EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2023, 24(9), 45–54
https://doi.org/10.12912/27197050/173004
ISSN 2719-7050, License CC-BY 4.0

Received: 2023.09.04
Accepted: 2023.10.08
Published: 2023.11.15

Analysis of the Effectiveness of Biological Plant Protection on Sunflower Productivity under Different Cenosis Density under the Non-Irrigated Conditions of the Steppe Zone

Yevhenii Domaratskiy[1*], Oleh Kovalenko[1], Tetiana Kachanova[1], Vitalii Pichura[2], Yurii Zadorozhnii[1]

[1] Mykolayiv National Agrarian University George Gongadze St., 9, Mykolayiv, 54020, Ukraine
[2] Kherson State Agrarian and Economic University, 73006, Kherson, Stritens'ka, Ukraine
* Corresponding author's e-mail: jdomar1981@gmail.com

ABSTRACT

The purpose of the article was to determine how foliar treatments of plants with environmentally friendly combined-action substances affect the yield of new sunflower hybrids under non-irrigated conditions of the Ukrainian Steppe zone. The field experiments were conducted in 2021–2022 on the experimental field of the Mykolaiv State Agricultural Research Station of the Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine under non-irrigated conditions on southern chernozem. The humus content in the arable soil layer was 2.90%, the depth of the humus layer was 0–30 cm, and the transitional layer was 30–60 cm. The research was conducted by establishing a three-factor field experiment, where factor A was sunflower hybrids of the Plant Production Institute named after V.Ya. Yuriev of National Academy of Agrarian Sciences of Ukraine - Vyrii, Yarylo, Blysk, Yaskravy and Epikur; factor B – different plant densities (30, 40 and 50 thousand/ha) and factor C – treatment of vegetative plants in the phase of budding with substances of biological origin (Helafit Combi, Organic Balance and Biocomplex BTU). The field experiment was located on the winter wheat forecrop. Fertilizers were applied during the main cultivation at a dose of N30P30K30. Sowing was carried out with a row spacing of 70 cm in the last decade of April. Yield accounting and the evaluation of the crop structure were carried out by manual threshing of plants selected from the accounting area of the test plots and recalculation by 8% seed moisture. From the results of observations, it was found that the foliar treatments of sunflowers with environmentally friendly combined-action substances contributed to the prolongation of the interphase periods in the second half of the growing season of all studied hybrids. Treatment of plants with environmentally friendly substances helped to reduce the level of damage to all hybrids by pathogenic microflora, the highest fungicidal efficacy was observed in Helafit Combi and Organic Balance. All hybrids formed the highest yields at a density of 40 thousand units/ha. Dense plantings up to 50 thousand units/ha were inferior in yield to the ones with a planting density of 40 thousand units/ha and were almost at the same level as the ones with 30 thousand units/ha. Hybrids Yarylo, Epikur and Yaskravy were significantly inferior in productivity; however, their foliar treatments also had a similar tendency to increase their productivity.

Keywords: sunflower, environmentally friendly substances, yield, Helafit Combi, Organic Balance.

INTRODUCTION

Years with dry conditions during the summer growing season prevail (60%) in the southern Ukraine. Droughts during the seed formation phase are particularly common and have a negative impact on the harvest. Almost every second year (46%) is characterized by a lack of moisture during the optimal sowing period, which causes the problem of achieving timely and healthy germination. For seven years out of forty-four, there has been a combination of spring and summer drought, which undermined all efforts to obtain an economically valuable crop (Pichura et al. 2017, Makarova et al. 2021, Osadchyi et al. 2022). In the southern Ukraine, years with dry conditions

during the summer growing season are prevalent (60%). The future food security of Ukraine depends on the efficiency and timeliness of adaptation of agricultural production to the new conditions created by global anthropogenic warming. Thus, the problem of determining the nature and scope of the impact of potential climate changes on agro-climatic growing conditions, productivity, and overall harvest is especially relevant (Ebi et al. 2021, Fei et al. 2023). On the basis of the agro-climatic conditions during the sunflower growing season under the constant climate change scenario, it was found that the sowing days and subsequent development phases will occur earlier than now, which will lead to a shorter growing season in the majority of the studied area (Martsinevskaya et al. 2018, Pichura et al. 2018). A comparative analysis of temperature and precipitation regimes shows that it is reasonable to believe that the expected weather conditions will be more favorable for sunflower cultivation in the Western and Central Forest-Steppe, as well as on the Right Bank and in the Donetsk sub-zone of the Ukrainian Northern Steppe (Medinets et al. 2016, Pichura et al. 2021). The highest risk of sunflower seed yield decline in certain years is expected in the Ukrainian Southern Steppe (Domaratsky 2021).

In order to reduce the negative impact on agrocenoses of extreme weather conditions caused by a lack of natural moisture and a high hydrothermal coefficient, foliar treatments of plants with various environmentally friendly substances with anti-stress effects are increasingly used in technological schemes of crop production (Domaratskiy et al. 2022, Mitra et al. 2023). The effectiveness of foliar fertilization of plants with microelements is well-known. Nowadays, complex microfertilizers are quite popular. The transfer of a microelement into a biologically active chelated form is possible with the help of special complexing agents (Sajyan et al. 2020, Kuznetsov et al. 2021, Sabaghnia et al. 2023). During the plant's foliar treatment, the surface of the leaf makes the most contact with a compound substance. The study of the effect of the complexonate on leaf biochemistry, namely, on photosynthesis processes, and the resulting issues of optimizing foliar treatment may have practical importance. Moreover, considering that a single plant has leaves with different levels of maturity and light exposure, as well as anthocyanin-pigmented leaves, the response to the substance may vary significantly (Agrawal et al. 2022). The most important requirement of agricultural production for modern sunflower hybrids is the ability to consistently display signs of productivity under various biotic and abiotic environmental factors, as well as to respond positively to their improvement, i.e. to be adaptable (Debaeke et al. 2023). Environmental adaptability is caused by the response of the genotype to changes in environmental conditions, which are manifested in phenotypic variability. It characterizes variation in cultivar traits as a result of the interaction between genotype-environmental systems in a particular soil and climatic zone (Vancostenoble et al. 2022, Giannini et al. 2022).

The stability of a hybrid may be associated either with the high adaptability of each genotype to different growing conditions (individual buffering) or with the adaptability of each of the genotype groups that make up the hybrid to a specific environment (population buffering). Stability characterizes the ability of a genotype to maintain a certain phenotype under different growing conditions as a result of the organism's regulatory mechanisms (Soleymani 2017, Petrenko et al. 2023). Thus, the hybrids which maintain high levels of stability in their productivity and quality of their oilseeds and are environmentally adaptable, should be considered the most valuable (Lee et al. 2023).

Application of various growth regulators in foliar treatments helps to more fully unlock the genetic potential of crop cultivars and hybrids. Therefore, foliar application of combined growth regulators fits into the system of mandatory agrotechnical practices for growing and maintaining crops and does not require additional costs; thus, their use will not only increase gross production but also reduce its cost, which is especially important under market conditions (Hussain et al. 2018, Domaratskiy et al. 2022). The implementation of such growth regulating substances of biological origin in production is a way to biologize field crop cultivation technologies, which can significantly reduce the chemical exposure of agrophytocenoses (Niu et al. 2022, Cheng et al. 2023). The purpose of the research was to determine the effectiveness of foliar treatments with environmentally friendly combined-action substances on the productivity of new sunflower hybrids under the non-irrigated conditions of the Ukrainian Steppe zone.

MATERIAL AND METHODS

The field experiments were conducted in 2021–2022 at the experimental field of the

Mykolaiv State Agricultural Research Station of The Institute of Climate-Smart Agriculture of The National Academy of Agrarian Sciences of Ukraine under non-irrigated conditions on southern chernozem. The humus content in the arable soil layer was 2.90%, the depth of the humus layer as 0-30 cm, and the transitional layer was 30–60 cm. The pH of the soil solution was close to neutral (pH 6.5–6.8), hydrolytic acidity was in the range of 2.00–2.52 mg. equiv. per 100 g of soil. As for the content of mobile elements, the soil of the experimental plot was characterized by an average content of nitrogen and phosphorus and very high potassium content.

The climatic conditions of the experimental plot are continental, characterized by drastic and frequent changes in annual and monthly air temperatures, as well as a hard hydrothermal coefficient of the observation area. The average annual precipitation is 360–380 mm, and 170 mm during the spring and summer growing season of winter crops. Autumn and winter precipitation plays the main role in the accumulation of moisture in the soil, when moisture is less consumed by plants and evaporates less due to relatively high humidity. Precipitation is unevenly distributed throughout the year, with July being the rainiest month and March the driest. The annual average air humidity is 60–70%, and 40–60% in the summer months. Mild, moderate and strong winds are observed annually, and especially intense winds are observed in about 4 out of 10 years. The growing season lasts 230–240 days.

The corresponding area of research was implemented by establishing a three-factor field experiment to study the effect of environmentally friendly combi-action substances and different pre-harvest plant density on the productivity of new sunflower hybrids. Thus, the sunflower hybrids selected by the Plant Production Institute named after V.Ya. Yuriev of National Academy of Agrarian Sciences of Ukraine – Vyrii, Yarylo, Blysk, Yaskravy and Epikur – were the factor A; factor B – different plant densities (30, 40 and 50 thousand/ha) and factor C – treatment of vegetative plants in the phase of budding with substances of biological origin (Helafit Combi, Organic Balance and Biocomplex BTU). Sunflower plants were sprayed according to the research scheme using a knapsack sprayer.

The experiment was repeated three times, the sown area of the first plot was 168 m^2, and the experimental area was 120 m^2. The field experiment was located on the winter wheat predecessor. Fertilizers were applied during the main cultivation at a dose of N30P30K30. Sowing was performed with a row spacing of 70 cm in the second ten days of May. Formation of the plant density in each row was adjusted manually to achieve the intended density. Yield accounting and evaluation of the crop structure were performed by manual threshing of plants selected from the registered area of the experimental plots and recalculation by 8% seed moisture. The yield was in fact recalculated to the basic moisture content (8%) and considering the impurities content. The experimental data were processed by multi-factor analysis of variance according to V.O. Ushkarenko (Ushkarenko et al. 2020). Modeling of yield formation was performed using the licensed "Statistica 10.0" software.

RESULTS AND DISCUSSION

The main limiting aspect of unleashing the genetic potential of sunflower hybrids under the conditions of severe hydrothermal coefficient in the southern Steppe zone is the lack of soil and atmospheric moisture. The analysis of weather conditions in 2021-2022 proves that they can be classified as medium-dry, typical for this growing zone. However, the moisture conditions for sunflower growing season in 2022 should be classified as difficult and unfavorable. The weather conditions during the years of field experiments in comparison with the average long-term indicators are shown in Figures 1 and 2.

When analyzing the level of moisture supply during the research years, it should be noted that the moisture conditions in the spring of 2021 were favorable for the vegetation of the studied sunflower hybrids in general. The reduced temperature regime along with precipitation in the first half of plant growth and development had a positive impact on the productivity of agrocenosis later on. As for the soil moisture reserves of the arable and one-meter layers, they can also be qualified as quite favorable for crop cultivation. They amounted to 34 mm in the arable layer and 134 mm in the one-meter layer, respectively. Productive precipitation in late May created the conditions for sufficient moisture in the sowing layer of the soil, and moderate temperature conditions created favorable conditions for sowing and obtaining healthy sunflower seedlings in the future.

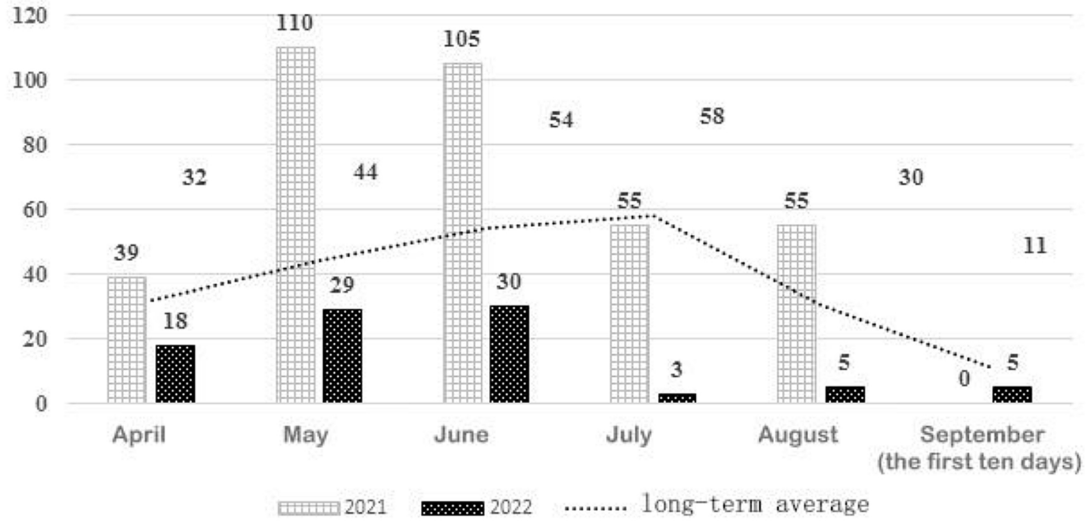

Figure 1. The amount of precipitation during the growing season of sunflower compared to the long-term average for 2021 and 2022, mm

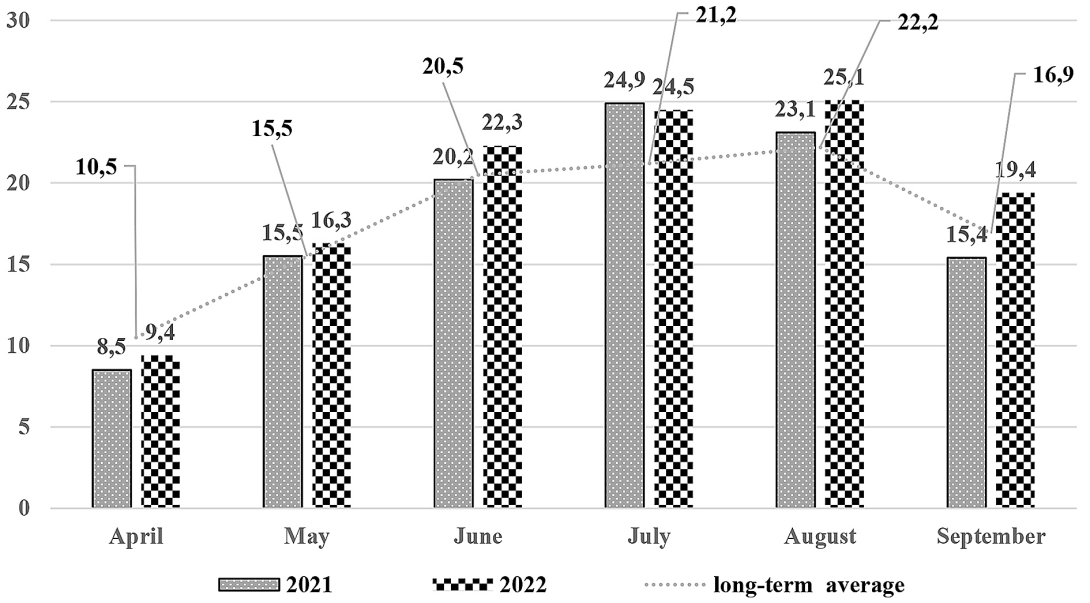

Figure 2. Average monthly air temperature during the growing season of sunflower compared to the long-term average for 2021 and 2022, °C

In contrast, the level of moisture supply in 2022 was quite low in comparison to 2021. The lack of precipitation due to high temperature conditions led to a significant shortage of moisture during the critical periods of sunflower growing season. Over the entire growing season of sunflower hybrids in 2022, 90 mm of precipitation was recorded, which is only 39% of the long-term average, and their distribution was uneven. According to the first evaluation of soil moisture reserves, which was conducted on March 28th, 2022, the reserves of productive moisture in both the arable and one-meter layers of soil were sufficient and amounted to 39 mm and 115 mm, respectively. In April, the weather was mostly warm, save for the second ten-day period, when low temperatures were typical for late March, but the average air temperature was within norm. Precipitation in April was noticeably below normal. Due to the predominance of dry and often windy weather in April, the upper layers of the soil dried out. Sowing of the experiment in both years under study was carried out in the second decade of May. When analyzing the temperature regime of

2021, it can be characterized as typical for a given zone. The average monthly temperature was within the range of long-term averages. Only in July 2021, the air temperature exceeded the long-term average by 3.7°C. As for the temperature regime during the sunflower growing season in 2022, it was significantly higher compared to the long-term average in each month. The recorded high temperatures along with the deficit of soil and air moisture created difficult conditions for the main phenological stages of crop development and the development of agrocenosis productivity. In July, hot weather and precipitation deficit sped up the course of sunflower phenological stages. High temperatures, low air humidity, and lack of precipitation resulted in intensive soil moisture consumption for transpiration and evaporation. Dry winds in the first half of the sunflower growing season led to weakened plant turgor during the daytime, so that only at night the plants managed to recover their condition.

From the results of observations, it was found that thinning or densening of the plantings did not have any significant effect on the course of the main transitional stages of crop development during the entire vegetation period of sunflowers. As for the foliar treatment of plants with substances of biological origin, it was found that the hybrids reacted differently to the introduction of biological components (Table 1).

The results of the research showed that the treatment of sunflower plants with substances of biological origin extended the vegetation period of all the studied hybrids during the stages from flowering to full maturity. This prolongation of the generative phase in 2021 was more effective, due to more favorable weather conditions during the growing season. In the areas where foliar treatments of plants with Helafit Combi and Organic Balance were applied on the hybrids, the period of seed ripening was prolonged by 8–10 days in 2021 and by 2–7 days in 2022 on average. Sunflower treatments with Biocomplex BTU had a slightly lesser impact on the extension of the growing season; the prolongation of the hybrids' vegetation under such conditions was within 5–8 and 2–4 days, respectively. Extremely unfavorable vegetation conditions in 2022 practically eliminated the positive effect of the substances on prolonging the vegetation of the crop in the generative phase. The prolongation of the photosynthetic apparatus activity is explained by the fact that the studied biological substances included not only trace elements in chelated form, but also fungal and bacterial complexes with their metabolic products. Such substances suppressed the development of pathogenic microflora during the generative phase of sunflower development and increased the overall immunity of the agrocenosis.

Later (in August-September), the conditions for sunflower development were unfavorable. Soil drought continued to intensify and deepen across the area. Sunflower was harvested in late September. Difficult weather conditions in 2022 led to almost simultaneous ripening of all sunflower hybrids in the experimental plots. However, in the areas treated with substances of biological origin, the ripening of hybrids was slowed down by 4–7 days compared to the control (without treatment with biological substances). Intense precipitation, high humidity along with low temperature conditions in 2021 in the first half of the growing season in some way contributed to the spread of diseases in the later stages of sunflower hybrids' organogenesis. Dry weather conditions in 2022, on the contrary, did not favor the spread of pathogenic microflora. Regarding different pre-harvest plant densities, sunflower hybrids did not have significant (mathematically proven) differences in this factor in all variants of the experiment. However, they reacted differently to foliar treatments with biological substances of vegetative plants (Table 2). The research results showed that the hybrids were similar in their resistance to pathogens of major diseases, but Yarylo and Epikur hybrids had a slightly lower percentage of plants affected by phomosis compared to Blysk, Yaskravy and Vyrii. This pattern was observed in both 2021 and 2022. Regarding the resistance of sunflower to downy mildew and gray mold rot, all the tested hybrids had almost the same high level of resistance to these pathogens (only a few plants were affected). Notably, in the severely dry year of 2022, the development of gray mold on the capitulum was not recorded at all.

Foliar plant treatments with substances of biological origin tended to reduce the damage of all studied hybrids throughout both years of research. Helafit Combi and Organic Balance had the highest fungicidal efficiency, and their application reduced the level of plant damage by pathogenic microflora by almost half, both in the severely dry year of 2022 and in moist year of 2021. The Biocomplex BTU was less effective in this regard, but it also reduced the number of affected plants compared to the control groups that did not receive any treatment at all.

Table 1. The main phenological phases of sunflower hybrids development depending on plant treatment with substances of biological origin in 2022

The development phase, types of work	Date			
	Control	Helafit Combi	Organic Balance	Biocomplex BTU
Blysk				
Sowing	16.05	16.05	16.05	16.05
Seedlings	23.05	23.05	23.05	23.05
Emergence of 2–4 leaves	05.06	05.06	05.06	05.06
Inflorescence emergence	24.06	24.06	24.06	24.06
Flowering	22.07	22.07	22.07	22.07
Fruit maturity	12.09	19.09	19.09	16.09
Harvest	20.09	20.09	20.09	20.09
Vyrii				
Sowing	16.05	16.05	16.05	16.05
Seedlings	23.05	23.05	23.05	23.05
Emergence of 2–4 leaves	05.06	05.06	05.06	05.06
Inflorescence emergence	24.06	24.06	24.06	24.06
Flowering	23.07	23.07	23.07	23.07
Fruit maturity	12.09	14.09	14.09	12.09
Harvest	20.09	20.09	20.09	20.09
Yarylo				
Sowing	16.05	16.05	16.05	16.05
Seedlings	23.05	23.05	23.05	23.05
Emergence of 2–4 leaves	05.06	05.06	05.06	05.06
Inflorescence emergence	26.06	26.06	26.06	26.06
Flowering	24.07	24.07	24.07	24.07
Fruit maturity	14.09	18.09	18.09	17.09
Harvest	20.09	20.09	20.09	20.09
Epikur				
Sowing	16.05	16.05	16.05	16.05
Seedlings	23.05	23.05	23.05	23.05
Emergence of 2–4 leaves	05.06	05.06	05.06	05.06
Inflorescence emergence	26.06	26.06	26.06	26.06
Flowering	24.07	24.07	24.07	24.07
Fruit maturity	14.09	17.09	16.09	17.09
Harvest	20.09	20.09	20.09	20.09
Yaskravy Яскравий				
Sowing	16.05	16.05	16.05	16.05
Seedlings	23.05	23.05	23.05	23.05
Emergence of 2–4 leaves	05.06	05.06	05.06	05.06
Inflorescence emergence	26.06	26.06	26.06	26.06
Flowering	24.07	24.07	24.07	24.07
Fruit maturity	13.09	16.09	16.09	16.09
Harvest	20.09	20.09	20.09	20.09

Table 2. Degree of sunflower damage by major diseases, depending on plant treatment with biological substances in 2021 and 2022, %

Hybrid	Substance	Phoma, %		Downy mildew, %		Gray mold on the capitulum, %	
		2021	2022	2021	2022	2021	2022
Blysk	Control	12	9	6	2	1	0
	Helafit Combi	5	4	4	0	0	0
	Organic Balance	6	5	3	1	0	0
	Biocomplex BTU	10	5	4	0	0	0
Vyrii	Control	13	8	7	4	0	0
	Helafit Combi	6	5	2	0	0	0
	Organic Balance	6	5	2	1	0	0
	Biocomplex BTU	11	6	3	1	0	0
Yarylo	Control	11	6	7	3	0	0
	Helafit Combi	4	2	2	1	0	0
	Organic Balance	5	3	2	1	0	0
	Biocomplex BTU	10	3	3	1	0	0
Epikur	Control	11	6	8	2	1	0
	Helafit Combi	4	1	3	0	0	0
	Organic Balance	4	2	4	0	0	0
	Biocomplex BTU	9	1	5	1	0	0
Yaskravy	Control	14	7	6	2	1	0
	Helafit Combi	4	4	2	0	0	0
	Organic Balance	3	3	2	0	0	0
	Biocomplex BTU	10	3	3	1	0	0

Table 3. The height of sunflower hybrids depending on the experimental variants, cm

Substances (C)	Hybrid (A)									
	Blysk		Vyrii		Yarylo		Epikur		Yaskravy	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Plant density - 30 thousand plants/ha (B)										
Control (no treatment)	195	171	180	168	171	155	174	156	177	160
Helafit Combi	196	171	180	168	174	155	178	155	180	159
Organic Balance	198	170	183	168	173	155	177	156	181	159
Biocomplex BTU	198	171	182	167	176	155	181	156	180	160
Plant density - 40 thousand plants/ha (B)										
Control (no treatment)	208	170	207	168	190	154	188	157	194	160
Helafit Combi	210	171	210	167	190	155	190	156	196	160
Organic Balance	209	170	210	167	193	154	192	156	196	159
Biocomplex BTU	210	170	211	167	193	154	191	155	198	161
Plant density - 50 thousand plants/ha (B)										
Control (no treatment)	210	171	209	167	191	155	187	157	195	161
Helafit Combi	211	171	212	167	192	156	189	157	196	160
Organic Balance	211	170	211	168	194	154	190	157	197	161
Biocomplex BTU	213	171	212	168	193	156	190	156	197	161
$HIP_{05,\ cm}$ (ABC)	3.1	2.8	3.2	2.7	3.1	2.4	3.4	2.7	3.3	2.6

By observing the processes of growth and development of sunflower plants in 2021 and 2022, it was found that the treatment with substances of biological origin did not have any significant (mathematically proven) effect on the height of the studied hybrids, but the increase in height due to the treatment with the biological substances was observed in almost all studied hybrids (Table 3).

The height variations were caused by different pre-harvest densities and genetic characteristics of a particular hybrid. The analysis of the observation data revealed that the high level of soil moisture reserves, productive precipitation during the growing season and favorable temperature conditions in 2021 generally ensured the development of sufficiently tall plants of the studied hybrids. Sowing sunflower at a reduced rate of 30 thousand units/ha formed slightly shorter plants compared to the rates of 40 and 50 thousand units/ha. There was no difference in plant height in the groups of 40 and 50 thousand plants/ha. The tallest plants in the experiment were hybrids Blysk and Vyrii. Increasing the sowing rate to 40–50 thousand plants/ha contributed to an increased linear size of plants of all studied hybrids by 8–10 cm. On the other hand, as far as the harsh weather conditions of 2022 are concerned, the lack of moisture due to high temperature contributed to the formation of shorter plants. There was no mathematically proven difference in linear plant size depending on different planting densities in the experiment as a whole. This can be said for all the studied hybrids. A slight difference in plant height occurred only in relation to a particular hybrid, which is based on purely genotypic characteristics of a particular hybrid. When analyzing the results of the related studies, it can be argued that foliar treatments with various biological substances are an effective and efficient way to improve the plant development conditions (Table 4).

The analysis of previous studies for 2021 shows that, under the conditions of sufficient moisture, reducing the pre-harvest density of sunflower plants from 50 thousand plants/ha to 30 thousand plants/ha is unnecessary, which is true for all the studied hybrids. The difference in the yield of different sunflower hybrids at densities of 40 and 50 thousand plants/ha is insignificant. Regarding the severely dry year of 2022, the results of the research showed that all hybrids produced the highest yield at a density of 40 thousand units/ha. Dense plantings of up to 50 thousand plants/ha were inferior in yield to the areas with a planting density of 40 thousand plants/ha and were almost at the same level as the variants of 30 thousand plants/ha. The overall highest productivity in both years of research was recorded in hybrids Blysk and Vyrii. Biological products also had a positive impact on the productivity of the studied

Table 4. Sunflower yield depending on the experimental variations, tons/ha

Substances (C)	Hybrid (A)									
	Blysk		Vyrii		Yarylo		Epikur		Yaskravy	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Plant density - 30 thousand plants/ha (B)										
Control (no 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 plants/ha (B)										
Control (no 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 plants/ha (B)										
Control (no 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
$HIP_{05,\ т/га}$ (ABC)	0,07	0.05	0,09	0.06	0,07	0.06	0,09	0.07	0,08	0.06

agrocenoses. In 2021, the highest yield in the experiment of 3.61 tons/ha was formed by the hybrid Vyrii in the area with a pre-harvest density of 50 thousand plants/ha under the treatment with Helafit Combi, the degree of influence of the Biocomplex BTU substance of 3.60 tons/ha in the same hybrid at a density of 50 thousand plants/ha was almost at the same level. The analysis of the yield data of the experimental plots for 2022 showed that the most productive hybrid was Vyrii on the variant of plant treatment with Helafit Combi and a pre-harvest density of 40 thousand units/ha – 2.22 t/ha. The results of two-year research proved that hybrids Yarylo, Epikur and Yaskravy were significantly inferior in the productivity to hybrids Blysk and Vyrii in the overall experiment for all the variations. However, foliar treatments of plants with biological agents of these hybrids also had a similar tendency to increase their productivity. The lowest yield in 2021 (1.66 tons/ha) was formed by the Epikur hybrid on the control area with a pre-harvest density of 30 thousand units/ha, and in 2022 – (1.51 tons/ha) also on the same area. Moreover, low productivity in 2022 was observed in the variations where sowing was carried out at a rate of 50 thousand units/ha with hybrids Yarylo (1.55 t/ha) and Epikur (1.58 t/ha).

CONCLUSIONS

According to the results of experimental data from field research conducted in 2021–2022 aimed at determining the effectiveness of the use of new environmentally friendly combined-action substances in sunflower cultivation technologies, it was found that foliar treatments of sunflower plants with environmentally friendly combined-action substances helped to prolong the transition stages in the second half of the growing season of all the studied hybrids. Even under unfavorable weather conditions, the ripening of plants on the areas treated with biological substances was slowed down by 4–7 days compared to the control area (without treatment with biological agents.

Treatment of plants with environmentally friendly substances helped to reduce the level of damage by pathogenic microflora for all hybrids, the highest fungicidal efficiency was observed in Helafit Combi and Organic Balance, with their application the damage by pathogenic microflora was reduced almost twice. All hybrids produced the highest yields at the density of 40 thousand plants/ha. Dense plantings of up to 50 thousand plants/ha were inferior in yield to the variations with a planting density of 40 thousand plants/ha and were almost at the same level as the variations of 30 thousand plants/ha. The highest productivity in both years of the experiment was observed in the Blysk and Vyrii hybrids (2.25–2.89 tons/ha on average in 2021–2022).

Bological substances also had a positive impact on the productivity of the studied agrocenoses. In 2022, the most productive hybrid was Vyrii in the variation of plant treatment with Helafit Combi and a pre-harvest density of 40 thousand units/ha – 2.22 tons/ha. Hybrids Yarylo, Epikur and Yaskravy were significantly inferior in productivity, but their foliar treatments also had a similar tendency to increase their productivity.

REFERENCES

1. Agrawal, S., Kumar, V., Kumar, S., Kumar Shahi, S. 2022. Plant development and crop protection using phytonanotechnology: A new window for sustainable agriculture. Chemosphere, 299, 134465.
2. Cheng, Yu, Luo, M., Zhang, T., Yan, S., Wang, Ch., Dong, Q., Feng, H., Zhang, T., Kisekka, I. 2023. Organic substitution improves soil structure and water and nitrogen status to promote sunflower (Helianthus annuus L.) growth in an arid saline area. Agricultural Water Management, 283, 108320.
3. Debaeke, P., Attia, F., Champolivier, L., Dejoux, J.-F., Micheneau, A., Al Bitar, A., Trépos, R. 2023. Forecasting sunflower grain yield using remote sensing data and statistical models. European Journal of Agronomy, 142, 126677.
4. Domaratskiy Ye. 2021. Leaf Area Formation, Photosyntetic Activity of Sunflower Plents Depending on Fertilizers and Growth Regulators. Journal of Ecological Engineering, 22(6), 99–105.
5. Domaratskiy Ye., Kozlova O., Dobrovolskiy A. and Bazaliy V. 2022. Optimization of water consumption of high-oleic sunflower hybrids under non-irrigated conditions of the steppe zone of Ukraine. Journal of Ecological Engineering, 23(6), 14–21.
6. Domaratskiy, Ye., Bazaliy, V., Dobrovolskiy, A., Pichura, V., Kozlova O. 2022. Influence of Eco-Safe Growth-Regulating Substances on the Phytosanitary State of Agrocenoses of Wheat Varieties of Various Types of Development in Non-Irrigated Conditions of the Steppe Zone. Journal of Ecological Engineering, 23(8), 299–308.
7. Ebi, K.L., Anderson, C.L., Hess, J.J., et al., 2021. Nutritional quality of crops in a high CO2 world: an agenda for research and technology development. Environ. Res. Lett. 16(6), 064045.

8. Fei, Ch., Jagermeyr, J., McCarl, B, Contrerasf, E., Mutterf, C., Phillipsf, M., Ruane, A., Sarofim, M., Schultz, P. Vargo, A. 2023. Future climate change impacts on U.S. agricultural yields, production, and market. Anthropocene, 42, 100386.
9. Giannini, V., Mula, L., Carta, M., Patteri, G., Roggero P.-P. 202). Interplay of irrigation strategies and sowing dates on sunflower yield in semi-arid Mediterranean areas. Agricultural Water Management, 260, 107287.
10. Hussain, M., Farooq, Sh., Hasan, W., Ul-Allah, S., Tanveer, M., Farooq, M. Nawaz, A. 2018. Drought stress in sunflower: Physiological effects and its management through breeding and agronomic alternatives. Agricultural Water Management, 201, 152–166.
11. Kuznetsov, I., Alimgafarov, R., Islamgulov, D., Nafikova, A., Dmitriev, A. 2021. Effect of growth regulator Melafen and chelated fertilizer Metallocene on yield and quality of winter wheat. Biocatalysis and Agricultural Biotechnology, 38, 102198.
12. Lee, K. Wang, K. 2023. Strategies for genotype-flexible plant transformation. Current Opinion in Biotechnology, 79, 102848.
13. Makarova, T., Domaratskiy, Ye., Hapich, G. Kozlova, O. 2021. Agromeliorative efficiency of phosphogypsum application on irrigation saline soils in the Northern Steppe of Ukraine. Indian Journal of Ecology, 48 (3), 789–795.
14. Martsinevskaya, L.V., Pichura, V.I., Tsybenko, V.V. 2018. Successive Steps to Organize Rational Use of Soils for Formation of Ecologically Stable Agro Landscapes. Research Journal of Pharmaceutical, Biological and Chemical Sciences, 9 (3), 172–177.
15. Medinets, S., Gasche, R., Skiba, U., Medinets, V., Butterbach-Bahl, K. 2016. The impact of management and climate on soil nitric oxide fluxes from arable land in the Southern Ukraine. Atmospheric Environment, 137, 113–126.
16. Mitra, D., De Los Santos-Villaribos, S., Parra-Cota, F., Montelongo, A., Blanco, E., Lira, V., Olatunbosun, A., Khoshru, B., Mondal, R., Chidambaranathan, P., Panneerselvam, P., Mohapatra, P. 2023. Rice (Oryza sativa L.) plant protection using dual biological control and plant growth-promoting agents: Current scenarios and future prospects. Pedosphere, 33(2), 268–286.
17. Niu, T., Wang, X., Abbas, M., Shen, J., Liu, R., Wang, Z., Liu, A. 2022. Expansion of CONSTANS-like genes in sunflower confers putative neofunctionalization in the adaptation to abiotic stresses. Industrial Crops and Products, 176, 114400.
18. Osadchyi, V., Skrynyk, O., Palamarchuk, L., Skrynyk, O., Osypov, V., Oshurok, D., Sidenko, V. 2022. Dataset of gridded time series of monthly air temperature (min, max, mean) and atmospheric precipitation for Ukraine covering the period of 1946–2020. Data in Brief, 44, 108553.
19. Petrenko, V., Topalov, A., Khudolii, L., Honcharuk, Yu., Bondar, V. 2023. Profiling and geographical distribution of seed oil content of sunflower in Ukraine. Oil Crop Science, 8(2), 111–120.
20. Pichura, V.I., Domaratsky, Y.A., Yaremko, Yu.I., Volochnyuk, Y.G., Rybak V.V. 2017. Strategic Ecological Assessment of the State of the Transboundary Catchment Basin of the Dnieper River Under Extensive Agricultural Load. Indian Journal of Ecology, 44 (3), 442–450.
21. Pichura, V.I., Potravka, L.A., Dudiak, N.V., Skrypchuk, P.M., Stratichuk, N.V. 2018. Retrospective and Forecast of Heterochronal Climatic Fluctuations Within Territory of Dnieper Basin. Indian Journal of Ecology, 46 (2), 402–407.
22. Pichura. V., Potravka. L., Dudiak. N., Vdovenko. N. 2021. Space-Time Modeling of Climate Change and Bioclimatic Potential of Steppe Soil. Indian Journal of Ecology, 48(3), 671–680.
23. Sabaghnia, N., Janmohammadi, M. 2023. Influence of some nano-fertilizers on chickpeas under three irrigation strategie. Plant Nano Biology, 4, 100037.
24. Sajyan, T.K., Alturki, S.M., Sassine, Yo.N. 2020. Nano-fertilizers and their impact on vegetables: Contribution of Nano-chelate Super Plus ZFM and Lithovit®-standard to improve salt-tolerance of pepper. Annals of Agricultural Sciences, 65(2), 200–208.
25. Soleymani, A. 2017. Light response of sunflower and canola as affected by plant density, plant genotype and N fertilization. Journal of Photochemistry and Photobiology B: Biology, 173, 580–588.
26. Ushkarenko V.O. and Vozhegova R.A., 2020. Methodology of the field experiment. Oldie+: Odesa. Ukraine. 448.
27. Vancostenoble, B., Blanchet, N., Langlade, N., Bailly, Ch. 2022. Maternal drought stress induces abiotic stress tolerance to the progeny at the germination stage in sunflower. Environmental and Experimental Botany, 201, 104939.