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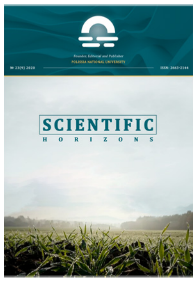

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Photosynthetic activity of sunflower hybrids under growth regulators in the Steppe of Ukraine

Olha Onyshchenko*
Asistant
Dmytro Motornyi Tavria State Agrotechnological University
69006, 226 Soborny Ave., Zaporizhzhia, Ukraine
https://orcid.org/0000-0001-7749-5273
Liubov Pokoptseva
Candidate of Agricultural Sciences, Associate Professor
Dmytro Motornyi Tavria State Agrotechnological University
69006, 226 Soborny Ave., Zaporizhzhia, Ukraine
https://orcid.org/0000-0001-8259-0136
Maksym Kolesnikov
Candidate of Agricultural Sciences, Associate Professor
Dmytro Motornyi Tavria State Agrotechnological University
69006, 226 Soborny Ave., Zaporizhzhia, Ukraine
https://orcid.org/0000-0002-5254-841X
Tetiana Gerasko
Candidate of Agricultural Sciences, Associate Professor
Dmytro Motornyi Tavria State Agrotechnological University
69006, 226 Soborny Ave., Zaporizhzhia, Ukraine
https://orcid.org/0000-0002-1331-4397

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Abstract. The climate of the southern steppe zone of Ukraine in recent years has been characterized by substantial warming, with a low, uneven amount of precipitation during the growing season of plants, which leads to a decrease in the reserves of productive moisture in the soil, and hydrothermal stress occurs in plants. Opportunities to increase the adaptation of plants to adverse factors are the use of plant growth regulators and the use of various methods of tillage aimed at preserving moisture. The purpose of this study was to investigate the influence of the plant growth regulator AKM+Ca on the operation of the photosynthetic apparatus of sunflower hybrids against the background of various methods of basic tillage in the conditions of the Southern Steppe of Ukraine. The following methods were used during the study: field, chemical (to determine qualitative indicators), and statistical (to assess the reliability of data). Field studies were conducted during 2017-2019 on southern heavy loamy chernozems. In the experiment, modified plant growth regulator AKM+Ca was used for pre-sowing

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*Corresponding author

seed treatment and foliar spraying of sunflower plants (beginning budding phase) of Talento and Colombi hybrids against the background of deep loosening or ploughing. It was found that the use of deep loosening, in contrast to ploughing, helps increase the dry matter content in sunflower plants and the net productivity of photosynthesis due to better preservation of moisture in the soil. The use of plant growth regulator AKM+Ca, regardless of the method of soil cultivation, contributes to the increase in the leaf surface area up to 31.2%, increases the photosynthetic potential of plants to 21.6% and the net productivity of photosynthesis to 15.9% during the growing season, and also increases the content of dry matter, compared to the control. The proportion of influence of the plant growth regulator AKM+Ca on the formation of the leaf surface area is 54.2%. The maximum positive effect was obtained with the combined use of AKM+Ca for pre-sowing treatment and spraying of sunflower plants during the growing season against the background of deep loosening of the soil. The research results can be used to adjust elements of agricultural technologies for growing sunflower seeds, increase crop productivity and conduct profitable agribusiness

Keywords: photosynthetic potential; net photosynthesis productivity; sunflower; plant growth regulator; ploughing; deep loosening

INTRODUCTION

Sunflower (*Helianthus appiis* L.) is the main oilseed crop in Ukraine. In the Steppe zone of the country under the cultivation of this crop, the main cultivated areas are concentrated. This is a drought-resistant crop that can withstand soil and atmospheric droughts for a long time. The oil from this crop is biologically and technically valuable. It has a prominent caloric content; it has good taste properties. According to the Ministry of Economic Development, Trade, and Agriculture of Ukraine, in 2021, the sown area of sunflower amounted to 6.5 million ha. The growth of acreage allocated for sunflower indicates a prominent level of its profitability. New varieties and hybrids of sunflower, which are more resistant to drought, broomrape, diseases, etc., are being intensively introduced into production in Ukraine. Therewith, the yield of sunflower seeds in Ukraine is significantly lower than in European countries (Germany, France, the Czech Republic, etc.). Therefore, studies of modern sunflower hybrids to improve the elements of cultivation technology through plant growth regulators and various methods of tillage are relevant and of practical interest.

Another reason for the need to reduce sunflower crops is the imbalance of scientifically based crop rotations and a rather sharp decrease in soil fertility. Non-observance of crop rotation is a consequence of violation of the phytosanitary condition, use of large reserves of water from the soil (Tsyliuryk *et al*., 2021; Degani *et al*., 2022). Against the background of the deterioration of the crop structure, the characteristic features of the Steppe zone of Ukraine are increased water and wind erosion. This limits the use of fertilizers (due to insufficient precipitation), leads to soil degradation and loss of organic substances on chernozems. Galliano *et al*. (2018) and Fedchyshyn *et al*. (2022) believe that such issues point to the need to normalize the action of anthropogenic factors by introducing certain elements of technologies aimed at minimizing soil cultivation and moisture conservation.

Chaika *et al*. (2019) and Kolesnikov *et al*. (2022) believed that the aggravation of the ecological situation in agriculture and the gradual loss of soil fertility led to a rethinking of the essence of the formation of the agricultural landscape. This was prompted by the consequences of the catastrophic scale of maximum loosening and turnover of the soil slice during conventional cultivation.

Yeremenko *et al*. (2018) pointed out that the reason for the low realization of the genetic potential of new sunflower hybrids is also the imperfection of technological measures for plant adaptation to unfavourable growing conditions. This is compounded by the high cost of energy resources (fuel, fertilizers, pesticides) and the need to further increase crop productivity. The solution to this issue is possible by using preparations to regulate growth and production processes. In their works, the authors (Khan *et al*., 2020) described that plant growth regulators stimulate the germination process, protect seeds during their prolonged stay in adverse conditions, increase the field germination of seeds, contribute to the active development of the root system, and improve mineral nutrition.

Kohut *et al*. (2020) noted that the photosynthesis that occurs during the growing season of plants is one of the key biological processes. Thanks to photosynthesis, organic substances are formed from carbon dioxide and water under the influence of light. It is known that 80-90% of solar radiation is absorbed by the green leaf surface and only 1-2% of this energy is used for photosynthesis, the rest goes for transpiration (very rarely this indicator reaches 5-8%) (Aslam *et al*., 2021; Shafiq *et al*., 2021). The use of the latest elements of technologies, including growth regulators, allows for better formation of the photosynthetic apparatus of agricultural plants. They help regulate individual stages of plant ontogenesis to mobilize the potential capabilities of the plant, and their effectiveness has been proven in several studies (Jan *et al.,* 2019; Novytska *et al.,* 2020).

At the same time, research on the influence of growth regulators on plant growth and development in conditions of unstable moisture supply and high air temperatures against the background of various tillage is extremely insufficient, which determined the area of the present study. The purpose of this study was to establish the effect of the plant growth regulator AKM+Ca on the photosynthetic activity of sunflower hybrids using various methods of basic tillage in the Steppe zone of Ukraine.

MATERIALS AND METHODS

The experiment was conducted during 2017-2019 in the Melitopol District of Zaporizhzhia region. The Southern Steppe zone is substantially different from other zones of the country in terms of climatic and soil conditions and, accordingly, has its specific features for growing agricultural crops.

The weather conditions that developed during the experiment were marked by prominent amounts of active temperatures during the growing season (Table 1). Precipitation for the year falls about 480 mm, of which during the growing season – 253 mm (according to long-term data). In 2017 and 2019, humidification conditions were close to the long-term average values and are more favourable for growing oilseeds. The hydrothermal coefficient (HTC) over the years of research ranged within 0.46-0.85, which indicates that the area belongs to an arid zone. Notably, in 2018, against the background of high amounts of active temperatures, low precipitation (147 mm) was observed, and the hydrothermal coefficient was 70-85% lower than the other growing seasons under study.

Table 1. *Weather conditions of the experiment (2017-2019)*

Year of research	HTC	Precipitation during the growing season, mm	Sum of active temperatures, °C
2017	0.78	218	2,801
2018	0.46	147	3,223
2019	0.85	257	3,037

Source: *compiled by the author*

The soils of the experiment site are southern heavy loam chernozems with a humus content of 3.1%. Soils have a close to neutral reaction (water pH 7.1). The availability of easily hydrolyzable nitrogen in the arable layer is low (103 mg/kg according to Cornfield), mobile phosphorus is high (114 mg/kg according to Chirikov), exchangeable potassium is high (139 mg/kg according to Chirikov). However, uneven and insufficient precipitation during the growing season blocks the full use of nutrients by plants. In the experiment, mid-early high-oleic hybrids of Colombi and Talento sunflowers were studied under conditions of different main tillage and different methods of application of plant growth regulator AKM+Ca. The sunflower hybrids under study are recommended for growing in the Steppe zone of Ukraine. The scheme of the experiment is presented in Table 2.

Table 2. *Experiment scheme*

<table>
<tr><th>Tillage</th><th>Sunflower hybrid</th><th colspan="2">Experiment variant</th></tr>
<tr><td rowspan="8">Deep loosening</td><td rowspan="4">Talento</td><td>1</td><td>Control (pre-sowing treatment of seeds with water)</td></tr>
<tr><td>2</td><td>Pre-sowing treatment of seeds with AKM+Ca</td></tr>
<tr><td>3</td><td>Spraying plants with AKM+Ca in the budding phase</td></tr>
<tr><td>4</td><td>Pre-sowing treatment of seeds with AKM+Ca + spraying of plants with AKM+Ca in the budding phase</td></tr>
<tr><td rowspan="4">Colombi</td><td>1</td><td>Control (pre-sowing treatment of seeds with water)</td></tr>
<tr><td>2</td><td>Pre-sowing treatment of seeds with AKM+Ca</td></tr>
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<tr><td>4</td><td>Pre-sowing treatment of seeds with AKM+Ca + spraying of plants with AKM+Ca in the budding phase</td></tr>
<tr><td rowspan="8">Ploughing</td><td rowspan="4">Talento</td><td>1</td><td>Control (pre-sowing treatment of seeds with water)</td></tr>
<tr><td>2</td><td>Pre-sowing treatment of seeds with AKM+Ca</td></tr>
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<tr><td>3</td><td>Pre-sowing treatment of seeds with AKM+Ca + spraying of plants with AKM+Ca in the budding phase</td></tr>
</table>

Source: *compiled by the author*

AKM is included in the list of pesticides and agrochemicals permitted for use in Ukraine as a plant growth regulator (Yashchuk *et al.*, 2016). It is a semisynthetic film-forming anti-stress preparation. The formulation includes distinol 0.015 g/l (dimethylsulfoxide + ionol), PEG – 1500 (440 g/l) and PEG – 400 (190 g/l), the rest – water (Kalytka *et al.*, 2011). According to laboratory studies, the plant growth regulator AKM was modified by adding Ca^{2+}ions (1.0 g/l). The resulting preparation seed material was inlaid a day before sowing (200 ml/t). The total volume of the working solution is 10 l/t of seeds. The plants were sprayed with AKM+Ca (500 ml/ha) in the phase of the inflorescence emergence (BBCH 50-51) based on the calculation of the consumption of the working solution of 200 l/ha.

The technology of growing sunflower seeds was generally accepted for this soil and climatic zone and was the same for all variants of the experiment, except for the factors under study. The seeds were sown at the beginning of the third decade of April, when the soil warmed up to 10-12°C. The seeding rate is 55 thous. pcs./ha with a row spacing of 70 cm. Predecessor – winter wheat.

The beginning of each phase of growth and development of sunflower was established after its onset in 10% of plants, complete – in 75% of plants, and the BBCH scale was used. During the studies, the leaf surface area was determined using the gravimetric method. The gravimetric method relates the weight of leaves from 10 plant samples to the weight of leaf cuttings (D=10 mm). Knowing the area of the leaf cuttings, the area of the leaf surface was calculated, and the area was given in thous. m^2 per 1 ha of the sown area (Hrytsaenko *et al.*, 2003).

The photosynthetic potential was defined as the total leaf surface that participated in photosynthesis from the beginning of vegetation to the end of photosynthesis (Hrytsaenko *et al.*, 2003) and was calculated according to the following formula (1):

$$PhSP = \frac{(S_1+S_2)\times n_1 + (S_2+S_3)\times n_2 + \dots + (S_{n-1}+S_n)\times n_n}{2}, \quad (1)$$

where PhSP is the photosynthetic potential, thous. m^2/ha × days; $S_1, S_2, S_3 \dots S_n$ is the area of leaves per 1 ha of sowing in the corresponding terms of determination, m^2/ha; n, $n_2 \dots n_n$ is the number of days between the two corresponding definitions.

The net photosynthetic productivity (NPP) was calculated as the ratio of the growth of plant dry mass over a certain period of time to the half sum of the leaf surface areas at the beginning and at the end of the period. The NPP was calculated using the following formula (2):

$$NPP = \frac{B_2 - B_1}{0.5(S_1+S_2)n}, \quad (2)$$

where *NPP* is the net photosynthesis productivity, g/m^2·day; B_1 and B_2 are the dry matter mass of plants in the beginning and at the end of the accounting period, g; ($B_2 - B_1$) is the growth of the dry matter mass of plants in n days, g; S_1 and S_2 are the leaf areas in the beginning and at the end of the accounting period, m^2; 0.5($S_1 + S_2$) is the average working leaf area during the experiment; *n* is the period between two observations, days.

The dry mass of the substance was determined gravimetrically according to generally accepted methods (Hrytsaenko *et al.*, 2003). Statistical assessment of the data was carried out according to the Yeshchenko (2005) method and the Agrostat program.

RESULTS AND DISCUSSION

The onset and duration of phenological phases primarily depends on the weather conditions of the year. In shaping the productivity of sunflower and other agricultural crops, it is important that plants undergo all phenological phases in full because this, first of all, affects the indicators of seed quality and the yield of this crop (Zimaroieva *et al.*, 2021).

During 2017-2019, it was found that the rate of development of sunflower plants was mainly influenced by ambient temperature, and in some interphase periods and humidification conditions, the general picture of the duration of interphase periods is presented in Table 3.

Table 3. *Duration of interphase periods of sunflower plant development, days*

Year	Hybrid	Sowing – germination (BBCH 00-12)	Development of 4-5 true leaves (BBCH 14-15)	Development of 6-7 true leaves (BBCH 16-17)	Development of 8-9 true leaves (BBCH 18-19)	Asterisk stage (BBCH 50-51)	Flowering-full ripeness (BBCH 63-99)	Duration of the growing season (BBCH 00-99)
2017	Talento	15	28	7	7	17	35	109
2018		12	25	7	7	23	32	106
2019		14	28	8	9	22	31	112
2017	Colombi	13	28	7	7	17	41	113
2018		12	26	7	7	20	38	110
2019		17	25	7	7	16	43	115

Source: *compiled by the author*

The growing season of 2018, unlike other years under study, was characterized by a low amount of precipitation and a higher sum of active temperatures, which somewhat affected the reduction in the duration of the growing season of sunflower hybrids Columbi and Talento. In general, the duration of the mid-early hybrids under study in the conditions of the Southern Steppe of Ukraine was 111±5 days. Thus, in the conditions of the Southern Steppe of Ukraine, when growing sunflower seeds, it is advisable to pay special attention to tillage technologies for better accumulation and preservation of moisture.

A fundamental element in plant productivity is photosynthetic activity, which is mainly determined by the area of the leaf surface, the number and mass of leaves, and the mesostructural composition of the leaf.

In the experiment on the investigation of the effect of tillage and methods of using the modified plant growth regulator AKM on the dynamics of the formation of the sunflower leaf surface area, the dependence of this indicator on the factors of the variety and the method of treatment with the plant growth regulator was observed (Table 4).

Table 4. *The dynamics of the formation of the leaf surface area of sunflower hybrids depending on the methods of soil cultivation and the use of plant growth regulators, thous. m^2/ha (2017-2019)*

Tillage (A)	Sunflower hybrid (B)	Experiment variant (C)	BBCH plant development phase				
			12-14	18-20	39-41	50-51	63-65
Deep loosening	Colombi	1	12.0	16.7	19.8	27.8	45.2
		2	13.4	19.9	23.6	30.2	50.1
		3	-	-	-	-	48.7
		4	-	-	-	-	53.9
	Talento	1	11.9	17.0	20.0	27.3	40.0
		2	13.2	20.2	22.1	29.7	46.8
		3	-	-	-	-	43.2
		4	-	-	-	-	52.5
Ploughing	Colombi	1	12.6	16.7	21.6	27.4	47.7
		2	13.1	18.8	24.5	29.7	50.7
		3	-	-	-	-	49.1
		4	-	-	-	-	55.8
	Talento	1	11.9	16.6	20.9	25.4	39.1
		2	13.5	18.6	23.3	27.6	43.8
		3	-	-	-	-	41.7
		4	-	-	-	-	51.1
LSD_{05}	A		1.3	2.4	2.9	3.5	7.6
	B		1.3	1.4	2.8	2.2	4.6
	C		0.6	1.3	1.1	1.2	4.0

Source: *compiled by the author*

Already from the BBCH 12-14 development phase, an increase in the area of the leaf surface is observed. The gradual growth of this indicator reaches a maximum in the flowering stage (BBCH-63-65). Substantial changes occur in the variant with pre-sowing seed treatment with the PGR AKM+Ca for both hybrids under study, where the growth of this indicator was by 4-18%, compared to the control, regardless of the method of tillage.

Additional spraying of sunflower plants of Columbi and Talento hybrids with AKM+Ca in the inflorescence emergence phase (BBCH 50-51) contributes to the growth of the leaf surface area to the mass flowering phase (BBCH 63-65) by 18-31%, compared to the control. This is especially true for the Talento hybrid with the maximum increase in this indicator, where the influence of the variety factor is very well traced. Therefore, it should be expected that an increase in the leaf surface area will contribute to the growth of photosynthetic activity and increase the productivity of sunflower plants. In general, the formation of the leaf apparatus by plants directly depends on the amount of precipitation (BBCH 00-65). A close correlation is established here (r=0.87). The share of the effect of AKM+Ca on the formation of this indicator was 54.2% (Fig.1).

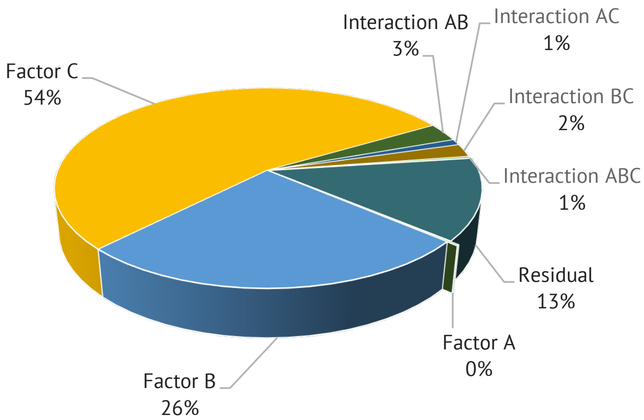

Figure 1. *The share of influence of the factors under study on the dynamics of the leaf surface area of sunflower, %*
Source*: compiled by the author*

The dry matter content of sunflower plants varies widely depending on the phase of hybrid development, hydrothermal conditions of the year and elements of cultivation technologies (Table 5).

Table 5. *Dynamics of dry matter accumulation by sunflower plants, g/ m²*

Tillage (A)	**Sunflower hybrid (B)**	**Experiment variant (C)**	**BBCH plant development phase**				
			12-14	**18-20**	**39-41**	**50-51**	**63-65**
Deep loosening	Colombi	1	26.9	45.3	154.7	245.6	752.3
		2	29.3	56.7	180.7	270.7	790.7
		3	-	-	-	-	763.8
		4	-	-	-	-	816.0
	Talento	1	26.5	51.1	143.8	244.1	707.6
		2	28.4	59.2	175.2	271.3	746.5
		3	-	-	-	-	725.6
		4	-	-	-	-	798.0
Ploughing	Colombi	1	27.8	45.8	167.2	243.9	712.6
		2	29.7	56.1	186.5	266.7	795.5
		3	-	-	-	-	775.0
		4	-	-	-	-	804.1
	Talento	1	25.0	46.8	153.6	207.0	695.0
		2	28.9	53.8	184.1	243.1	741.2
		3	-	-	-	-	721.8
		4	-	-	-	-	789.4
LSD_{05} B C		A	0.3	6.7	21.1	26.8	29.3
		0.3	3.5	13.5	17.0	15.7	
		1.3	3.5	16.4	9.9	57.5	

Source*: compiled by the author*

Already at the beginning of the development of sunflower plants (BBCH 12-14), a more intense accumulation of dry matter occurred in the variants of the experiment with the pre-sowing treatment of seeds with the PGR AKM+Ca, where this indicator was higher than the control by 6.8-15.6%, depending on the hybrid and the method of soil cultivation. In the subsequent growing season, this indicator gradually increased, and during the flowering phase, the dry matter content reached a maximum in all variants of the experiment.

The Columbi sunflower hybrid in the flowering phase had higher indicators of dry matter content with both methods of main tillage by 2.5-6.3%, compared to the Talento hybrid. Notably, with deep loosening as the main method of tillage, the Columbi hybrid has significantly higher values of dry matter content compared to ploughing, which can be explained by better preservation of moisture in the soil. Plants of this variant of the experiment were able to better use moisture and nutrients dissolved in it to form a more powerful phytomass.

Additional spraying of sunflower plants with the plant growth regulator AKM+Ca has the maximum positive effect on changes in the dry matter content. Thus, spraying plants with this preparation in the BBCH 50-51 phase significantly increases the dry matter content of the hybrids under study in both variants of tillage by 8.5-13.6% (BBCH 63-65). The general picture of the dependence of the dynamics of dry matter accumulation on the factors under study is presented in Fig. 2.

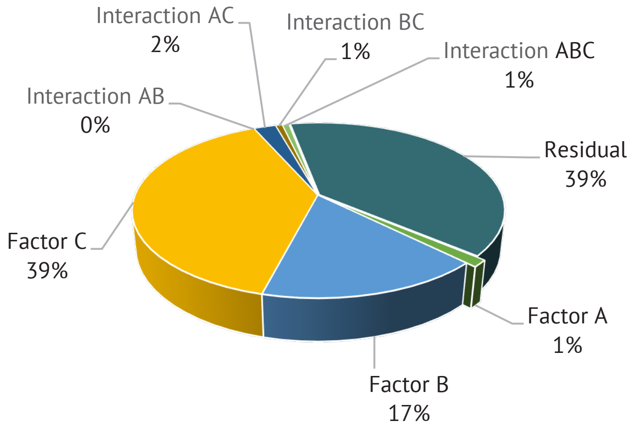

Figure 2. *The proportion of influence of the factors under study on the accumulation of dry matter by sunflower plants, %.*
Source*: compiled by the author.*

The process of photosynthesis is the main source of formation of plant biomass, provides energy to all growth processes, and energy is exchanged. It is the size and productivity of the photosynthetic apparatus that determines the yield of agricultural plants. The dynamics of photosynthetic potential of sunflower plants depending on the factors under study is presented in Table 6.

Table 6. *Photosynthetic potential of sunflower plants depending on the main tillage and the use of the PGR, million m^2·days/ha*

Tillage (A)	Sunflower hybrid (B)	Experiment variant (C)	BBCH plant development phase (for the period)			
			(BBCH 12-14)-(BBCH 18-20)	(BBCH 18-20)-(BBCH 39-41)	(BBCH 39-41)-(BBCH 50-51)	(BBCH 50-51)-(BBCH 63-65)
Deep loosening	Colombi	1	0.10	0.24	0.38	0.40
		2	0.12	0.28	0.43	0.44
		3	-	-	-	0.41
		4	-	-	-	0.46
	Talento	1	0.10	0.24	0.38	0.37
		2	0.11	0.28	0.41	0.42
		3	-	-	-	0.38
		4	-	-	-	0.45
Ploughing	Colombi	1	0.10	0.25	0.39	0.41
		2	0.11	0.27	0.43	0.44
		3	-	-	-	0.42
		4	-	-	-	0.47
	Talento	1	0.10	0.24	0.37	0.35
		2	0.11	0.27	0.41	0.39
		3	-	-	-	0.37
		4	-	-	-	0.41

Table 6, Continued

Tillage (A)	Sunflower hybrid (B)	Experiment variant (C)	BBCH plant development phase (for the period)			
			(BBCH 12-14)-(BBCH 18-20)	(BBCH 18-20)-(BBCH 39-41)	(BBCH 39-41)-(BBCH 50-51)	(BBCH 50-51)-(BBCH 63-65)
LSD_{05} B C		A	0.01	0.04	0.03	0.06
		0.01	0.01	0.02	0.04	
		0.01	0.02	0.02	0.02	

***Source**: compiled by the author*

Thus, the pre-sowing treatment of the seeds of the sunflower hybrids under study contributes not only to the increase in dry matter in plants, the leaf surface, but also increases the photosynthetic potential of plants during the growing season. This is especially true for the BBCH 39-65 period, where there is a significant increase in this indicator. For the Columbi sunflower hybrid during the BBCH 39-51 period, the increase in photosynthetic potential under the action of the plant growth regulator was 10.3-13.1%, for the Talento hybrid – by 7.9-10.8%, compared to the control. In further development during the BBCH 50-65 period, this growth was, respectively, by 7.3-10.0% and 11.4-13.5%. Additional treatment of AKM+Ca plants at the inflorescence emergence contributed to an even greater increase in photosynthetic potential for the Colombi sunflower hybrid by 14.6-15.0%, and for the Talento hybrid – by 17.1-21.6%, compared to the control variant of the experiment. Therefore, the use of a modified plant growth regulator AKM+Ca contributes not only to the growth of plant biomass, but also to the activation of photosynthesis of sunflower plants, energy exchange for obtaining a high yield.

In the period of the inflorescence emergence-full flowering, varietal differences between hybrids can be traced on ploughing, where the Colombi sunflower hybrid had a higher photosynthetic activity by 17.1%, compared to the Talento hybrid. In general, the method of basic tillage did not substantially affect the photosynthetic potential.

During photosynthesis, approximately 95% of the total plant biomass is formed. Therefore, the indicator of the net productivity of photosynthesis is essential because when the dry mass of the plant changes, it characterizes the work of the leaf apparatus, reflects their assimilation activity and conditions the plant's potential for crop formation (Table 7).

***Table 7.** Net photosynthetic productivity of sunflower plants under the conditions of the factors under study, g/m^2 per day*

Tillage (A)	Sunflower hybrid (B)	Experiment variant (C)	BBCH plant development phase			
			(BBCH 12-14)-(BBCH 18-20)	(BBCH 18-20)-(BBCH 39-41)	(BBCH 39-41)-(BBCH 50-51)	(BBCH 50-51)-(BBCH 63-65)
Deep loosening	Colombi	1	0.77	3.99	3.34	8.66
		2	0.90	4.19	3.82	9.16
		3	-	-	-	8.93
		4	-	-	-	10.04
	Talento	1	1.20	3.50	3.73	10.21
		2	1.29	3.83	4.24	10.92
		3	-	-	-	10.85
		4	-	-	-	10.82
Ploughing	Colombi	1	0.80	4.21	2.95	8.21
		2	0.85	4.44	3.13	8.34
		3	-	-	-	8.43
		4	-	-	-	8.50
	Talento	1	1.07	3.99	2.29	9.55
		2	1.09	4.36	2.28	9.68
		3	-	-	-	9.78
		4	-	-	-	9.91
LSD_{05} B C		A	0.05	0.24	0.53	1.48
		0.04	0.27	0.23	0.78	
		0.03	0.17	0.29	0.76	

***Source**: compiled by the author*

Already at the beginning of leaf development (BBCH 12-20) in the experiment, the dependence of the NPP on the method of soil cultivation in the sunflower hybrid Talento was observed. The use of deep loosening, in contrast to ploughing, allows for better formation of phytomass and an increase in the NPP indicator by 12.1%. Such dynamics in this hybrid is observed during the BBCH 12-51 period, and the maximum growth of NPP is observed in the phase of the inflorescence emergence (62.9%).

Between the hybrids of sunflower Columbi and Talento, there are varietal features that are especially clearly traced in the variant of the experiment with deep loosening of the soil. Thus, during the BBCH 18-41 period, the Columbi hybrid had a higher NPP value than the Talento hybrid by 14.0%. However, in the next period (BBCH 39-65), the situation changes in the opposite direction and the Talento hybrid exceeds the Columbi hybrid in the indicator under study by 11.7-17.9%. In the version of the experiment using ploughing, the Talento hybrid also had advantages over the Colombi hybrid in the period of the inflorescence emergence–full flowering, where the indicator under study was higher by 16.3%.

When investigating the influence of the factor of using a plant growth regulator, certain features were also established, especially in the variant of the experiment using deep loosening of the soil. Thus, pre-sowing treatment of seeds with the PGR AKM+Ca significantly increases the NPP index during the entire study period by 5.0-26.9% in both hybrids under study.

Additional spraying of sunflower plants of the Columbi with the PGR AKM+Ca hybrid in the phase of the inflorescence emergence in the variant of the experiment with deep loosening of the soil contributed to the activation of the net photosynthesis productivity during the BBCH 50-65 period, where the NPP index was higher than the control by 15.9% and higher than the variant with pre-sowing treatment of seeds by 9.6%. The general picture of the dependence of changes in the indicators of net photosynthesis productivity on the factors under study is presented in Fig. 3.

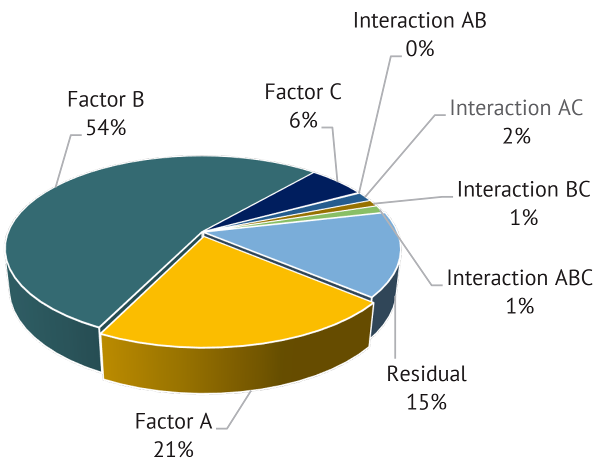

Figure 3. *The proportion of influence of the factors under study on the net photosynthesis productivity of sunflower plants, %*

Source*: developed by the authors*

The variety factor (54.0%) has a substantial influence on the net photosynthesis productivity from the factors under study. Therefore, with the observance of a high level of agriculture, the use of the latest elements of crop cultivation technology, namely, the use of plant growth regulators and methods of soil cultivation, it is possible to adjust the yield of sunflower well, because sunflower is still an economically attractive crop for growing in the Steppe of Ukraine.

During the growing season, weather conditions have a substantial impact on the formation of the sunflower crop: ambient temperature, the amount, and uniformity of precipitation (Hilwa *et al.*, 2019). In the arid zone of the Steppe, in the early stages of their development, sunflower plants use the moisture of the arable layer accumulated in the winter-spring period. Due to the further development of the root system and its penetration into the soil, sunflower plants use the moisture of groundwater (Vozhegova *et al.*, 2021). This contributes to the normal development and survival of plants during the period of harmful effects of air drought, which is most dangerous during the period of flowering of plants and seed ripening.

Turning the ploughed layer affects the redistribution of nutrients enriched with available nutrients of the entire ploughed layer at the expense of the upper part, as a result of which the overall productivity of the soil increases. However, this process can be harmful, especially in arid zones, because when the wet layer is turned over to the soil surface, it dries quickly. Research

(Liabah, 2022) found that when growing sunflowers on sod-podzolic soils with a light granulometric composition, the use of disc tillage tools to a depth of 10-12 cm is not substantially inferior to a deep loosener to a depth of 40-45 cm. Therefore, to solve the problem of reducing erosion processes, destroying the compacted subsoil, improving the infiltration properties of agricultural lands and preserving soil fertility, it is advisable to use deep loosening. Deep loosening of the soil involves loosening, crumbling, partial mixing, but without rotation of the layer, resulting in loosening of the soil aimed at preventing water erosion. When using a deep loosener, the stubble stays on the surface, which fixes the surface of the soil and does not allow it to be blown away by the wind (Yeremenko *et al.*, 2020). The positive effect of deep loosening on the NPP indicator, compared to ploughing, is confirmed by the conducted studies.

One of the factors for obtaining stable yields is a well-developed photosynthetic apparatus, which has an optimal area and dynamics of functioning (Domaratskyi, 2021; Ma *et al.,* 2022). According to scientists, the optimal area of the leaf surface of agricultural crops, due to which the formation of maximum productivity is achieved, is 40 thous. m^2/ha. Other researchers (Gamayunova *et al.*, 2019; Melnyk *et al.*, 2020) found that for varieties and hybrids of the intensive type, which currently prevail in agricultural production, the optimal leaf area is within 50-60 thous. m^2/ha. The higher the coefficient of energy utilization for photosynthesis, the more completely dry phytomass is formed, and the smaller amount is spent on water transpiration.

For optimal formation of the photosynthetic apparatus of agricultural plants, regulation of individual stages of ontogenesis and mobilization of their potential, it is recommended to use growth regulators (Almashova *et al.*, 2022; Kolesnikov *et al.*, 2022; Bielashov *et al.*, 2022). The published data are in good agreement with the conducted studies. Scientists also claim that plant growth regulators have a wide positive spectrum of action, which not only stimulates growth processes at various stages of ontogenesis, but also reduces the effect of the pesticide load on the plant, increases the yield of crops, improves the quality of grain and seeds, and strengthens the resistance of crops to adverse agroclimatic conditions, which is especially valuable in arid regions of the country (Karpenko *et al.*, 2018). The use of Ca^{2+} with the AKM growth regulator contributed to the increase in the leaf surface area of sunflower, which is probably explained by the fact that calcium ions, as a structural component of photosystem II, improve the efficiency of photosynthesis, stimulate the links of plant antioxidant protection, which was proven when using exogenous calcium chloride (Sadak *et al.*, 2023). Stimulation of the formation of the photoasimilation apparatus of sunflower plants under the action of calcium ions occurs through the effect on the pigment complex. Since, with calcium deficiency, a decrease in the rate of photosynthesis and transpiration, the productivity of photosystem II was shown (Sitko *et al.*, 2019).

Thus, the research results confirm the data of other scientists on the influence of growth regulators on the formation of the photosynthetic surface of plants and its activity in arid conditions in the south of Ukraine.

CONCLUSIONS

The duration of sunflower interphase periods depends on environmental conditions: the sum of active temperatures and precipitation. The plants of sunflower hybrids under study, upon using deep loosening, have a high dry matter content and an indicator of net photosynthesis productivity, which is explained by the better preservation of moisture in the soil. The use of plant growth regulator AKM+Ca for pre-sowing seed treatment increases the leaf surface area by 4.0-18.0%, increases the indicators of the photosynthetic potential of plants during the growing season by 7.3-13.5% and the net photosynthesis productivity by 5.0-26.9%, compared to the control, regardless of the method of tillage.

The combined use of pre-sowing seed treatment and spraying of plants with AKM+Ca at the beginning of budding (BBCH 50-51) increases the area of the leaf surface by 18-31%, contributes to the growth of the dry matter content in both tillage options by 8.5-13.6% (BBCH 63-65) and photosynthetic potential by 14.6-21.6%, compared to the control. The combination of pre-sowing treatment and treatment of sunflower plants of the Colombi hybrid with the AKM+Ca against the background of deep loosening of the soil contributed to an increase in the net photosynthesis productivity (BBCH 50-65) by 15.9%, compared to the control, and by 9.6%, compared to the pre-sowing treatment seed.

In the period of the inflorescence emergence-full flowering, varietal differences between hybrids can be traced on ploughing, where the Colombi sunflower hybrid had a higher photosynthetic activity by 17.1%, compared to the Talento hybrid. The method of basic tillage did not substantially affect the photosynthetic potential. In addition, varietal features can be traced between hybrids according to the NPP indicator against the background of deep loosening of the soil. The influence of the variety factor is 54.0%. The obtained data confirm the prospects for further research into the crop structure, the biological yield of sunflower hybrids and the quality of products under plant growth regulators in the conditions of the Steppe zone of Ukraine, which will provide the population with high-quality food raw materials.

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CONFLICT OF INTEREST

None.

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Фотосинтетична активність гібридів соняшнику за дії регуляторів росту в умовах Степу України

Ольга Вячеславівна Онищенко

Асистент

Таврійський державний агротехнологічний університет імені Дмитра Моторного

69006, просп. Соборний, 226, м. Запоріжжя, Україна

https://orcid.org/0000-0001-7749-5273

Любов Анатоліївна Покопцева

Кандидат сільськогосподарських наук, доцент

Таврійський державний агротехнологічний університет імені Дмитра Моторного

69006, просп. Соборний, 226, м. Запоріжжя, Україна

https://orcid.org/0000-0001-8259-0136

Максим Олександрович Колесніков

Кандидат сільськогосподарських наук, доцент

Таврійський державний агротехнологічний університет імені Дмитра Моторного

69006, просп. Соборний, 226, м. Запоріжжя, Україна

https://orcid.org/0000-0002-5254-841X

Тетяна Володимирівна Герасько

Кандидат сільськогосподарських наук, доцент

Таврійський державний агротехнологічний університет імені Дмитра Моторного

69006, просп. Соборний, 226, м. Запоріжжя, Україна

https://orcid.org/0000-0002-1331-4397

Анотація. Клімат південної зони Степу України за останні роки характеризується суттєвим потеплінням, з низькою, нерівномірною кількістю опадів протягом вегетації рослин, що призводить до зниження запасів продуктивної вологи в ґрунті, у рослин виникає гідротермічний стрес. Можливостями підвищення адаптації рослин до несприятливих факторів є використання регуляторів росту рослин та застосування різних способів обробітку ґрунту, направлених на збереження вологи. Мета досліджень – дослідити вплив регулятору росту рослин АКМ+Са на роботу фотосинтетичного апарату гібридів соняшнику на фоні різних способів основного обробітку ґрунту в умовах південного Степу України. При виконанні досліджень використовували наступні методи: польовий, хімічний (для визначення якісних показників) та статистичний (для оцінки достовірності даних).Польові дослідження проводили впродовж 2017-2019 років на чорноземах південних важкосуглинкових. У досліді використовували модифікований регулятор росту рослин АКМ+Са для передпосівної обробки насіння та позакореневого обприскування рослин соняшнику (фаза початку бутонізації) гібридів Таленто і Коломбі на фоні глибокого рихлення або оранки. Встановлено, що застосування глибокого рихлення, на відміну від оранки, сприяє збільшенню показників вмісту сухої речовини в рослинах соняшнику і чистої продуктивності фотосинтезу за рахунок кращого збереження вологи у ґрунті. Використання регулятора росту рослин АКМ+Са, незалежно від способу обробітку ґрунту, сприяє наростанню площі листкової поверхні до 31,2 %, збільшує фотосинтетичний потенціал рослин до 21,6 % та чисту продуктивність фотосинтезу до 15,9 % протягом вегетації, а також підвищує вміст сухої речовини, порівняно з контролем. Частка впливу регулятора росту рослин АКМ+Са на формування площі листової поверхні становить 54,2 %. Максимальний позитивний ефект отримано при сумісному застосуванні препарату АКМ+Са для передпосівної обробки і обприскування рослин соняшнику по вегетації на фоні глибокого рихлення ґрунту. Результати досліджень можуть бути використані для корегування елементів агротехнологій вирощування соняшнику, підвищення продуктивності культури та ведення прибуткового агробізнесу

Ключові слова: фотосинтетичний потенціал; чиста продуктивність фотосинтезу; соняшник; регулятор росту рослин; оранка; глибоке рихлення