/j.jafr.2025.101888
12. Shcherba M. M. (2021). *Vplyv poperednykiv i udobrennia na produktyvnist pshenytsi ozymoi.* [Influence of predecessors and fertilization on productivity of winter wheat]. *Peredhirne ta hirske zemlerobstvo i tvarynnytstvo*. № 69 (2). S. 137–153. https://doi.org/10.32636/01308521.2021-(69)-2-9 https://phzt-journal.isgkr.com.ua/69(2)/9.pdf [in Ukrainian].
13. Silifonov T. V. (2023). Grain yield and protein content in different ripening varieties of soft winter wheat using various types and doses of fertilizers. *Plant Varieties Studying and Protection*. 19(1), 44–51. https://doi.org/10.21498/2518-1017.19.1.2023.277770
14. Srivastava A. K., Safaei N., Khaki S., Lopez G., Zeng W., Ewert F., Gaiser T., Rahimi J. (2022). Winter wheat yield prediction using convolutional neural networks from environmental and phenological data. *Scientific Reports*. Volume 12, Article number: 3215. https://www.nature.com/articles/s41598-022-06249-w
15. Sylifonov T., Hospodarenko H., Liubych V., Polianetska I., Novikov V. (2021). *Urozhainist ta yakist zerna miakoi ozymoi pshenytsi na stadiiakh dozrivannia za riznykh system udobrennia v sivozmini*. [Yield and grain quality of soft winter wheat at ripening stages under different fertilization systems in crop rotation]. *Ahrobiolohiia*. №. 2. S. 146–156. https://doi.org/10.33245/2310-9270-2021-167-2-146-156 [in Ukrainian].
16. Tsentylo L. V. (2019). *Produktyvnist sivozminy zalezhno vid udobrennia i obrobitku gruntu*. [Productivity of crop rotation depending on fertilization and soil tillage]. *Visnyk ahrarnoi nauky Prychornomoria*. № 3. S. 52–60. https://bsagriculture.com.ua/web/uploads/pdf/Ukrainian%20Black%20Sea%20Region%20Agrarian%20Science_2019_Vol.%2023,%20No.%203-52-60.pdf [in Ukrainian].
17. Umrykhin N., Sokolovska I., Mashchenko Yu. (2024). Productivity and economic efficiency of winter wheat (*Triticum aestivum* L.) cultivation depending on preceding crops and sowing dates. *International Journal of Agricultural Technology*. Vol. 20(6):2589-2604. http://www.ijat-aatsea.com/pdf/v20_n6_2024_November/28_IJAT_20(6)_2024_Umrykhin,%20N.--2058.pdf

Mashchenko Yu.V., Sokolovska I.M., Shevchenko T.V.
Influence of the crop rotation factor and fertilization systems on productivity, quality indicators and economic efficiency of winter wheat

The study aimed to evaluate the influence of crop rotation structure and fertilization systems on productivity, feed value, and grain quality of winter wheat under the conditions of the Northern Steppe of Ukraine, particularly with the inclusion of legume predecessors and biologically active components in fertilization systems. Field experiments were conducted in 2016–2025 within the scientific crop rotation of the Institute of Agriculture of the Steppe of the NAAS of Ukraine using three crop rotations differing in soybean proportion and inclusion of a fallow predecessor; the following fertilization systems were applied: no fertilizers, biologized, mineral, mineral biologized, organo-mineral, and organo-mineral biologized. The soil and climatic conditions correspond to those of the Northern Steppe of Ukraine. The inclusion of a fallow predecessor increased winter wheat productivity under all fertilization systems. Grain yield rose from 5.58–5.98 t/ha in rotations with high soybean saturation to 6.63 t/ha in rotations with lower soybean content and a fallow field. The highest feed unit yield (9.81 t/ha) and digestible protein yield (0.83 t/ha) were obtained in the grain–fallow–row crop rotation under the organo-mineral biologized fertilization system. The biologized fertilization component significantly increased crop productivity and protein content, especially in rotations with a high share of legumes. Grain quality varied depending on crop rotation and fertilization system: protein content ranged from 9.0 to 13.1 %, gluten from 17.8 to 27.7 %, and grain class from 3 to 4. The integrated use of optimized crop rotations, inclusion of a fallow predecessor, and organo-mineral fertilization systems with a biologized component ensures increased productivity, feed value, and grain quality of winter wheat in the Northern Steppe of Ukraine. The results can be used for sustainable intensification of crop cultivation while maintaining yield and quality potential. The highest conditional net profit – 32466 UAH/ha with profitability of 96.6 % – was obtained when winter wheat was grown in the grain–fallow–row crop rotation under the organo-mineral biologized fertilization system.

Key words: crop rotation management, fertilization systems, winter wheat yield, digestible protein yield, grain and feed unit yield, winter wheat grain quality.

Мащенко Ю.В., Соколовська І.М., Шевченко Т.В. Вплив сівозмінного фактору та систем удобрення на продуктивність, якісні показники і економічну ефективність пшениці озимої

Дослідження спрямоване на оцінку впливу складу сівозмін та систем удобрення на продуктивність, кормову цінність та якість зерна пшениці озимої в умовах Північного Степу України, зокрема за включення бобових попередників та біологічно активних компонентів у систему удобрення. Полеві дослідження проводилися у 2016–2025 рр. за трьома сівозмінами з різною часткою сої та включенням парового попередника у науковій сівозміні Інституту сільського господарства Степу НААН України; використовували системи удобрення: без добрив, біологізовану, мінеральну, мінеральну біологізовану, органо-мінеральну та органо-мінеральну біологізовану. Ґрунтово-кліматичні умови розташування відповідають північному Степу України. Включення парового попередника підвищувало продуктивність пшениці озимої у всіх системах удобрення. Врожайність зерна зростала від 5,58–5,98 т/га у сівозмінах із високим насиченням соєю до 6,63 т/га у сівозмінах з меншим насиченням соєю та паровим попередником. Найвищий збір кормових одиниць досягався у зерно-паро-просапній сівозміні з органо-мінеральною системою біологізованою системою удобрення, 9,81 т/га, вихід перетравного протеїну, 0,83 т/га. Біологізований компонент удобрення значно підвищував продуктивність культури та вміст білка, особливо у сівозмінах з високою часткою бобових. Якість зерна варіювала: білок 9,0–13,1 %, клейковина 17,8–27,7 %, клас зерна 3–4, залежно від сівозміни та системи удобрення. Комплексне використання оптимізованих сівозмін, включення парового попередника та органо-мінеральних систем удобрення з біологізованим компонентом забезпечує підвищення продуктивності, кормової цінності та якості зерна пшениці озимої в Північному Степу України. Результати досліджень можуть бути використані для сталого інтенсифікування вирощування культури, збереження її врожайного та якісного потенціалу. Найвищий умовно-чистий прибуток – 32 466 грн/га при рентабельності 96,6 %. отримали при вирощуванні пшениці озимої в зерно–паро–просапній сівозміні за органо-мінеральної біологізованої системи удобрення

Ключові слова: управління сівозмінами, системи удобрення, урожайність пшениці озимої, вихід перетравного протеїну, збір зернових та кормових одиниць, якість зерна пшениці озимої.

Дата першого надходження статті до видання: 26.02.2026
Дата прийняття статті до друку після рецензування: 30.03.2026
Дата публікації (оприлюднення) статті: 06.05.2026