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Physiological features of yield formation of sunflower breeding samples in arid conditions of the Ukrainian steppe

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Abstract

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.

Key Words: *sunflower, net of photosynthesis productivity, consumption coefficient of soil moisture per unit of net of photosynthesis productivity, budding stage, early flowering stage, seeds weight of plant, yield.*

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

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

The assessment of plants by morphological characteristics was carried out in the field on experimental plots. 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%.

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.

The studies were conducted in accordance with generally accepted methods in plant growing. Statistical processing of the research results was performed in accordance with Dospekhov (1985), Aksyonov et al. (2023), using the Microsoft Office Excel 2010 application.

Results and discussion

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 m3/ha, respectively (Table 1).

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

Sample	CMA	NPP	CSMN	WHS
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

CMA: Consumption of soil moisture during the accounting period: phase of head formation - beginning of head flowering, m3/ha; NPP: Net productivity of photosynthesis (NPP) of plants: phase of head formation - beginning of head flowering, g/m2 per day; CSMN: Consumption of soil moisture per unit of NPP in the phase of head formation - beginning of head flowering, m3/g/m2 per day; WHS: Weight of head seeds, g

The minimum consumption of soil moisture during the period of head formation and the beginning of flowering of 10.2-13.2 m3/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/m2 per day. 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 m3/ha, had low net productivity of photosynthetic of 11.9; 10.1, 12.6 g/m2 per day, respectively. The maximum net productivity of photosynthetic of 16.8 and 17.3 g/m2 per day was characteristic of samples 33 and 65 with the average consumption of soil moisture of 20.9 and 21.9 m3/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. The ratio between the consumption moisture and net productivity of photosynthetic was 3.97 m3/g/m2 per day at sample 52 and 3.88 m3/g/m2 per day per day at sample 129. A decrease the productivity of the photosynthesis process to 9.6 and 11.2 g/m2 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 m3/g/m2 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 m3/g/m2 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 2).

Table 2. Correlation matrix of the relationship between the developmental traits of sunflower plants, (average for 2016-2023).

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

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 m3/ha and the reduced consumption of the soil moisture per unit of net productivity of photosynthesis: 1.01-1.05 m3/g/m2 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 m3/g/m2 per day formed the highest yield of 2.68-3.49 t/ha with a fat content in the seeds of 49.4-51.4% (Table 3).

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 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 m3/g/m2 per day, the productivity in droughty conditions of steppe was formed at the lowest level of 1.60-1.70 t/ha.

Table 3. Yield of the created varieties and samples of sunflower by estimate the consumption of moisture per unit net productivity of photosynthesis, t/ha, (average for 2016-2023).

Variety, sample	Duration of period vegetation	Duration of interphase period "seedling-flowering"	Plant Height, sm	Yield, t/ha	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
Smallest significant difference, 0.05	1.1	1.0	4.7	0.12	0.6

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 акщь epy 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 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.

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