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PRODUCTIVITY AND ECONOMIC EFFICIENCY OF SUNFLOWER GROWING IN DIFFERENT CROP ROTATIONS DEPENDING ON FERTILIZATION SYSTEMS

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The article presents the results of a study on the elements of sunflower cultivation technology as an important oilseed crop, proposing ways to optimize production in short-rotation crop rotations with varying sunflower saturation, balanced use of mineral fertilizers, organic residues, and biopreparation. The highest productivity and economic efficiency indicators for sunflower cultivation were obtained in a grain-fallow-row crop rotation (sunflower share 20 %) under an organo-mineral biologized fertilization system: seed yield – 3.42 t/ha, oil yield 67 t/ha, conditional net profit – 57,138 UAH/ha with a profitability level of 174.2%. The economic efficiency of sunflower cultivation primarily depended on the crop rotation factor – a decrease in sunflower concentration contributed to an increase in the value of produced products and conditional net profit. Fertilization systems enhanced the impact of crop rotation, with the greatest effect provided by the combined action of nutrient elements – a combination of mineral fertilizers, organic matter from predecessor by-products, and biopreparations.

Keywords: crop rotations, fertilization systems, sunflower saturation in crop rotations, yield, productivity, economic efficiency of sunflower cultivation.

Introduction. Sunflower, as one of the main oilseed crops, occupies a significant portion of sown areas in Ukraine and other countries, and its cultivation is directly related to the choice of optimal agronomic practices. The dominance of sunflower in the structure of oilseed production gives this crop a special role in the agricultural market of Ukraine (Chekhova 2022; Makarchuk 2022).

Oilseed crops in Ukraine account for a significant share (over 30 %) of the total structure of agricultural crop sown areas across all natural and climatic zones. The production of oilseeds in Ukraine is carried out through intensive methods, and the prospects for further development lie in increasing their gross yield by enhancing productivity based on the introduction of modern plant varieties and hybrids (Chekhova 2022).

Crop rotation, which involves alternating different crops, is crucial for maintaining soil fertility, reducing disease risk and pest prevalence, and improving overall productivity. Studies have shown that crop rotation can increase agricultural yields by 10-25 % compared to monoculture systems. By reducing dependence on chemicals and enhancing yields, crop rotation can significantly boost the profitability of farming operations. Implementing a well-designed crop rotation plan tailored to local soil and climatic conditions is essential for maximizing these benefits. This

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approach not only supports sustainable agriculture but also contributes to environmental health by reducing soil erosion, improving moisture use efficiency, and supporting biodiversity. As agriculture faces increasing challenges related to climate change and resource limitations, adopting crop rotation practices becomes increasingly important for ensuring the long-term sustainability of farming (Venkata 2025; Muhammad 2024; Aslam et al. 2024; Mashchenko 2023).

To mitigate negative factors (excessive anthropogenic load, deterioration of water, nutrient regimes, and humus content of the soil) and improve the nutrition system for sunflower plants, it is necessary to more widely utilize mineral, organic, and micronutrient fertilizers, as well as plant growth regulators. The regulatory mechanisms of biological preparations enhance the development of leaf area and activate essential functions necessary for the vitality of sunflower plants: membrane processes, cell division, respiration and nutrition, enzyme system activity, and photosynthesis. During the growth period, a branched root system with increased absorption capacity is developed (Tsyliuryk et al. 2021).

Fertilization systems also play a crucial role. Crop rotation, which involves alternating different crops, is essential for maintaining soil fertility, reducing the risk of diseases and pest prevalence, and improving overall productivity. Studies have shown that crop rotation can increase agricultural yields by 10-25% compared to monoculture systems. By reducing dependence on chemicals and enhancing yields, crop rotation can significantly boost the profitability of farming operations. Implementing a well-designed crop rotation plan tailored to local soil and climatic conditions is vital for maximizing these benefits. This approach not only supports sustainable agriculture but also contributes to environmental health by reducing soil erosion, improving moisture use efficiency, and supporting biodiversity. As agriculture faces increasing challenges related to climate change and resource limitations, adopting crop rotation practices becomes increasingly important for ensuring the long-term sustainability of farming (Venkata 2025; Muhammad 2024; Aslam et al. 2024; Mashchenko 2023).

To mitigate negative factors (excessive anthropogenic load, deterioration of water, nutrient regimes, and humus content of the soil) and improve the nutrition system for sunflower plants, it is necessary to more widely utilize mineral, organic, and micronutrient fertilizers, as well as plant growth regulators. The regulatory mechanisms of biological preparations enhance the development of leaf area and activate essential functions necessary for the vitality of sunflower plants: membrane processes, cell division, respiration and nutrition, enzyme system activity, and photosynthesis. During the growth period, a branched root system with increased absorption capacity is developed (Tsyliuryk et al. 2021).

Fertilization systems also play a key role in shaping sunflower yields. The use of mineral and organic fertilizers, as well as biological preparations, not only increases the nutrient content in the soil but also optimizes photosynthesis processes and oil accumulation in the seeds. Numerous studies have demonstrated the positive impact of biofertilizers and the interest in implementing innovative practices to improve soil fertility, conserve water resources, protect the environment, and ensure the development of sustainable organic agriculture (Meddich A., Oufdou K. et al. (2020); Sokolovska 2023).

Despite the fact that most biopreparations positively influence sunflower yield, some, such as Fitosporin in combination with Agrostimulin, have been observed to simultaneously increase fat content, which is indeed a unique phenomenon, as in most cases a negative correlation is observed in this regard (Domaratsky et al. 2019).

The results of research on the impact of factors on oil yield confirm that there were both positive and negative correlations between the main indicators of yield and seed quality in sunflowers; for example, an increase in nitrogen fertilizers leads to a decrease in crude fat and linoleic acid content (Wei Ping Li et al. 2017).

The application of nitrogen and phosphorus positively influences the protein and oil yield from sunflower seeds (Blamey 1981). According to research, th e use of complex fertilizers can increase oil yield from agricultural crops by 5-10% (Moradzadeh et al. 2021).

An important aspect is also the economic efficiency of implementing new fertilization and crop rotation technologies. The costs of fertilizers and their impact on the overall profit from oil sales are key factors for agricultural producers seeking to maximize their income. Researchers emphasize that one way to increase the economic efficiency of sunflower cultivation and reduce its burden in crop rotation is through a comprehensive set of measures to intensify production technology based on improving the fertilization system and using biopreparations (Mashchenko et al. 2024).

Thus, a comprehensive approach to managing crop rotations and fertilization systems not only contributes to increasing sunflower yields but also ensures the stability of economic indicators in agricultural production. This topic deserves further study and discussion, as effective agronomic practices can become a guarantee for the successful development of agriculture under changing climate conditions and growing food demands.

The aim of the research is to establish the impact of different fertilization systems, sunflower concentration in short-rotation crop rotations, and continuous cultivation on productivity levels, oil content, oil yield, yield, and economic efficiency.

Materials and Methods of Research. The study investigated the yield and productivity of sunflower in a stationary experiment under different crop rotations in the fields of the Agricultural Laboratory of the Institute of Agriculture of the Steppe of NAAS. Factor A consisted of short-rotation crop rotations with varying saturation of sunflower: grain-fallow-row crop rotation black/occupied fallow – winter wheat – soybean – corn for grain – sunflower (sunflower saturation 20 %); grain-row crop rotation (saturation of sunflower and corn at 50 % each); continuous cultivation of sunflower (saturation 100 %). Factor B included fertilization systems: without fertilizers; biologized fertilization system (pre-sowing inoculation of sunflower seeds with a biopreparation); mineral fertilization system ($N_{40}P_{40}K_{40}$); mineral biologized fertilization system ($N_{40}P_{40}K_{40}$ + pre-sowing inoculation of sunflower seeds with a biopreparation); organo-mineral fertilization system ($N_{40}P_{40}K_{40}$ + by-products of corn or in the case of continuous cultivation – sunflower); organo-mineral biologized fertilization system ($N_{40}P_{40}K_{40}$ + by-products of corn or in the case of continuous cultivation – sunflower + pre-sowing inoculation of sunflower seeds with a biopreparation).

The area of the plot is 105.9 m², with a repetition of three times. Sunflower was grown using the generally accepted agricultural practices for the Northern Steppe zone, except for the factors studied in the experiment. For conducting field and laboratory research, field research methods and mathematical-statistical methods were used.

For sowing, the hybrid sunflower LG 50510, developed by Limagrain and recommended for the Forest-Steppe, Polissya, and Northern Steppe zones of Ukraine, was utilized under classical technology. Pre-sowing treatment of sunflower seeds in the variants of the biologized fertilization system, mineral biologized fertilization system, and organo-mineral biologized fertilization system was carried out using the BTU company product Mikofrend (5.0 l/t).

A brief meteorological characterization during the period of field scientific research indicates that weather conditions were quite variable over the years and had a significant impact on yield levels and sunflower productivity indicators. It was established that the years 2021, 2022, and 2023 were favorable, with sufficient moisture levels in the soil during the sunflower growing season. The years 2024 and 2025 were less favorable. The growing season of 2021 was excessively moist, and despite the drop in temperature caused by frequent rains during sunflower cultivation, a sufficiently high productivity and yield level of the studied crop were achieved.

Research Results. In the context of climate change and increasing competition for resources, it is important to find optimal solutions for enhancing agricultural productivity. In this regard, the analysis of the impact of various fertilization systems on sunflower yield in modern crop rotations, where commercial crops are prioritized, deserves special attention.

Over five years of research, we established that higher sunflower yields were obtained in the grain-fallow-row crop rotation with a saturation of the crop up to 20 % – 3.11 t/ha. In the crop rotation where sunflower and corn were grown alternately, the sunflower yield was nearly 1 t/ha lower, amounting to 2.17 t/ha (Table 1).

Continuous cultivation of the crop in the rotation resulted in the lowest seed yield – 1.69 t/ha. Considering the significant difference based on factor A, the impact of the crop rotation on sunflower yield was substantial.

The fertilization systems we used in different crop rotations also determined the level of sunflower yield. For instance, when growing sunflower without fertilizers, we obtained an average yield of 1.94 t/ha across the crop rotations. The use of a biopreparation slightly increased the productivity of the crop to 2.11 t/ha, but the yield increase due to the action of microorganisms was within a significant difference, LSD_{05} for factor B = 0.23 t/ha. This allows us to conclude about the low effectiveness of biologization through seed inoculation with a biopreparation against the backdrop of natural soil fertility.

The use of mineral fertilizers in various crop rotations significantly influenced the increase in sunflower yield over the five years of our research. The yield increase due to additional macroelements amounted to 0.36 t/ha compared to the variant without fertilizers, resulting in a yield of 2.30 t/ha.

Incorporating the residues of the previous crop along with mineral fertilizer application ensured an increase in sunflower yield to 2.51 t/ha. The organo-mineral fertilization system significantly enhanced sunflower yield compared to the variant of growing the crop without fertilizers; however, it should also be noted that the effectiveness of the system was primarily ensured by the mineral components of nutrition. Due to the action of the organic component, the yield increase amounted to 0.21 t/ha, which was within a significant difference.

The higher yield level of 2.64 t/ha was ensured by the organo-mineral biologized fertilization system. The complex action of mineral, organic, and biological elements of the system contributed to an increase in yield by 0.70 t/ha, while the effects of the biopreparation and organic residues separately were less effective.

Table 1

Sunflower yield depending on crop rotation structure and fertilization system
(average for 2021–2025)

Crop rotations (sunflower saturation) (Factor A)	Fertilization systems (Factor B)	Yield	Difference, Factor A		Difference, Factor B		Average, Factor A	Average, Factor B
		t/ha	t/ha	%	t/ha	%	t/ha	t/ha
Continuous cultivation (100 %)	Without fertilizers	1.42	-	-	-	-	1.69	1.94
	Biologized	1.52	-	-	0.10	6.8		2.11
	Mineral	1.63	-	-	0.21	13.7		2.30
	Mineral biologized	1.73	-	-	0.31	18.9		2.43
	Organo-mineral	1.84	-	-	0.41	23.7		2.51
	Organo-mineral biologized	1.97	-	-	0.55	29.7		2.64
Grain-row crop rotation (50 %)	Without fertilizers	1.70	0.28	19.5	-	-	2.17	–
	Biologized	1.93	0.40	26.6	0.22	13.2		
	Mineral	2.18	0.54	33.3	0.48	24.7		
	Mineral biologized	2.29	0.56	32.2	0.59	27.0		
	Organo-mineral	2.38	0.55	29.8	0.68	29.7		
	Organo-mineral biologized	2.52	0.55	27.9	0.82	34.3		
Grain-fallow-row crop rotation (20 %)	Without fertilizers	2.82	1.28	89.5	-	-	3.11	
	Biologized	2.97	1.35	88.7	0.17	6.3		
	Mineral	3.19	1.46	89.4	0.39	13.7		
	Mineral biologized	3.34	1.53	88.2	0.56	18.2		
	Organo-mineral	3.36	1.47	80.2	0.61	18.6		
	Organo-mineral biologized	3.42	1.45	73.5	0.72	21.7		
LSD_{05} (t/ha): Factor A = 0.16, Factor B = 0.23, Factors AB = 0.39								

Considering that higher sunflower yield indicators, regardless of the fertilization system, were obtained in a grain-fallow-row crop rotation with a saturation of up to 20 %, larger yield increases due to the action of fertilization elements were recorded in the grain-row crop rotation, where sunflower constituted 50% of the crop rotation structure – from 0.22 t/ha to 0.82 t/ha. Moreover, it was interesting to note that the effectiveness of biological treatment in this crop rotation was also the highest in our study: due to the action of the biopreparation, the increase in sunflower seed yield was 0.22 t/ha – without using other fertilizers, 0.11 t/ha – with the mineral system, and 0.14 t/ha – with the organo-mineral fertilization system.

Crop rotation and fertilization system are key factors influencing not only yield but also productivity elements of sunflower, such as oil content. Choosing the right crops for rotation can improve soil structure, reduce the risk of diseases and pests, and increase nutrient availability. The use of different types of fertilizers, such as organic and mineral, can significantly impact the physiological processes of plants, which in turn affects the oil content in seeds.

In our study, sunflower oil content ranged from 48.72 % to 50.24 %, and considering the LSD_{05} for factor A is 0.47 t/ha, we can conclude that crop rotation and its structure significantly influenced sunflower seed quality. However, unlike yield, where increasing additional nutrient elements in the soil contributed to its increase, we observed a reverse trend. Thus, with continuous sunflower cultivation, the average seed oil content across fertilization systems was 49.98% and was the highest in the study. The introduction of corn into the crop rotation and alternating crops every other year had almost no effect on oil content in seeds, with a slight decrease to 49.92 %. However, in the grain-fallow-row crop rotation, where sunflower saturation decreased to 20 % and the crop returned to the field after four years, oil content in seeds decreased to 49.11 %, which corresponded to a significant reduction (Table 2).

Table 2

Sunflower oil content depending on crop rotation structure and fertilization system, (average for 2021–2025)

Crop rotations (sunflower saturation) (Factor A)	Fertilization systems (Factor B)	Oil content, %	Difference, Factor A	Difference, Factor B	Average, Factor A	Average, Factor B
Continuous cultivation (100 %)	Without fertilizers	49.98		-	49.98	49.89
	Biologized	49.82		-0.16		49.81
	Mineral	50.02		0.04		49.71
	Mineral biologized	50.02		0.04		49.71
	Organo-mineral	49.96		-0.02		49.51
	Organo-mineral biologized	50.08		0.10		49.40
Grain-row crop rotation (50 %)	Without fertilizers	50.20	0.22	-	49.92	49.89
	Biologized	50.24	0.42	0.04		
	Mineral	49.86	-0.16	-0.34		
	Mineral biologized	50.20	0.18	0.00		
	Organo-mineral	49.86	-0.10	-0.34		
	Organo-mineral biologized	49.18	-0.90	-1.02		
Grain-fallow-row crop rotation (20 %)	Without fertilizers	49.48	-0.50	-	49.11	
	Biologized	49.38	-0.44	-0.10		
	Mineral	49.24	-0.78	-0.24		
	Mineral biologized	48.92	-1.10	-0.56		
	Organo-mineral	48.72	-1.24	-0.76		
	Organo-mineral biologized	48.94	-1.14	-0.54		
LSD_{05} (%): Factor A = 0.47, Factor B = 0.66, Factors A B = 1.14						

Among the fertilization options, it is worth noting the organo-mineral biologized system used in the grain-row crop rotation with 50 % sunflower saturation: seed oil content of 49.18 % was the lowest and compared to the unfertilized option, it decreased by 1.02%. Moreover, the effect of the fertilization factor was greatest in this crop rotation – seed oil content decreased by 1.02 % compared to the unfertilized option, while using other systems this indicator decreased by 0.34 %.

In a grain-fallow-row crop rotation with 20 % sunflower saturation, the oil content was the lowest in the experiment. In the absence of fertilizers, due to the effect of the crop rotation factor alone, the oil content in the seeds decreased by 0.50 %, which was significant. Increasing the nutrient background led to a decrease in the oil content in the seeds, with the lowest values recorded when using the organo-mineral fertilization system at 48.72 %. It is important to note the influence of the biopreparation on sunflower seed quality. Although the oil content in seeds from biologized crop rotations did not significantly differ from that in traditional crop rotations (where the biopreparation was not used), it should be noted that inoculating seeds before sowing in crop rotations with 100 % and 20 % sunflower saturation under the organo-mineral fertilization system contributed to a slight increase in oil content of +0.12-0.18 t/ha; whereas in a crop rotation with 50 % sunflower saturation, it decreased by 0.68 t/ha.

We established a strong negative correlation between the yield and oil content of sunflower, -0.87, with the closeness of the relationship between the indicators equal to 0.7684, which is also strong (Figure 1). With higher seed yields in the experiment, achieved by growing sunflower in a grain-fallow-row crop rotation with 20 % crop saturation and an organo-mineral fertilization system combined with a biological element, yielding 3.36 t/ha and 3.42 t/ha, the oil content of the seeds was the lowest at 48.72 % and 48.94 %, respectively.

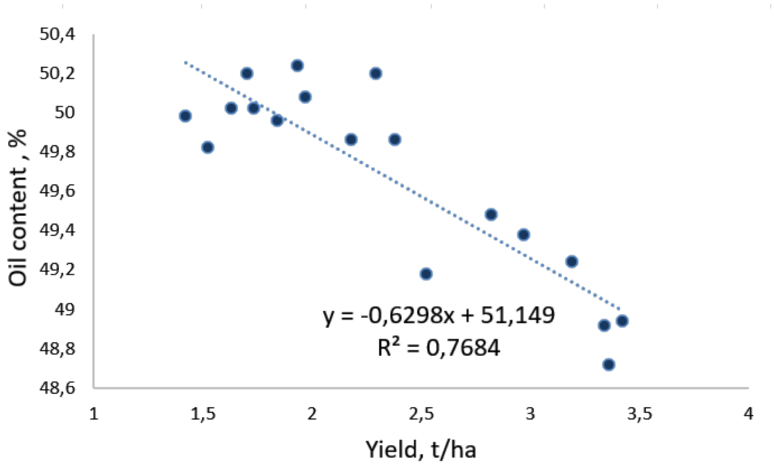

Fig. 1. **Correlation-regression dependence of yield and oil content of sunflower**

The oil yield is a key indicator of sunflower cultivation efficiency, as it determines the economic benefit from production. A high oil yield indicates seed quality and the correctness of agronomic practices, allowing farmers to achieve maximum profit. Additionally, this indicator affects the competitiveness of products in the oilseed market.

In our study, over an average of 5 years, sunflower oil yields ranged from 0.71 to 1.67 t/ha. The highest oil yield was provided by the grain-fallow-row crop rotation with 20% sunflower saturation – 1.53 t/ha. When growing sunflower in rotation with corn, the oil yield decreased to 1.08 t/ha, and with continuous cultivation, it dropped to 0.84 t/ha (Table 3).

It is also worth noting the significant impact of the fertilization system on sunflower oil yield. Considering the smallest significant difference for factor B, all fertilization systems we studied provided an increase in oil yield compared to the unfertilized option.

Table 3

Oil yield depending on crop rotation structure and fertilization system
(average for 2021–2025)

Crop rotations (sunflower saturation) (Factor A)	Fertilization systems (Factor B)	Oil yield	Difference, Factor A		Difference, Factor B		Average, Factor A	Average, Factor B
		t/ha	t/ha	%	t/ha	%	t/ha	t/ha
Continuous cultivation (100 %)	Without fertilizers	0.71			-	-	0.84	0.97
	Biologized	0.76			0.05	6.8		1.05
	Mineral	0.82			0.11	14.0		1.14
	Mineral biologized	0.87			0.16	19.4		1.20
	Organo-mineral	0.92			0.21	24.1		1.24
	Organo-mineral biologized	0.99			0.28	30.0		1.30
Grain-row crop rotation (50 %)	Without fertilizers	0.86	0.15	20.4	-	-	1.08	
	Biologized	0.97	0.21	27.9	0.12	13.4		
	Mineral	1.09	0.27	33.6	0.24	24.2		
	Mineral biologized	1.15	0.28	32.4	0.30	27.0		
	Organo-mineral	1.19	0.27	29.2	0.33	29.0		
	Organo-mineral biologized	1.24	0.26	25.8	0.39	32.5		
Grain-fallow-row crop rotation (20 %)	Without fertilizers	1.34	0.63	88.7	-	-	1.53	
	Biologized	1.42	0.67	87.6	0.08	6.2		
	Mineral	1.52	0.71	86.5	0.18	12.8		
	Mineral biologized	1.59	0.72	83.3	0.25	16.6		
	Organo-mineral	1.61	0.69	74.6	0.27	16.7		
	Organo-mineral biologized	1.67	0.69	69.6	0.33	20.7		
LSD_{05} (t/ha): Factor A = 0.08, Factor B = 0.12, Factors AB = 0.20								

When analyzing the impact of factors on oil yield, we observed a trend similar to that of yield formation. Thus, the mineral fertilization system had a greater effect on increasing oil content, with an oil yield of 1.14 t/ha and a yield increase of 0.17 t/ha. The combination of the mineral fertilization system with an organic element provided an even higher oil yield of 1.24 t/ha (+0.27 t/ha compared to the variant without fertilizers). However, considering the LSD_{05} for factor B at 0.12 t/ha, the incorporation of residues from the previous crop did not significantly affect the difference in oil yield compared to the mineral fertilization system.

In biologized crop rotations, the oil yield was somewhat higher, as in traditional ones (similar to yield formation), at +0.6-0.8 t/ha, but no significant difference was established between them. The highest average oil yield was achieved through the combined use of mineral and organic fertilizers along with a biopreparation, regardless of the crop rotation structure, at 1.30 t/ha.

Growing sunflower in a grain-fallow-row crop rotation with a minimal share of sunflower, up to 20 %, ensured higher productivity of the crop, with an oil yield ranging from 1.34 to 1.67 t/ha. The largest increases in oil yield, 0.71-0.72 t/ha or 83-86 %, were achieved through the use of a mineral fertilization system and its combination with a biological component. However, in terms of oil yield, this variant was not the best in the experiment, with yields of 1.52 t/ha and 1.59 t/ha. Higher indicators in this crop rotation were noted with the organo-mineral and organo-mineral biologized fertilization systems, yielding 1.61 t/ha and 1.67 t/ha, respectively, while the effectiveness of the crop rotation was somewhat lower, with oil yield increases of 74.6 % and 69.6 %, respectively.

It should also be noted that the fertilization systems had the most effective impact on increasing oil yield in crop rotations with a 50 % saturation of sunflower. The yield increase under the mineral fertilization system was 0.24 t/ha or 24.2 %, while under the organo-mineral system it was 0.33 t/ha or 29.0 %. The use of biopreparations enhanced the effects of both mineral and organic components of the fertilization systems, resulting in oil yields that were 27.0 % and 32.5 % higher, respectively.

Moreover, the additional nutrients were utilized more effectively by sunflower plants in crop rotations with a 100 % saturation of the crop than those that formed their productivity in rotations where sunflower constituted 20 % of the structure. This is particularly true for the use of the organo-mineral fertilization system and its biological enhancement, where the oil yield increase in these variants was 24.1-30.0 % and 12.8-16.6 %, respectively.

An important indicator of the results of the scientific work conducted, which should be used for practical implementation in production, is the economic analysis of cultivation. To determine the economic efficiency of sunflower cultivation, prices for services, seed, and harvested material that had formed in the Ukrainian market as of October 22, 2025, were used.

With an average sunflower yield established over five years of research, the lowest yield occurred in the variant of continuous cultivation (100 % saturation of the crop rotation with sunflower) without fertilizers, which had the lowest production costs of 18,995 UAH/ha (Table 4).

However, in this variant, the lowest level of yield led to the lowest cost of produced goods – 37346 UAH/ha. The use of a mineral fertilization system under continuous sunflower cultivation resulted in the lowest conditional net profit – 13455 UAH/ha with the lowest profitability of 45.7 %.

The use of a biologized fertilization system in continuous sunflower cultivation contributed to an increase in profitability to the level of 104.7 %. The higher conditional net profit in continuous sunflower cultivation was observed with the organo-mineral biologized fertilization system, amounting to 21556 UAH/ha.

It was established that reducing the concentration of sunflower in various crop rotation models contributed to an increase in economic indicators regarding conditional net profit. In a grain-cultivated crop rotation with a sunflower saturation of up to 50 %, it ranged from 25223 UAH/ha in the variant without fertilizers to 35,052 UAH/ha with the organo-mineral biologized fertilization system, achieving maximum values in a grain-fallow-row cultivated crop rotation with a sunflower saturation of up to 20 %, where the indicators varied from 49283 UA H/ha (profitability 234 %) for the mineral system to 57138 UAH/ha (profitability 174.2 %) for the organo-mineral biologized fertilization system.

Table 4

Economic efficiency of sunflower cultivation depending on crop rotation structure, average for 2021–2025

Fertilization systems (Factor B)	Yield, t/ha	Production costs, UAH/ha	Cost of gross output, UAH/ha	Conditional net profit, UAH/ha	Profitability, %
Continuous cultivation (100 % sunflower saturation)					
Without fertilizers	1.42	18995	37346	18351	96.6
Biologized	1.52	19531	39976	20445	104.7
Mineral	1.63	29413	42869	13455	45.7
Mineral biologized	1.73	30213	45499	15286	50.6
Organo-mineral	1.84	29121	48392	19271	66.2
Organo-mineral biologized	1.97	30255	51811	21556	71.2
Grain-row crop rotation (50 % sunflower saturation)					
Without fertilizers	1.70	19487	44710	25223	129.4
Biologized	1.93	20253	50759	30506	150.6
Mineral	2.18	30382	57334	26952	88.7
Mineral biologized	2.29	31199	60227	29028	93.0
Organo-mineral	2.38	30071	62594	32523	108.2
Organo-mineral biologized	2.52	31224	66276	35052	112.3
Grain-fallow-row crop rotation (20 %					
Without fertilizers	2.82	21248	71010	49762	234.2
Biologized	2.97	21908	75481	53573	244.5
Mineral	3.19	31984	81267	49283	154.1
Mineral biologized	3.34	32907	85738	52831	160.5
Organo-mineral	3.36	31709	87053	55344	174.5
Organo-mineral biologized	3.42	32808	89946	57138	174.2

Thus, economic indicators when cultivating sunflowers can primarily be improved through crop rotation factors, which allows us to assert the regularity: the lower the concentration of sunflowers in the crop rotation, the higher the level of economic efficiency and yield. Against the backdrop of crop rotation factors, economic indicators depended on the fertilization system. The least costly element in sunflower cultivation concerning fertilization is the use of a biologized system, which allows for an increase in economic indicators in continuous sunflower cultivation compared to the variant without fertilizers, yielding a conditional net income increase of 2094 UAH/ha in a grain-row crop rotation with a sunflower saturation of 50 % – 5283 UAH/ha, and in a grain-fallow-row crop rotation with a sunflower saturation of 20 % – by 3815 UAH/ha. The highest economic efficiency of sunflower cultivation was observed in a grain-fallow-row crop rotation with a sunflower saturation of 20 % under the organo-mineral biologized fertilization system, which contributed to achieving the highest level of conditional net profit of 57138 UAH/ha with a profitability of 174.2 %.

Discussion and conclusions. Modern agriculture faces numerous challenges, including climate change, increasing demands for productivity, and the need to ensure the sustainability of agro-systems. In the context of these challenges, crop rotations and effective fertilization systems become key factors that can significantly impact sunflower cultivation outcomes.

Discussion and analysis of data obtained from other studies will allow for consideration of the practical aspects of implementing these strategies in the production process, enabling farmers to make informed decisions to enhance the efficiency of their operations.

The results of research conducted at the Poltava State Agricultural Research Station named after M. Vavilov demonstrated a positive impact of the fertilization system on the yield and quality of sunflower hybrid seeds of various maturity groups. In the study, the oil content in sunflower seeds varied depending on the dose of mineral fertilizers and the type of foliar feeding. The combination of primary application of mineral fertilizers ($N_{32}P_{32}K_{32}$) and foliar feeding of sunflower plants provided the highest oil yield per unit area (1.23-1.42 t/ha) (Totsky et al., 2024).

The combination of the synergistic action of the preparations Phytosporin and Agrostimulant during seed treatment in the experiments by Domaratsky and co-authors on seed yield and oil content resulted in a conditional oil yield of 1.49 t/ha, while applying it at the budding phase yielded 1.65 t/ha, which was 35-50 % higher compared to the control (Domaratsky et al., 2019).

The use of the preparations Ceron (0.5 l/ha) and Architect (0.5 l/ha) in experiments conducted in the conditions of Northern Steppe Ukraine contributed to an increase in oil content by 3-8 % and 4-6 %, respectively (Tsyliuryk et al., 2021).

The yield of sunflower seeds grown with a crop rotation saturation of 12.5 % to 20 % in Tsymbal's experiments ranged from 3.91 to 4.44 t/ha, while the oil content in sunflower seeds was at the level of 45.4 % to 45.7 %. The economic efficiency of sunflower cultivation within the structure of multi-rotation crop rotations is as follows: conditional net profit – 24.93-30.14 thousand UAH/ha with a high level of profitability – 176-211 % (Tsymbal et al., 2022).

The results of our research confirm the role of crop rotations and fertilizers in shaping the yield and productivity of sunflowers; the differences in indicators are determined by the conditions of the research and the complex of factors studied.

Thus, we have proven that in the conditions of the Northern Steppe of Ukraine, growing sunflowers as the main oilseed and commercial crop is an economically viable and promising direction for agricultural production. This is due to high profitability, stable market demand for oil, and the possibility of adapting modern agronomic technologies that contribute to increased yield and product quality, namely:

– continuous sunflower cultivation using an organo-mineral biologized fertilization system can ensure sunflower yields at the level of 1.97 t/ha, which is higher compared to other crop rotations, with an oil content of 50.08 %. The profitability of this technology was 71.2 %, with a conditional net income of 21556 UAH/ha;

– in a crop rotation with 50 % saturation with sunflowers, introducing corn, which is an important and commercially attractive crop, also provided higher efficiency for sunflower cultivation through the organo-mineral biologized fertilization system: yield level of 2.52 t/ha, oil yield of 1.24 t/ha. The profitability of production increased to 112.3 %, while conditional income rose to 35052 UAH/ha;

– higher production and economic efficiency indicators can be achieved when growing sunflowers in a grain-fallow-row crop rotation with saturation up to 20% against the background of an organo-mineral biologized fertilization system: yield – 3.42 t/ha, oil content 48.94 %, and oil yield – 1.67 t/ha, with a profitability level of 174.2 % and the highest conditional net income of 57,138 UAH/ha;

– economic indicators when growing sunflowers can primarily be increased through the crop rotation factor, allowing us to assert the regularity – the lower the concentration of sunflowers in the crop rotation, the higher the level of economic efficiency. Against the background of the crop rotation factor, economic indicators depended on the fertilization system;

– the least costly element when growing sunflowers concerning the fertilization factor is the use of a biologized fertilization system, which contributed to obtaining additional conditional net profit from continuous cultivation of the crop at the level of 2094 UAH/ha; in a grain-row crop rotation with 50 % saturation of sunflowers – 5283 UAH/ha; in a grain-fallow-row crop rotation with 20 % saturation of sunflowers – by 3815 UAH/ha.

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ПРОДУКТИВНІСТЬ ТА ЕКОНОМІЧНА ЕФЕКТИВНІСТЬ ВИРОЩУВАННЯ СОНЯШНИКУ В РІЗНИХ СІВОЗМІНАХ ЗАЛЕЖНО ВІД СИСТЕМ УДОБРЕННЯ

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В статті представлені результати дослідження елементів технології вирощування соняшника, як важливої олійної культури, запропоновані шляхи оптимізації виробництва продукції в короткоротаційних сівозмінах з різним насиченням соняшником, збалансованим використанням мінеральних добрив, органічних решток та біопрепарату. Найвищі показники продуктивності та економічної ефективності вирощування соняшнику отримали в зерно-паро-просапній сівозміні (частка соняшнику 20 %) на фоні органо-мінеральної біологізованої системи удобрення: урожайність – 3,42 т/га, вихід олії – 1,67 т/га, умовно-чистий прибуток – 57138 грн/га з рівнем рентабельності 174,2 %. Економічна ефективність вирощування соняшнику, в першу чергу, залежала від сівозмінного фактору – зменшення концентрації соняшнику сприяло збільшенню вартості вирощеної продукції та умовно-чистого прибутку. Системи удобрення підсилюють вплив сівозміни, найбільший ефект забезпечує комплексна дія елементів живлення – комбінація мінеральних добрив, органічної речовини побічної продукції попередника та біопрепаратів.

Ключові слова: сівозміни, системи удобрення, насичення сівозмін соняшником, урожайність, продуктивність, економічна ефективність вирощування соняшнику.