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Physiological Features of Yield Formation of Sunflower Breeding Samples in Arid Conditions of the Ukrainian Steppe

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A R T I C L E I N F O

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A B S T R A C T

The research methodology was based on determining the soil moisture consumption per unit of photosynthesis productivity, establishing the influence of the moisture consumption coefficient on the productivity of photosynthesis on the yield of sunflower genotypes. The aim of the research was to determine the physiological characteristics of the formation of plant productivity of different sunflower samples and use them in assessing and creating genotypes for cultivation in arid conditions. The conducted investigations allowed to determine physiological factors and properties of plants that determine the level of formation of the weight of seeds of the head and the yield of sunflower. The weight of seeds of the head is determined by the amount of soil moisture consumption per unit of net productivity. Between the indicators of soil moisture consumption per unit of net productivity at the stage of formation of the head - the beginning of flowering, a direct negative correlation interdependence was established. Sunflower varieties with a minimum consumption of soil moisture per unit of net productivity of photosynthesis of 1.01-1.05 m^{-3} g m^{-2} per day form in arid conditions of the Steppe of Ukraine the maximum level of weight of seeds of the head of 58.7-78.7 g, which ensures obtaining a high yield within 2.68-3.49 t ha^{-1}. The conducted assessment of genotypes by indicators of soil moisture consumption per unit of net productivity made it possible to create highly productive varieties of sunflower Emelard, Igolya, Orlik.

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Introduction

The main regions of sunflower cultivation in Ukraine are located in the steppe zone and are characterized by dry weather conditions during the growing season.

The varieties and hybrids of sunflower have a high level of adaptation to growing in arid conditions. The root system of sunflower plants is able to absorb moisture from deep soil layers (El-Bially et. al., 2022). However, over the past decades in the Steppe of Ukraine, the amount of precipitation during the growing season of sunflower has decreased and falls within the range of 80 to 110 mm. The deficit of moisture content in the soil limits and restricts the level of formation of the productivity of sunflower varieties and hybrids in such weather conditions of the growing season (Aksyonov, 2010; Aksyonov and Gavrilyuk, 2013). Guaranteed and stable yield of sunflower is possible with the creation of highly productive varieties and hybrids that are adapted to growing in drought conditions and understanding the physiological properties of productivity formation.

Studying and understanding the processes of formation of high productivity of plants under conditions of moisture deficiency is the key to creating drought-resistant sunflower source material (Salem et. al., 2021; Ramadan et. al., 2023). The studies show that in dry conditions, the activity of plant growth and development is largely determined by photosynthesis processes. The photosynthesis processes ensure the accumulation of dry matter in the vegetative and generative organs of plants, ensure the level of formation of plant productivity. The influence of photosynthesis processes on the formation of generative organs in the conditions of abiotic stress of plants during drought is one of the main points in the formation of the productivity of varieties and hybrids (Gao et al., 2018; Oikawa and Ainsworth, 2016).

At the same time, drought, moisture deficiency in the soil during the vegetation period of plants can suppress the processes of vegetative development of sunflower, reduce the area of the leaf surface of plants, and reduce the rate of photosynthesis. A decrease in the level of aboveground biomass of sunflower plants contributes the formation of photosynthetic products in the plant to a lesser extent. A decrease of the photosynthetic capacity of leaves and the amount of dry matter accumulation by vegetative organs of the plant limits reproductive growth and can lead to a significant decrease of the productivity of sunflower plants (Cao et al., 2009; Saudy et al., 2023).

The conducted studies did not establish a direct correlation between the elements of productivity and net productivity of photosynthesis and the amount of moisture in the soil. Plant productivity of sunflower varieties and hybrids depended on the greater extent on individual traits of photosynthesis and growing conditions that contributed to a change in the intensity of photosynthesis processes (Aksyonov, 2007).

Regarding the moisture deficit in the soil, studies show that sunflower genotypes have different reactions to the moisture content in the soil depending on the stage of plant development. Deficiency of moisture content in the soil during the drought period in the stage of sunflower flowering can reduce the level of formed yield in the agrocenosis. At the same time, the moisture deficit in the soil шт the stage of initial seed formation does not contribute the decrease of yield. In this case, the decrease of the the number of seeds in the head is compensated by an increase of the weight of the seeds in the head and the yield level is stabilized (Jensen et al., 2010; Karam et al., 2007).

Establishing and evaluating the physiological characteristics of sunflower genotypes allows in the breeding process to create varieties and hybrids with a high level of productivity for growing in the conditions of moisture deficit. In the breeding of varieties and hybrids, breeders use several strategies for assessing physiological characteristics in order to create drought-resistant genotypes. One of the directions in creating such genotypes is the assessment of only the lower leaf canopy of plants, reducing transpiration, reducing water consumption on forming a unit of yield. This approach in breeding allows to create genotypes with a high level of drought resistance, but with a low level of productivity (Birck et al., 2017; Rauf and Sadaqat, 2008). Therefore, for creation varieties and hybrids in drought conditions, a breeder must understand the physiological characteristics that ensure the creation of highly productive genotypes and consider the formation of plant productivity in a complex relationship with the intensity of photosynthesis and the moisture content in the soil.

Therefore, the study and establishment of physiological characteristics for the comprehensive assessment of the criteria of photosynthetic activity and moisture reserves in the soil in the specific phases of sunflower plant development in relation to droughty periods of vegetation in the steppe zone, allowing the creation of highly productive genotypes, determine the prospects and practical significance of the studies.

The purpose of this research work was to establish the physiological properties of the formation of high plant productivity, identify genotypes with high productivity potential for cultivation in the steppe zone of Ukraine.

Materials and method

Materials

The studies were carried out at the Luhansk National University and the Dnipro State Agrarian and Economic University during 2016-2023.

Field experiments were laid in a 7-field crop rotation. The soil of the experimental plot is ordinary chernozem, medium-deep, low-humus, heavy loamy soil with a humus content of 3.2-3.6%.

The material for research is self-pollinated samples and new sunflower varieties. Sunflower in the experiment was sown after winter wheat.

The method of basic tillage - plowing to a depth of 27-30 cm.

Two soil cultivations were carried out in spring:

- early spring soil cultivation to a depth of 8.0-10.0 cm with simultaneous harrowing;
- pre-sowing cultivation to a depth of 6.0-8.0 cm.

Cultivations were carried out with KPS-4 cultivator.

Sowing of sunflower was carried out at the end of the third decade of April: April 25-30. The width of row spacing was 70 cm. Plant stand density before harvesting was equal to 40 thousand hectares. The plots in the field experiment had 4 rows. The counted area of each plot was 12.2 m^{-2}. Each variant (sample, variety) of the experiment had three replications.

The assessment of plants by morphological characteristics was carried out in the field on experimental plots. During the growing season of sunflower, we carried out phenological observations of plants, a description of plants by morphological characteristics, determination of soil moisture content, and calculations based on the net productivity of photosynthesis. Determination of the content of soil moisture reserves, the area of the leaf surface of plants, and the content of dry matter in a sunflower plant were performed at stages 6-8 of ontogenesis at the stage of head formation - the beginning of flowering of plants.

Sunflower samples that had different qualitative morphological characteristics of plants and a vegetation period of 100-110 days were included in the research.

Methods

The studies were conducted in accordance with generally accepted methods in plant growing.

Crop care consisted of formation of plant stand density, two row spacing cultivations. During the period of crop care, two inter-row cultivations were performed. Sunflower harvesting from experimental plots was carried out hand with the subsequent threshing of heads in laboratory. Phenological observations, biometrics were carried out, the water regime of the soil, dry matter content, leaf surface area, the net productivity of photosynthesis of plants were determined in the period of vegetation.

After harvest and threshing the heads of sunflower samples, the weight and quantity of seeds of one head were calculated, the mass of 1000 seeds, the yield of sunflower were determined.

Determiming the reserves of soil moisture, the leaf surface area of plants, the content of dry matter in plants were performed at the of the phase head formation - the beginning of flowering of plants.

Taking soil samples for moisture determination was carried out in the soil horizon of 0-100 cm every 10 cm in three repetitions along the diagonal of the plot.

To determining the moisture reserve of the soil horizon of 0-100 cm, calculations were made for each individual layer of soil: 0-10 cm, 10-120 cm, 20-30 cm, 90-100 cm. The reserves of moisture of each layer of soil were calculated by the next formula:

$$Wozv = \frac{V \times d \times h}{10} \quad (1)$$

Where:
Wozv: Total moisture reserve in a separate soil layer, mm;
W : Total moisture of the soil layer, %;
d : Density of the studied soil layer, g cm^{-3};
h : Thickness of the studied soil layer, cm.

The determining of moisture reserve was established by calculating for each separately soil layers, which have different soil density - d.

Next, the content of productive moisture was determined on each layer of soil:

$$Wpr = \frac{(Wozv - Wwilt) \times d \times h}{10} \quad (2)$$

Where:
W_{pr} : Productive moisture in soil layer, mm;
W_{ozv} : Total moisture of soil layer, %;
W_{wilt} : Wilting moisture, %;
d : Density of soil layer, g/cm^3;
h : Thickness of the studied soil layer, cm.

The total content of moisture in the studied meter profile of the soil was obtained by summing the indicators calculated separately for each layer: ($W_{pr} = W_{pr1} + W_{pr2} + W_{pr3} + ….. + W_{pr10}$).

The calculation of total water consumption for the studied period of development of sunflower (phase of head formation - the beginning of flowering of plants) was determined by the formula:

$$\Sigma W = (W_{pr}0 + Pr0\text{-}1 - W_{pr}1) \times KO \quad (3)$$

Where:
ΣW – total water consumption during the study period: the phase of head formation - the beginning of flowering of plants, mm ha^{-1}.
$W_{pr}0$ – total content of productive moisture at head formation phase, mm;
Pr0-1 – precipitation for the period: phase of head formation - the beginning of flowering of plants, mm;
$W_{pr}1$ – total moisture supply at the end of the studied period of development of sunflower - phase of beginning of flowering of plants, мм;
KO – coefficient of precipitation using (adopted of 0.7).

To transfer the soil moisture supply in m^{-3}, the amount of moisture in millimeters (mm) was multiplied by 10, since a layer of water with a thickness of 1.0 mm on an area of 1.0 ha corresponds to 10.0 tons (1.0 m^{-3}) of water.

The area of leaf surface of the sunflower plant was determined by the method of die-cutting:

$$S = \frac{M_l \times a \times \pi D^2}{M_{dc} \times 10000} \quad (4)$$

Where:
S : Area of leaf surface of one plant, m^{-2};
M_l : Total weight of leaves of one plant, g;
a : The number of die-cutting from the leaves of one plant, pieces;
πD2 : The area of one die-cutting from the leaves of a one plant, cm^{-2};
π : 3,14;
D : The diameter of the drill, which is used to make die-cutting in the leaves of the plant, cm;
Mdc : Weight of die-cutting per plant, g;
10000: Square centimeter to square meter conversion coefficient (conversion base:
1 m^{-2} = 10000 sm^{-2}).

The content of dry matter in sunflower plants was determined by the gravimetric method by drying in an oven at a temperature of 105ºC.

The net productivity of photosynthesis (NPF), showing the accumulation intensity of biomass plants by unit area of leaves per unit time (g m^{-2} per day) and characterizing the difference between photosynthesis and respiration of plants, was calculated by the formula:

$$NPP = \frac{(B_2 - B_1)}{0.5\,(S1 + S2) \times t} \quad (5)$$

Where:
NPP: Net productivity of photosynthesis of sunflower plants, g m^{-2} per day;
B_2: Dry weight of sunflower plants per square meter of sowing at the end of the accounting (investigated) period (beginning of plants flowering), g;
B_1 : Dry weight of sunflower plants per square meter of sowing at the beginning of the accounting (investigated) period (phase of head formation), g;
S_1 : Leaf area of sunflower plants at the beginning of the accounting (investigated) period (phase of head formation), m^{-2};
S_2 : Leaf area of sunflower plants at the end of the accounting (investigated) period (beginning of plants flowering), m^{-2};
t : Period (in days) between selection samples in the experiment at the beginning and end of the accounting (investigated) period, days.

Statistical Analysis

In investiganion was used to test of the experiment data reliability using analysis of variance the software packages: ANOVA, Microsoft Office Excel. Reliability of experimental data, verification of significance between the studied indicators were carried out on the basis of the least significant difference (LSD) test. The indicators values of experiment in article are expressed as mean at years investiganions. Statistical processing of the research results was performed in accordance also with methods Dospekhov (1985), Aksyonov et al. (2023).

Results

The results of the conducted studies showed that during the period of plant development from the stage of head formation to flowering, sunflower samples 52 and 129 had the highest consumption of the moisture from the soil: 38.1 and 43.5 m^{-3} ha, respectively (Table 1).

The minimum consumption of soil moisture during the period of head formation and the beginning of flowering of 10.2-13.2 m^{-3} ha was observed at the sunflower varieties Emerald, Igolya, Orlik. Sunflower sample 52, with a high level of the consumption of soil moisture, was characterized by the lowest net photosynthetic productivity – 9.6 g m^{-2} per day.

The maximum weight of the head seeds 78.7 and 60.2 g was formed at new varieties Igolya and Emerald. The maximum weight of the head seeds 78.7 and 60.2 g was formed at new varieties Igolya and Emerald. The seeds weight of head these varieties was more on 7.3 – 15.6 g, than at variety-control Sur.

Research shown, that in the arid conditions of the Ukrainian Steppe, the duration of the period and the duration of the period of plant development "seedlings - flowering" did not determine to a significant extent the level of yield of these samples and varieties of sunflower with a vegetation period of 102 - 110 days (Table 2).

For example, with the same growing season 110 days sample of 129 and variety Igolya had the defferent level yield. The yield of sample 129 was formed on the level 1.7 t ha^{-1}, the variety yield of Igolya was formed on the level 2.49 t ha^{-1}.

The yield level was determined by the formed mass of seeds in the head. The varieties of Emerald and Igolya, having more maximum weight of head seed, formed more high level of yield: 2.79 - 3.49 t ha^{-1}.

It should be noted that in the conditions of the Steppe Ukraina, the sunflower samples of 52, 129, 44 with less yield 1.60; 1.70; 1.97 t ha^{-1} had more the high content of feat in the seeds of 52.9; 52.3; 52.4%.

Discussion

A comparative analysis of the experimental data showed that, the newly obtained varieties of the sunflower Emelard, Igolya, and Orlik, with the minimum consumption of moisture from the soil in this stage of plant development – 12.4; 10.2, and 13.2 m^{-3} ha, had low net productivity of photosynthetic of 11.9; 10.1, 12.6 g m^{-2} per day, respectively.

The maximum net productivity of photosynthetic of 16.8 and 17.3 g m^{-2} per day was characteristic of samples 33 and 65 with the average consumption of soil moisture of 20.9 and 21.9 m^{-3} ha.

In the comprehensive assessment of plant development, the consumption indicators of soil moisture and net productivity of photosynthetic determined different levels of the ratio between these indicators. The high level consumption of soil moisture with low productivity of photosynthetic determined the maximum high ratio between these indicators of plant development at samples of aunflower 52 and 129.

Table 1. Traits indicators of of sunflower plants, (average for 2016-2023).

Sample	CSM	NPP	CSMPU	Weight of head seeds, g*
33	20.9	16.8	1.24	52.9
44	22.4	10.4	2.15	45.7
52	38.1	9.6	3.97	36.0
65	21.9	17.3	1.26	51.0
129	43.5	11.2	3.88	38.8
Malakhit	19.7	16.0	1.23	54.2
Emerald	12.4	11.9	1.04	60.2
Igolya	10.2	10.1	1.01	78.7
Orlik	13.2	12.6	1.05	58.7
Least significant difference 0.05	2.5	2.2	0.12	3.4

CSM: Consumption of soil moisture during the accounting period: phase of head formation - beginning of head flowering, m-3 ha*; NPP: Net productivity of photosynthesis (NPP) of plants: phase of head formation - beginning of head flowering, g m^{-2} per day*; CSMPU: Consumption of soil moisture per unit of NPP in the phase of head formation - beginning of head flowering, m^{-3} g m^{-2} per day*; *Significance level is $p < 0.05$. Values were calculated by taking the average of three replicates. No statistically significant difference was found between the years in the variance analysis.

Table 2. Yield of the created varieties and samples of sunflower by estimate the consumption of moisture per unit net productivity of photosynthesis, t ha^{-1}, (average for 2016-2023).

Variety, sample	DPV	DIP	Plant height, cm*	Yield, t ha^{-1}*	Content of seed fat, %*
Sur (control)	107	55	139.2	2.49	49.1
33	104	50	142.3	2.24	53.0
44	104	50	145.6	1.97	52.4
52	107	55	157.1	1.60	52.3
65	105	51	152.9	2.15	51.9
129	110	57	127.9	1.70	52.9
Malakhit	102	51	115.4	2.41	49.1
Emerald	102	50	98.1	2.79	50.4
Igolya	110	55	110.2	3.49	51.4
Orlik	102	50	107.8	2.68	49.4
Least significant difference, 0.05	1.1	1.0	4.7	0.12	0.6

DPV: Duration of period vegetation, day*; DIP: Duration of interphase period “seedling-flowering”, day*; *Significance level is $p < 0.05$. Values were calculated by taking the average of three replicates. No statistically significant difference was found between the years in the variance analysis

Table 3. Correlation matrix of the relationship between the developmental traits of sunflower plants, (average for 2016-2023).

Correlation coefficient	Value
Consumption of soil moisture and net productivity of photosynthesis	- 0.21
Consumption of soil moisture and consumption of soil moisture per unit of NPP	0.95
Consumption of soil moisture and weight of head seeds	- 0.87
Net productivity of photosynthesis and consumption of soil moisture per unit of NPP	- 0.50
Net productivity of photosynthesis and weight of head seeds	0.03
Consumption of soil moisture per unit of NPP and weight of head seeds	- 0.91

The ratio between the consumption moisture and net productivity of photosynthetic was 3.97 m^{-3} g m^{-2} per day at sample 52 and 3.88 m^{-3} g m^{-2} per day per day at sample 129. A decrease the productivity of the photosynthesis process to 9.6 and 11.2 g m^{-2} per day at samples 52 and 129 did not lead to the decrease in the consumption of soil moisture per unit of net productivity of photosynthetic due to the maximum consumption of the water by plants during the period of plant development from head formation to the beginning of flowering.

The lowest consumption of soil moisture per unit of net productivity of photosynthetic was 1.04; 1.01; 1.05 m^{-3} g m^{-2} per day were characteristic for the varieties of the Emelard, Igolya, and Orlik, which consumed a minimal amount consumption of moisture from the soil and had minimal rates of photosynthesis in the arid conditions of the Steppe.

The sunflower varieties with lower consumption of soil moisture per unit of net productivity of the photosynthetic formed a greater weight of seeds in one head. The maximum weight of seeds in one head was noted at the varieties Emerald (60.2 g), Igolya (78.7 g), Orlik (58.7 g). Increase the consumption of soil moisture per unit of net productivity 0f the photosynthetic had a negative effect on the formation of the weight of seeds in the head and contributed to decrease of the seeds weight in the head. The sunflower samples 52 and 129 with the maximum consumption soil moisture per unit of NPP of 3.97 and 3.88 m^{-3} g m^{-2} per day formed the minimum weight of seeds in one head of 36.9 g and 38.8 g in the droughty conditions. The varieties and samples of sunflower with a greater weight of seeds in the head had lower values of soil moisture consumption at stages 5-8 of ontogenesis and consumed less the soil moisture per unit of net productivity photosynthetic.

The conducted correlation analysis of the development indicators of sunflower plants did not show a correlation between the moisture consumption during the study period and the net productivity of photosynthesis, the correlation coefficient was r = -0.21 (Table 3).

Increasing or decreasing in moisture consumption during the period of head formation – beginning of flowering did not contribute and not fully affect the increasing of the photosynthetic productivity. The strong positive correlation was found between the soil moisture consumption and soil moisture consumption per unit of net productivity of photosynthetic, the correlation coefficient r = 0.95. Correlation analysis shows a negative direct relationship between soil moisture consumption per unit of net productivity of photosynthetic and the weight of head seeds: r = -0.91. The increasing weight of head seeds in sunflower genotypes was due the decreasing of the consumption of soil moisture per unit of net productivity of photosynthetic. Sunflower genotypes that form the maximum weight of head seeds in droughty conditions had less dependence from the consumption of soil moisture at the stage of plant development: head formation – beginning of flowering. The maximum weight of seeds in the head of 58.7-78.7 g at the varieties Emelard, Igolya, Orlik was determined the reduced consumption of the moisture from the soil: 10.2-13.2 m^{-3} ha and the reduced consumption of the soil moisture per unit of net productivity of photosynthesis: 1.01-1.05 m^{-3} g m^{-2} per day in the phase of head formation - the beginning of flowering.

The weight of the seeds of the head determined the level of formation of the yield in samples and varieties of sunflower. Over the years of research, the newly obtained varieties of sunflower Emelard, Igolya, Orlik in droughty conditions of the growing season with a minimum consumption of soil moisture per unit of net productivity of photosynthesis of 1.01-1.05 m^{-3} g m^{-2} per day formed the highest yield of 2.68-3.49 t ha^{-1} with a fat content in the seeds of 49.4-51.4%.

The varieties that require the less quantity of moisture and consume the less quantity of moisture per unit of net productivity of the photosynthetic have the ability to forming the high levels of yield in relation to droughty conditions of vegetation periods.

Such varieties formed the yield on 0.19-1.0 t ha^{-1} higher than the control variety Sur. At the sunflower samples 52 and 129 with the highest amount of soil moisture consumption per unit of net productivity photosynthetic of 3.97 and 3.88 m^{-3} g m^{-2} per day, the productivity in droughty conditions of steppe was formed at the lowest level of 1.60-1.70 t ha^{-1}. By the absence of a direct effect of net productivity of photosynthetic on the formation of the weight of seeds in the head and the yield of sunflower genotypes, the indicators of soil moisture consumption of plants and the consumption of soil moisture per unit of net productivity photosynthetic at the fifth stage of ontogenesis can be reliable criteria for assessing genotypes for drought resistance and adaptability of genotypes for growing in arid conditions of the Steppe of Ukraine.

By the absence of a direct effect of net productivity of photosynthetic on the formation of the weight of seeds in the head and the yield of sunflower genotypes, the indicators of soil moisture consumption of plants and the consumption of soil moisture per unit of net productivity photosynthetic at the fifth stage of ontogenesis can be reliable criteria for assessing genotypes for drought resistance and adaptability of genotypes for growing in arid conditions of the Steppe of Ukraine.

Thus, the level of formation of the yield of sunflower genotypes in the arid conditions of the Steppe of Ukraine is largely determined by a lower consumption of soil moisture per unit of net productivity of photosynthetic in the phase of plant development: formation of the head – the beginning of flowering. More highly productive varieties adapted to growing in arid conditions consume less moisture on the stage of formation of generative organs of plants.

Conclusions

The net productivity of photosynthesis at the stage of formation of generative organs of sunflower plants does not have a direct effect on the formation of the weight of the seeds of the head. In the greater extent, the formation of the weight of the seeds of the head depends on the amount of consumed moisture from soil by plants during this period of development.

In the drought conditions of the steppe of Ukraine, the weight of the seeds of the sunflower head has strongly dependence from the consumption amount of soil moisture per unit of net productivity of photosynthesis in the phase of plant development: of the formation of the head - the beginning of flowering. The minimum consumption of soil moisture per unit of net productivity of photosynthesis objectively characterizes the ability of sunflower genotypes to form the maximum mass of seeds of the head, ultimately forming the maximum yield.

A negative correlation was established between the indicators of soil moisture consumption by plants per unit of net productivity of photosynthesis and the weight of the seeds of the head, the correlation coefficient was $r = -0.91$.

In the conditions of the Steppe of Ukraine, the decreasing of level of moisture consumption per unit of net productivity of photosynthesis at the fifth stage of plant ontogenesis ensures the formation of maximum yield of 2.68-3.49 t ha^{-1} at sunflower varieties Emelard, Igolya, Orlik.

Determining the level of soil moisture consumption during the period of head formation - the beginning of flowering allows to evaluate and select the genotypes highly productive of sunflower that consume less moisture per unit of dry matter accumulation by plants in the phase of formation of generative organs of plants in the most critical period for water consumption.

Knowledge and understanding of the physiological and biological patterns of sunflower development at fifth stage of plant ontogenesis allows us to select and create genotypes with a high level of productivity, adapted to cultivation in the Steppe of Ukraine.

Declarations

Author Contribution Statement

Contributed to this work of authors.

Aksyonov Igor: development of an experimental project, project administration, analisis data, supervision, conceptualization, methodology, writing the end option of article, review and editing.

Koychenko Marina: Data collection, investigation, formal analysis, and writing the original draft.

Conflict of Interest

The authors declare no conflict of interest.

References

Aksyonov, I. (2007). Effect of cultıvatıon measures on ındex of photosynthesıs and yıeld of sunflower. *Helıa*, *30 (47)*, 79-86. https://doi:10.2298/HEL0747079A

Aksyonov, I. V., Gavrilyuk, Yu. V. (2013). The influence of the main tillage on the agrophysical properties of the soil and the infestation of crop rotation crops in the conditions of the Steppe of Ukraine. *Scientific and methodological journal of the Belarusian State Agricultural Academy*, *3*.

Aksyonov, I. 2010. Use of minimum tillage in sunflower crowing under steppe conditions of southern Ukraine. *Helia*, *33 (3)*, 221-227. https:// doi:10.2298/HEL1053221A

Bırck, M., Dalchıavon, F. C., Stasıak, D., Iocca, A. F. S., Hıolanda, R., Carvalho, C. G. P. (2017). Performance of sunflower cultivars at different seeding periods in central Brazil. *Ciencia e Agrotecnologia*, *41*, 42-51. https://doi.org/10.1590/1413-70542017411021216.

Cao, S. K., Feng, Q., Si, J. H., Chang, Z. Q., Zhuo, M. C., Xi, H. Y. (2009). Summary on the plant water use efficiency at leaf level. *Acta Ecologica Sinica,* 29 (7), 3882–3892. https://doi:10.3321/j.issn:1000-0933.2009.07.051

Dospekhov, B. F. (1985). Methods of field experience. *Moscow: Agropromizdat*.

El-Bially, M. E., Saudy, H. S., El-Metwally, I. M., Shahin, M. G. (2022). Sunflower response to application of L-ascorbate under thermal stress associated with different sowing dates. *Gesunde Pflanzen. 74 (1)*, 87–96. https://doi:10.1007/s10343-021-00590-2

Gao, G., Feng, Q., Zhang, X. Y., Si, J. H., Yu, T. F. (2018). An overview of stomatal and non-stomatal limitations to photosynthesis of plants. *Arid Zone Research, 35 (04)*, 929–937. https://doi:10.13866/j.azr.2018.04.22

Jensen, C. R., Battilani, A., Plauborg, F., Psarras, G., Chartzoulakis, K., Janowiak, F. (2010). Deficit irrigation based on drought tolerance and root signalling in potatoes and tomatoes. *Agricultural Water Management, 98 (3)*, 403–413. https://doi:10.1016/j.agwat.2010.10.018

Karam, F., Lahoud, R., Masaad, R., Kabalan, R., Breidi, J., Chalita, C. (2007). Evapotranspiration, seed yield and water use efficiency of drip irrigated sunflower under full and deficit irrigation conditions. *Agricultural Water Management,* 90 (3), 213–223. https://doi:10.1016/j.agwat.2007.03.009

Oikawa, S., Ainsworth, E. A. (2016). Changes in leaf area, nitrogen content and canopy photosynthesis in soybean exposed to an ozone concentration gradient. E*nvironmental pollution, 215*, 347–355. https://doi: 10.1016/j.envpol.2016.05.005

Ramadan, K. M. A., El-Beltagi, H. S., Abd El-Mageed, T. A., Saudy, H. S., Al-Otaibi, H. H., Mahmoud, M. A. A. (2023). The changes in various physio-biochemical parameters and yield traits of faba bean due to humic acid plus 6-benzylaminopurine application under deficit irrigation. *Agronomy-Basel*, *13 (5*), 16. https://doi: 10.3390/agronomy13051227

Rauf, S.; Sadaqat, H. A. (2008). Identification of physiological traits and genotypes combined to high achene yield in sunflower (*Helianthus annuus* L.) under contrasting water regimes. *Australian Journal of Crop Science, 1*, 23-30.

Salem, E. M. M., Kenawey, K. M. M., Saudy, H. S., Mubarak, M. (2021). Soil mulching and deficit irrigation effect on sustainability of nutrients availability and uptake, and productivity of maize grown in calcareous soils. *Communications in Soil Science and Plant Analysis, 52 (15)*, 1745–1761. https://doi: 10.1080/00103624.2021.1892733

Saudy, H. S., El-Bially, M. E., Hashem, F. A., Shahin, M. G., El-Gabry, Y. A. (2023). The changes in yield response factor, water use efficiency, and physiology of sunflower owing to ascorbic and citric acids application under mild deficit irrigation. *Gesunde Pflanzen,* 75 *(4*), 899–909. https://doi: 10.1007/s10343-022-00736-w