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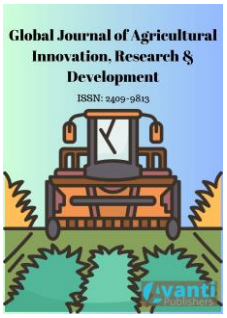

Economic Efficiency of Applying Biological Growth Regulators for Growing Sunflower in the Zone of Steppe Soils

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ABSTRACT

In the conditions of climate change, the selection and adjustment of crop cultivation systems in the moisture deficit zone and the management of risky agriculture to ensure the profitability of production remain an urgent issues. In particular, the Steppe of Ukraine is a zone of increased risk for agricultural production, which is associated with difficult climatic conditions characterized by droughts and low rainfall. An effective measure to ensure stable harvests is the use of growth-regulating biological preparations. Therefore, the purpose of the research was to establish the regularities of the influence of growth-regulating biological preparations on the formation of productivity and the economic efficiency of sunflower cultivation in the zone of risky agriculture. The study was conducted in 2021–2022 in the Mykolaiv region of Ukraine. A three-factor field experiment was set up to study the influence of various biological preparations (Helafit Combi, Organic Balance, and Biocomplex-BTU) and plant stand density (30, 40, and 50 thousand pcs/ha) on the productivity of sunflower hybrids Vyrii, Yarylo, Blysk, Yaskravyi, and Epikur. It was found that the hybrids Yarylo, Epikur, and Yaskravyi had considerably lower levels of productivity. However, foliar fertilization had a positive effect and contributed to an increase in their productivity. A low level of productivity in 2022 (1.51 t/ha) was observed in the hybrid Epikur under the plant density of 30 thousand pcs/ha. The results of the field experiments allowed establishing that foliar fertilization with different biological preparations is an efficient and effective method for improving plant growth conditions, and can increase the level of agrocenosis genetic potential realization. It was found that the hybrid Vyrii with a seeding rate of 40 thousand pcs/ha and plant treatment with the biological preparation Helafit Combi is the most economically efficient hybrid, with a profitability of 25.59%, and a net profit of $127.20 per ha.

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1. Introduction

Climate change is a determinant of the development of the agricultural sector of Ukraine's economy since it affects the volume and structure of agricultural production costs [1-4]. Therefore, agricultural crop varieties and hybrids adapted to climate change with advanced cultivation technologies become topical [5-7]. The research found that, under conditions of an increase in the air temperature, the Western and the Central Forest Steppes, Right-bank Ukraine, and Donetsk sub-zone of the Northern Steppe of Ukraine will be favorable areas for growing sunflowers [8]. The Steppe of Ukraine is a zone of increased risks [9, 10].

The impact of climate change makes it necessary to improve cultivation technology [11, 12]. Climate change also stimulates the utilization of plant fertilization [13, 14] that involves foliar fertilization with macro- and micro-elements [15, 16], application of plant growth regulators which enhance plant nutrition [17-19], increase the level of their stress-resistance, improve protection against unfavorable conditions of the environment, pests, and diseases [20-22]. Therefore, their effect can lead to an increase in the crop productivity of 5-15% [23, 24]. Therefore, the application of plant growth regulators is the most profitable method for increasing crop productivity [25-27]. Research on the economic efficiency of applying these preparations in different climatic zones for each agricultural variety or hybrid becomes highly topical in this context.

Sunflower is a major oil-bearing crop in Ukraine, its share in the structure of crop rotations is 25-28%. Seeds of modern released varieties and hybrids contain 50-52% of oil, and those of selected varieties and hybrids – up to 60%, therefore they require a high level of moisture content [28-30]. Therefore, sunflower cultivation is a priority direction in crop production [31-33]. According to the data of the State Statistics Committee of Ukraine, crop area under sunflower cultivation in Ukraine increased sharply from 1.5 to 6.5 million hectares over the past 20 years. Forecast analysts indicate that there will be a tendency for an increase in the crop areas [34, 35].

Opportunities for expanding crop areas arose after breeding the genotypes resistant to broomrape and also after implementing advanced plant protection products and herbicides [36-39] that allowed removing the previous restrictions on crop areas under sunflower within 7–8% of arable lands under conditions of seven- or eight-field crop rotations [29, 32]. It is worth mentioning that technologies for growing sunflowers have been improved [40-43], and highly productive and adaptive hybrids [44-46] capable of producing high yields under dry conditions of the Steppe zone have been bred. In particular, the average sunflower productivity in Ukraine has increased from 0.98 t/ha to 1.89 t/ha for the past 20 years [47]. However, the above high results can be improved due to the implementation of advanced production technologies based on the application of eco-friendly preparations that increase the economic efficiency of crop production.

The purpose of the study is to show the economic efficiency of using eco-friendly multi-functional preparations in technological schemes for sunflower cultivation under non-irrigated conditions in the Steppe zone of Ukraine.

2. Material and Methods

Field experiments were conducted in 2021-2022 under non-irrigated conditions in the experimental field of Mykolaiv State Agricultural Research Station of the Institute of Climate-Oriented Agriculture of the National Academy of Agricultural Sciences. This research direction means conducting a three-factor field experiment identifying the impact of different biological preparations and plant density on sunflower hybrid productivity. Location of the research field and placement of sunflower hybrid crops: N 46°98'16.4'' E 32°14'57.0''. Factor A is a sunflower hybrid bred by the Plant Production Institute named after V.Ya. Yuriev of the NAAS: Vyrii, Yarylo, Blysk, Yaskravyi and Epikur; Factor B – different plant densities (30, 40 and 50 thousand pcs/ha); and Factor C – plant treatment at the vegetative stage at the beginning of budding with biological preparations (Helafit Combi, Organic Balance and Biocomplex-BTU). Sunflower plants were treated with a backpack sprayer according to the research scheme. The experiment was replicated three times; the crop area of the first-order plot was 168 m^2, and the registered crop area was 120 m^2. Winter wheat was a pre-crop in the field experiment. Fertilizers were applied with basic tillage at the rate of $N_{30}P_{30}K_{30}$. The seeds were planted with row spacing of 70 cm in the last decade of April. The plant density was formed manually in each row. The soil on the experimental plots is southern black soil.

The depth of a humus layer is 30 cm, and the depth of a transition layer is 60 cm. The pH of the soil solution is close to neutral (pH 6.5-6.8), and hydrolytic acidity is 2.00–2.52 mg equivalent per 100 g of soil. Availability of humus in the arable soil layer is 2.90%. Regarding mobile elements, medium nitrogen and phosphorus, and a high potassium content characterize the soil of the experimental plot. Registration of the yield and evaluation of the yield structure were performed using manual threshing of plants selected from the registered area of the experimental plots, the seed moisture content being 8%.

The research territory is located in a continental climate zone characterized by sharp and frequent fluctuations in air temperature, and dryness. The average annual precipitation is 360-380 mm, in spring and summer – 170 mm. Moisture accumulation in soil mainly occurs due to autumn and winter precipitation, when plants use less moisture, and evaporation is minimal. On average, the annual relative air humidity is 60–70%; in summer, it equals 40-60%. Annually, there are weak, medium, and intensive dry winds. The duration of the vegetative stage is 230–240 days.

In the research process, modeling of sunflower productivity was performed using the licensed program «Statistica 8.0». Calculations of economic efficiency were performed based on the average prices of 2022.

3. Results and Discussion

The research established that the level of moisture supply is a determining factor of sunflower hybrid in the conditions of the Steppe of Ukraine. Climatic conditions of 2021-2022 compared to the average multi-year indexes (norm – 1970-2020) are given in Fig. (**1**).

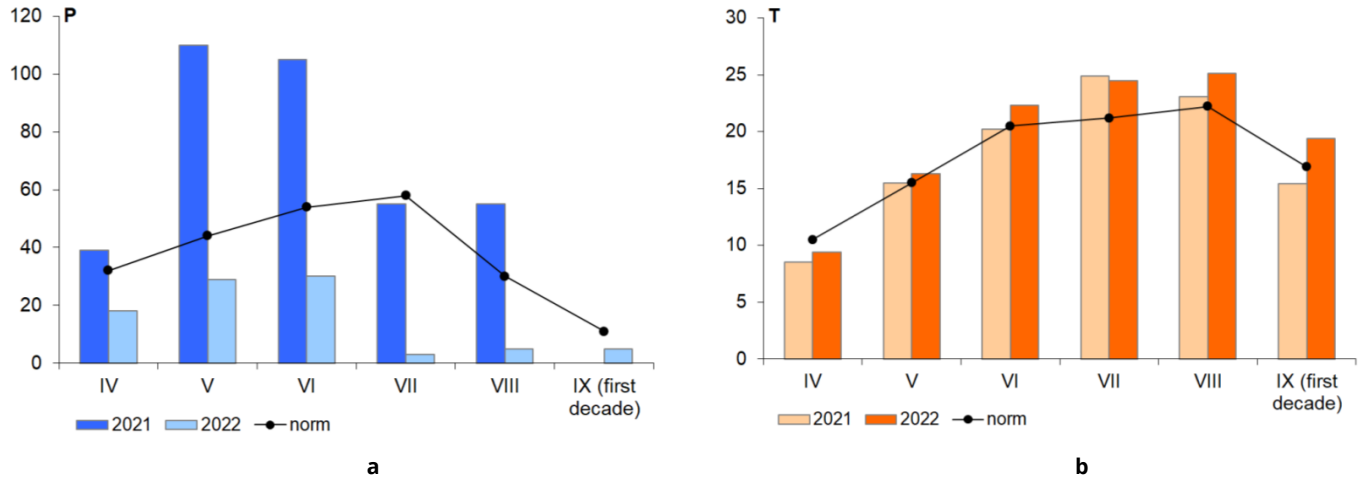

Figure 1: Climatic conditions of the vegetative stage of sunflower cultivation, 2021-2022: (**a**) amount of precipitation (P, mm); (**b**) average monthly air temperature (T, °C).

Analysis of the soil moisture shows that the soil moisture conditions of spring 2021 (Fig. **1a**) were favorable for sunflower growth. A decline in air temperature and precipitation was observed in the first half of the vegetative stage. Soil moisture reserves in the arable soil layer were favorable and sufficient for crop cultivation. Soil moisture was 34 mm in the arable layer and 134 mm in a meter soil layer. Sufficient moisture content in the topsoil due to productive rainfall and moderate air temperature at the end of May created favorable conditions for sowing and even the emergence of sunflower seedlings. However, the level of moisture supply in 2022 was insufficient, which caused a moisture deficit at the critical stages of crop growth. For instance, in the entire period of sunflower hybrid growth in 2022 there was 90 mm of rainfall, which was only 39% of the average multi-year norm, its uneven distribution.

The conditions of spring 2022 were characterized by drought. On March 28, 2022, productive moisture reserves in the arable and a meter soil layer were sufficient: the arable soil layer – 39 mm, a meter soil layer – 115 mm. The pre-sowing period was characterized by dry winds that considerably reduced soil moisture. Moisture deficit at the

end of May (the amount of precipitation in this period equaled 29 mm, being 66% of the norm) harmed sunflower growth and development.

The air temperature at the vegetative stage of sunflower growth in 2022 (Fig. **1b**) was high compared to the average multi-year indexes of each month. An increase in the air temperature against a background of soil and air moisture deficit created difficult conditions for the main phenological stages of crop development and the formation of agrocenosis productivity. Hot weather and rainfall deficit in July accelerated the phenological stages of the sunflowers. High air temperatures, low humidity, and a lack of precipitation determined intensive soil moisture loss because of transpiration and evaporation. Dry winds in the first half of the vegetative stage of sunflower development caused a turgor loss in plats in the daytime; its restoration occurred only at nighttime.

The results of the field experiments revealed that foliar fertilization with different biological preparations is an effective and efficient method for improving conditions of plant development, which is capable of increasing the level of realization of agrocenosis genetic potential on the whole (Table **1**).

Table 1: Sunflower hybrid productivity depending on plant density and biological preparations in 2021 and 2022, t/ha.

Preparations (C)	Hybrid (A)									
	Blysk		Vyrii		Yarylo		Epikur		Yaskravyi	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Plant density – 30 thousand pcs/ha (B)										
Control (without treatment)	2.43	1.74	2.84	1.83	1.73	1.58	1.66	1.51	1.71	1.63
Helafit Combi	2.79	1.88	3.38	2.05	1.89	1.66	1.76	1.68	1.93	1.81
Organic Balance	2.71	1.80	3.07	1.99	1.91	1.70	2.01	1.61	2.09	1.78
Biocomplex-BTU	2.68	1.81	3.31	1.94	1.88	1.69	1.93	1.63	2.00	1.77
Plant density – 40 thousand pcs/ha (B)										
Control (without treatment)	2.57	1.92	2.92	2.01	1.74	1.81	1.69	1.74	1.85	1.77
Helafit Combi	2.98	2.11	3.51	2.22	1.95	1.95	1.90	1.91	2.03	1.85
Organic Balance	2.99	2.09	3.55	2.19	2.06	1.94	1.97	1.88	1.99	1.84
Biocomplex-BTU	2.83	2.10	3.48	2.16	2.01	1.88	2.04	1.80	2.06	1.79
Plant density – 50 thousand pcs/ha (B)										
Control (without treatment)	2.63	1.77	3.00	1.85	1.83	1.55	1.70	1.58	1.88	1.70
Helafit Combi	3.07	1.84	3.61	1.92	2.01	1.64	2.02	1.63	2.13	1.81
Organic Balance	3.02	1.80	3.54	1.88	2.03	1.65	2.11	1.64	2.15	1.76
Biocomplex-BTU	3.04	1.81	3.60	1.90	1.99	1.60	2.08	1.63	2.09	1.75
$LSD_{05,\ t/ha}$ (ABC)	0.07	0.05	0.09	0.06	0.07	0.06	0.09	0.07	0.08	0.06

Analysis of the research results for 2021 shows that a reduction in the pre-harvesting sunflower plant density from 50 thousand pcs/ha to 30 thousand pcs/ha is not appropriate (it concerns all the examined hybrids) under conditions of sufficient moisture content. The difference in sunflower productivity of different hybrids under the plant density of 40 and 50 thousand pcs/ha is not considerable. Under drought conditions in 2022, the highest productivity was observed under the plant density of 40 thousand pcs/ha. The highest level of productivity was identified in the hybrids Blysk and Vyrii.

The research results prove that the treatment of vegetating plants with biological preparations positively affected the formation of productivity of the examined agrocenoses. In 2021, the highest productivity of 3.61 t/ha was registered in the hybrid Vyrii with a plant density of 50 thousand pcs/ha and plant treatment with Helafit Combi. The productivity was 3.60 t/ha with the plant density of 50 thousand pcs/ha plant treatment with

Biocomplex-BTU. In 2022, the hybrid Vyrii had the highest productivity of 2.22 t/ha with a plant density of 40 thousand pcs/ha and plant treatment with Helafit Combi.

The results of the two-year research prove that the yields of the hybrids Yarylo, Epikur, and Yaskravy were lower yields than those of the hybrids Blysk and Vyrii. It is worth mentioning that foliar fertilization with biological preparations applied to the hybrids with lower productivity also positively affected their yields. A low level of productivity in 2021 (1.66 t/ha) was characteristic of the hybrid Epikur with a plant density of 30 thousand pcs/ha; in 2022, this hybrid productivity equaled 1.51 t/ha with the same plant density. Low productivity in 2022 was observed in the hybrid Yarylo (1.5 t/ha) with a plant density of 50 thousand pcs/ha.

Economic analysis of the research results was performed based on the prices in Ukraine at the beginning of October 2022 (the price of 1 t of sunflower seeds was $325 (including VAT)). To perform analysis, production costs were calculated according to the flow process charts based on the pre-harvesting plant density and treatment with biological preparations (Tables **2-4**).

Table 2: Economic efficiency of sunflower hybrid cultivation depends on biological preparations under conditions of the pre-harvesting density of 30 thousand pcs/ha. (prices in 2022)

No.	Variant of the Experiment	Yield, t/ha	Production Costs, $ / ha	Operating Profit, $ /ha	Cost Price, $/t	Profitability, %
Blysk						
1	Control (without treatment)	1.74	565.00	0.50	324.70	0.09
2	Helafit Combi	1.88	571.25	39.75	303.85	6.95
3	Organic Balance	1.80	571.25	13.75	317.35	2.40
4	Biocomplex-BTU	1.81	571.25	17.00	315.60	3.00
Vyrii						
1	Control (without treatment)	1.83	565.00	29.75	308.75	5.26
2	Helafit Combi	2.05	571.25	95.00	278.65	16.63
3	Organic Balance	1.99	571.25	75.50	287.05	13.22
4	Biocomplex-BTU	1.94	571.25	59.25	294.45	10.37
Yarylo						
1	Control (without treatment)	1.58	565.00	-51.50	357.60	-9.11
2	Helafit Combi	1.66	571.25	-31.75	344.13	-5.56
3	Organic Balance	1.70	571.25	-18.75	336.03	-3.28
4	Biocomplex-BTU	1.69	571.25	-22.00	338.03	-3.85
Epikur						
1	Control (without treatment)	1.51	565.00	-74.25	374.15	-13.14
2	Helafit Combi	1.68	571.25	-25.25	340.03	-4.42
3	Organic Balance	1.61	571.25	-48.00	354.80	-8.40
4	Biocomplex-BTU	1.63	571.25	-41.50	350.45	-7.26
Yaskravyi						
1	Control (without treatment)	1.63	565.00	-35.25	346.63	-6.20
2	Helafit Combi	1.81	571.25	17.00	315.60	2.98
3	Organic Balance	1.78	571.25	7.25	320.93	1.27
4	Biocomplex-BTU	1.77	571.25	4.00	322.73	0.70

Table 3: Economic efficiency of sunflower hybrid cultivation depends on biological preparations under conditions of the pre-harvesting density of 40 thousand pcs/ha. (prices in 2022)

No.	Variant of the Experiment	Yield, t/ha	Production Costs, $/ ha	Operating Profit, $ /ha	Cost Price, $/t	Profitability, %
Blysk						
1	Control (without treatment)	1.92	568.25	55.75	295.95	9.81
2	Helafit Combi	2.11	574.50	111.25	272.28	19.36
3	Organic Balance	2.09	574.50	104.75	274.88	18.23
4	Biocomplex-BTU	2.10	574.50	108.00	273.56	18.80
Vyrii						
1	Control (without treatment)	2.01	568.25	85.00	282.70	14.96
2	Helafit Combi	2.22	574.50	147.00	258.78	25.59
3	Organic Balance	2.19	574.50	137.25	262.33	23.89
4	Biocomplex-BTU	2.16	574.50	127.50	265.98	22.19
Yarylo						
1	Control (without treatment)	1.81	568.25	20.00	313.95	3.52
2	Helafit Combi	1.95	574.50	59.25	294.63	10.31
3	Organic Balance	1.94	574.50	56.00	296.13	9.75
4	Biocomplex-BTU	1.88	574.50	36.50	305.58	6.35
Epikur						
1	Control (without treatment)	1.74	568.25	-2.75	326.58	-0.50
2	Helafit Combi	1.91	574.50	46.25	300.78	8.15
3	Organic Balance	1.88	574.50	36.50	305.58	6.35
4	Biocomplex-BTU	1.80	574.50	10.5	319.18	1.83
Yaskravyi						
1	Control (without treatment)	1.77	568.25	7.00	321.05	1.23
2	Helafit Combi	1.85	574.50	26.75	310.55	4.66
3	Organic Balance	1.84	574.50	23.50	312.23	4.10
4	Biocomplex-BTU	1.79	574.50	7.25	320.95	1.26

Production costs in all the variants of the experiments were identical and equaled $565/ha. However, the difference was determined by the cost of additional treatment with biological preparations ($6.25/ha), and the cost of seeds increased by approximately $3.25/ha because of a rise in the seeding rate by 10 thousand pcs/ha calculated per hectare. It was established that foliar fertilization with biological preparations applied to different sunflower hybrids under conditions of different sowing densities positively impacted plant development and increased crop productivity. On the whole, cultivation of the hybrids Blysk and Vyrii had the highest indexes of the level of profitability in comparison with the hybrids Yarylo, Epikur, and Yaskravyi. An increase in the pre-harvesting plant density in 2022 to 50 thousand pcs/ha caused unprofitability in growing the hybrids Yarylo, Epikur, and Yaskravyi. The level of unprofitability (-10.15%) was registered in the control variant of the hybrid Epikur with a plant density of 50 thousand pcs/ha.

Cultivation of the sunflower hybrids Blysk and Vyrii with a plant density of 40 thousand pcs/ha under conditions of plant treatment with biological preparations was profitable. The highest level of profitability (25.59%) and net profit ($127.20/ha) was reached in the variant of the hybrid Vyrii with a plant density of 40 thousand

pcs/ha and plant treatment with the preparation Helafit Combi. It is worth mentioning that a decline in sunflower production efficiency in 2022 is related to a fall in productivity caused by dry weather, a drop in purchase prices by 1.5 times, and an increase in the prices for plant protection products, fuels and lubricants, and replacement parts.

Table 4: The economic efficiency of sunflower hybrid cultivation depends on biological practices under the pre-harvesting density of 50 thousand pcs/ha. (prices in 2022)

No.	Variant of the Experiment	Yield, t/ha	Production Costs, $/ ha	Operating Profit, $ /ha	Cost Price, $/t	Profitability, %
Blysk						
1	Control (without treatment)	1.77	571.50	3.75	322.88	0.66
2	Helafit Combi	1.84	577.75	20.25	314.00	3.50
3	Organic Balance	1.80	577.75	7.25	320.98	1.25
4	Biocomplex-BTU	1.81	577.75	10.50	319.20	1.82
Vyrii						
1	Control (without treatment)	1.85	571.50	29.75	308.93	5.20
2	Helafit Combi	1.92	577.75	46.25	300.90	8.00
3	Organic Balance	1.88	577.75	28.25	307.30	4.89
4	Biocomplex-BTU	1.90	577.75	39.75	304.08	6.88
Yarylo						
1	Control (without treatment)	1.55	571.50	-67.75	368.70	-0.12
2	Helafit Combi	1.64	577.75	-44.75	352.28	-7.74
3	Organic Balance	1.65	577.75	-41.50	350.15	-7.18
4	Biocomplex-BTU	1.60	577.75	-57.75	361.10	-10.00
Epikur						
1	Control (without treatment)	1.58	571.50	-58.00	361.70	-10.15
2	Helafit Combi	1.63	577.75	-48.00	354.45	-8.31
3	Organic Balance	1.64	577.75	-44.75	352.28	-7.74
4	Biocomplex-BTU	1.63	577.75	-48.00	354.45	-8.31
Yaskravyi						
1	Control (without treatment)	1.70	571.50	-19.00	336.18	-3.32
2	Helafit Combi	1.81	577.75	10.50	319.20	1.81
3	Organic Balance	1.76	577.75	-5.75	328.28	-0.99
4	Biocomplex-BTU	1.75	577.75	-9.00	330.15	-1.56

4. Conclusion

The field experiments conducted in 2021 and 2022 allowed for establishing the efficiency of applying eco-friendly plant growth regulators for growing sunflower hybrids. The experiments make it possible to draw the following conclusions:

1. Droughts characterized the conditions of spring 2022. There was 90 mm of precipitation in the entire period of sunflower hybrid growth in 2022, which was only 39% of the average multi-year norm. The rainfall distribution was uneven, and that harmed crop productivity.

2. The research results of 2022 showed that all the hybrids had the highest productivity under the plant density of 40 thousand pcs/ha. Crop density at 50 thousand pcs/ha had lower yields than those in the variants with a plant density of 40 thousand pcs/ha and were almost identical to those with a plant density of 30 thousand pcs/ha. The highest productivity in the years of the research was observed in the hybrids Blysk and Vyrii.
3. Biological preparations had a positive impact on agrocenose productivity. The highest productivity of 2.22 t/ha in 2022 was characteristic of the hybrid Vyrii in the variant of plant treatment with Helafit Combi and the plant density of 40 thousand pcs/ha. The hybrids Yarylo, Epikur, and Yaskravy had a considerably lower level of productivity. However, foliar fertilization also had a positive effect and contributed to an increase in their productivity. A low level of productivity in 2022 (1.51 t/ha) was observed in the hybrid Epikur under the plant density of 30 thousand pcs/ha.
4. Plant foliar fertilization with biological preparations under conditions of different sowing densities improved sunflower productivity, proving their positive impact on the economic efficiency of crop production. A high level of profitability was characteristic of the hybrids Blysk and Vyrii, with a plant density of 40 thousand pcs/ha and plant treatment with biological preparations. The highest level of profitability (25.59%) and the maximum net profit ($127.20/ha) was reached when growing the sunflower hybrid Vyrii with a plant density of 40 thousand pcs/ha and plant treatment with the biological preparation Helafit Combi.

Conflict of Interest

All authors declared that they have no conflict of interest.

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