Received 04.06.2025 Revised 02.09.2025 Accepted 23.09.2025

Vol. 21, No. 5
2025

Scientific Reports of the National University of Life and Environmental Sciences of Ukraine

Journal homepage: https://scireports.com.ua/en

UDC 631.527.5:633.85:632.11

Doi: 10.31548/dopovidi/5.2025.98

Assessment of agrometeorological conditions for growing sunflower hybrids

Lesia Harbar
PhD in Agricultural Sciences, Associate Professor
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.ord/0000-0003-4249-0434

Maksim Vandzhura*
Postgraduate Student
National University of Life and Environmental Sciences of Ukraine
03041, 15 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0009-0001-6372-0641

Abstract. The aim of the study was to analyse the weather conditions during the vegetation period, their correspondence to the morphobiological characteristics of the hybrids, and to identify sunflower hybrids that are better adapted to the region where the research was conducted. The studies were carried out during 2022-2024 under the conditions of Ternopil region. An analysis of the agrometeorological indicators over the research years revealed considerable differences in the vegetation periods, both in terms of temperature indicators and the total monthly precipitation. According to the temperature data, values exceeded the long-term average. The analysis of weather conditions in the study region indicated that the conditions are suitable for cultivating sunflower hybrids of all maturity groups examined, in terms of both heat resources and moisture availability. The sum of active temperatures for the period from April to September was 3,162.1°C (biological minimum 5°C), and the sum of effective temperatures was 2,263.2°C. At a biological minimum of 10°C, the respective figures were 2,977.1°C and 1,409.1°C. During this period, the highest total of heat units was recorded at 3,642.4°C. The total heat units for the May-September period amounted to 3,433.4°C. Soil moisture reserves within the one-metre layer depended on the year's weather conditions and varied accordingly. The water consumption coefficient for early-maturing hybrids, under the influence of fertilisers, ranged from 1,173 to 1,012 m^3/t per tonne of seed; for mid-early hybrids – from 1,171 to 1,017 m^3/t; and for mid-season hybrids – from 1,100 to 989 m^3/t per tonne of seed. A correlation analysis between sunflower yield indicators

Suggested Citation:
Harbar, L., & Vandzhura, M. (2025). Assessment of agrometeorological conditions for growing sunflower hybrids. *Scientific Reports of the National University of Life and Environmental Sciences of Ukraine*, 21(5), 98-113. doi: 10.31548/dopovidi/5.2025.98.

**Corresponding author*

and soil moisture reserves showed a direct correlation, with a correlation coefficient of 0.8456. The results of this research can be used to optimise the timing of sowing and harvesting in accordance with forecasted agrometeorological conditions

Keywords: *Helianthus annuus*; temperature indicators; moisture availability; heat units; maturity group

Introduction

Global changes in climate and weather conditions caused by rising temperatures, sharp temperature fluctuations, uneven distribution of precipitation and insufficient rainfall, and frequent droughts have prompted a search for solutions to this problem in the field of crop production. Agricultural producers are putting a lot of effort into introducing and adapting new species and creating new varieties and hybrids that are highly stable and adaptable. Much effort is now being directed towards utilising the adaptive potential of agrocenoses, which involves comprehensive approaches to increasing adaptability through selection, management of exogenous influences on plants, and the creation of optimal crop structures. The creation and emergence of varieties and hybrids with high yield potential and resistance to a wide range of environmental factors cannot fully solve this problem. Sustainable crop production is possible through the management of plant production processes, taking into account and controlling biotic and abiotic factors. In other words, there is a need to create, develop and implement adaptive technologies for growing agricultural crops. With changing climatic conditions, crops from southern regions are moving northwards. An example of such crops is sunflower, the cultivation of which is rapidly spreading to the northern and western regions of Ukraine, which were not previously characteristic for its cultivation.

An analysis of the oilseed market indicates that it is strategically important, as there is a positive price trend for these crops, particularly sunflowers. The supply of this crop is determined by organisational and technological characteristics and the influence of unregulated environmental factors (soil and weather conditions). A series of studies by S.P. Ivanyuta *et al*. (2020) shows that global climate change caused by an increase in average monthly and, accordingly, average annual temperatures and changes in precipitation, mainly towards a decrease in its amount, creates long-term risks in the crop production sector. Crop yields depend on both temperature and moisture conditions and can be controlled by selecting adapted varieties and hybrids and improving cultivation techniques. The results of studies by M. Huz *et al*. (2024), conducted in several periods from 2008 to 2021, indicate significant changes in the analysis of sunflower production dynamics in Ukraine. The dynamics of the indicators were caused by changes in climatic conditions as a result of differences in weather conditions. Sunflower production indicators were characterised by a close dependence of crop yields on weather conditions in different regions of Ukraine. In addition to environmental conditions, market conditions also had an impact on sunflower production indicators. Based on production and yield indicators, polynomial trend models were constructed, which were characterised by a high degree of reliability and were able to reflect the real dynamics of the indicators.

In order to increase sunflower production, it is necessary to ensure growing conditions in which plants are able to realise their full potential. In particular, this means creating conditions that are more favourable in terms of moisture availability than in the southern regions of Ukraine. This is why there has been a migration of sunflower crops to the western and northern regions of Ukraine. The research by D. Baranskyi (2024) is aimed at studying the impact of sunflower cultivation in conditions of sufficient moisture in the Western Forest-Steppe on the dynamics of soil moisture reserves during the growing season. The results showed that the crop is capable of producing high yields in the presence of sufficient moisture in the 0-200 mm soil layer in the autumn-winter period. Research by O.L. Zhygailo *et al.* (2021) points to the formation of new economic conditions in all sectors, including crop production, as a result of global climate change. One of the crops affected by this is sunflower, whose yield is linked to the agroclimatic conditions in which it is grown. The authors emphasise that the profitability of growing this crop will depend on the natural and climatic zone in which it is grown.

Scientists I.V. Tomashuk & R.O. Horobchuk (2024) analysed the potential of Ukraine's agricultural sector and investigated opportunities for increasing the efficiency of its use in the cultivation of certain crops. One of the factors determining the level of production is the soil and weather conditions of the region where the crop is grown. According to V.M. Totskyi *et al.* (2024), crop cultivation technology, in particular the use of mineral fertilisers that provide a sufficient level of essential nutrients in the soil, is of great importance for sunflower cultivation and increasing its yield and seed quality. The level of nutrient uptake by plants is determined by a number of factors, including soil and climatic conditions. Research by O. Trembitska *et al.* (2021), conducted in the Polissya region on the cultivation of the Oplot hybrid sunflower to study the effect of fertilisation, showed a positive impact on both yield and seed quality. The highest yield indicators were obtained in the variant with the use of $N_{90}P_{90}K_{90}$ – 2.16 t/ha with a fat content in seeds of 44.2%. The cultivation of sunflowers in atypical conditions (in Polissya) and the search for optimal technological methods based on the results of research by O.A. Furmanets (2022) indicated the difficulties arising from unstable growing conditions, which do not allow the genetic potential of the crop to be realised. The use of fertilisers allows increasing the crop yield in conditions of sufficient moisture supply to 27%, and in arid conditions – to 44.0%.

In the context of changing climatic conditions, the development and implementation of adapted crop cultivation technologies is of great importance in the field of crop production. These technologies involve the optimisation of cultivation techniques and the selection of new crop varieties and hybrids capable of maximising their genetic potential in atypical growing conditions. The aim of the research was to analyse the weather conditions during the growing season and identify sunflower hybrids that are better adapted to the region where the research was conducted.

Materials and Methods

The research was conducted during 2022-2024 under the conditions of the Ternopil region. The field experiment was a three-factor design with four replications. The area of the experimental plot was 60 m², and the accounting (harvest) plot area was 42 m². The research design involved studying the following factors: factor A – maturity group: early, medium early, medium ripening; factor B – hybrids: RGT Wollf, Atilla, Belvedere, LG-5478, NK Brio, NK Kondi, P64LL155, factor C – fertilisation options: 1. $N_{60}P_{60}K_{80}$; 2. $N_{80}P_{80}K_{120}$. The preceding crop was winter wheat. The meteorological indicators and parameters used for calculations were taken from the data of the meteorological station in Ternopil.

The calculation of the coefficients of significance of deviations in temperature indicators and precipitation for the years of research and average long-term indicators was carried out using the formula:

$$Cs = \frac{(Xi - \bar{X})}{\sigma}, \quad (1)$$

where: *Cs* – coefficient of significance of deviations; *Xi* – weather elements for the current year;

$\bar{X}$ – indicator of the average long-term value; σ – mean square deviation.

The significance of the coefficients of materiality of deviations had the following gradations:

- *Cs* = 0 ÷ 1 – conditions close to normal;
- *Cs* = 1 ÷ 2 – conditions significantly different from long-term averages;
- *Cs* > 2 – conditions close to rare.

Heat units (CHU) were calculated for the period from emergence to full maturity of the crop according to the following methodology: heat units per day (Y_{max}) were calculated using the formula:

$$Y_{max} = 3.33 \cdot (T_{max} - 10) - 0.084 \cdot (T_{max} - 10), \quad (2)$$

at $T_{max} < 10$, $Y_{max} = 0$.

Calculation of heat units per night:

$$Y_{min} = 1.8 \cdot (T_{min} - 4.44), \quad (3)$$

at $T_{min} < 4.44$, $Y_{min} = 0$.

The next step was to calculate the heat units per day:

$$CHU = (Y_{max+} Y_{min})/2.0 \quad (4)$$

The sums of active and effective temperatures were determined by calculation for biologically active temperatures of 5 and 10°C. The amount of available moisture was determined using the thermostat-weight method, and total moisture consumption was determined using the water balance formula:

$$E = O + (Wn - Wk), \quad (5)$$

where *E* – the amount of moisture used by plants during vegetation, m³/ha; *Wn*, *Wk* – the amount of moisture at the beginning and end of vegetation, m³/ha; *O* is the amount of precipitation during vegetation, m³/ha.

The water consumption coefficient was determined using the formula:

$$Cc = E : Y, \quad (6)$$

where *Cc* – water consumption coefficient, m³/ha; *Y* – the sunflower yield, t/ha.

Yield was determined by sectional harvesting with a conversion to 8% moisture content. Based on the results obtained, a correlation analysis was performed between yield indicators and soil moisture reserves (Rozhkov *et al.*, 2016). The study complied with the requirements of the Convention on Biological Diversity (1992).

Results and Discussion

The availability of a huge range of varieties and hybrids of agricultural crops, in particular industrial crops, on the seed market poses a challenge for producers when selecting seed material, taking into account its plasticity to unregulated factors and the ability to maximise genetic potential in specific climatic conditions. An analysis of the weather conditions at the research site was carried out based on the significance coefficients of deviations of current weather data (2022-2024) from the long-term average parameters.

An analysis of agrometeorological indicators over the years of research shows significant differences between vegetation periods. These results were obtained from the analysis of both temperature indicators and the total amount of precipitation per month. The results of temperature indicators (2022-2024) show that they exceed the long-term average data (Fig. 1).

Analysis of agrometeorological data showed that March temperatures were significantly higher than the long-term average (1.7°C) in all years of the study and ranged from 4.0 to 4.6°C. In April, temperatures in 2022 and 2023 were lower than the long-term average (8.4°C) and ranged from 6.9 to 7.4°C. In 2024, the temperature was 11.2°C, which affected the timing of sunflower sowing. The temperature in May was as close as possible to the long-term average (14.2°C) and corresponded to values of 14.1, 14.2 and 15.7°C. All other months of the growing season from June to September were characterised by a significant increase in temperature indicators by 0.7-4.4°C.

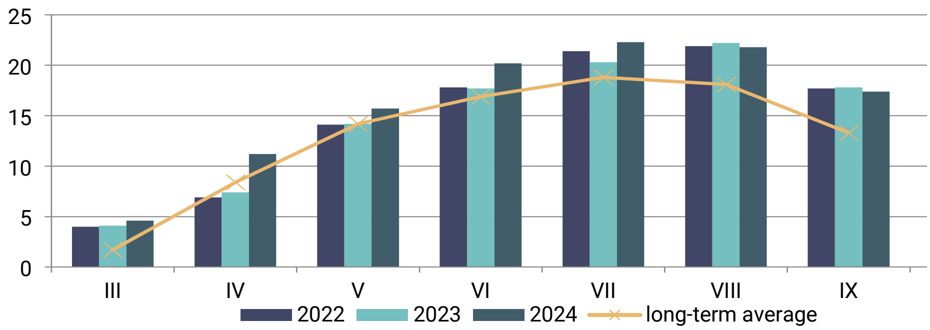

Figure 1. *Average monthly air temperature, 2022-2024, °C*
Source: developed by the authors

The amount of precipitation that fell during the sunflower growing season was insufficient, with a characteristic uneven distribution (Fig. 2). As the analysis of the indicators showed, May was characterised by the lowest amount of precipitation, with values almost twice lower than the long-term average in all years of the study.

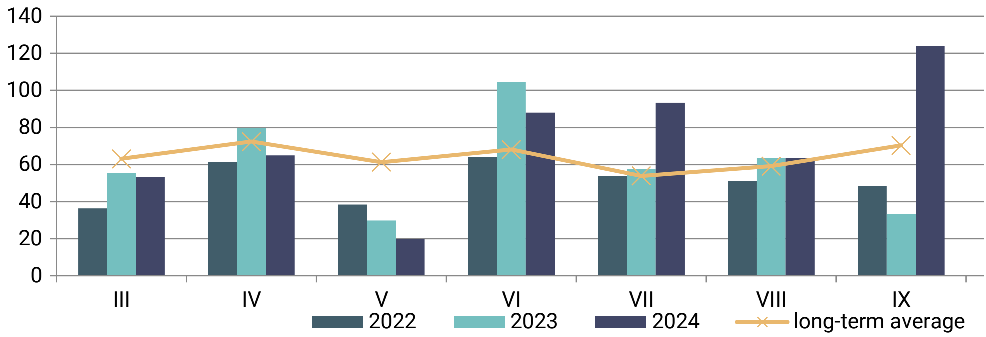

Figure 2. *Precipitation, 2022-2024, mm*
Source: developed by the authors

Precipitation in April was sufficient and, depending on the year of research, varied between 61.4 and 79.7 mm (average long-term figures – 72.4 mm). May turned out to be the driest of all the growing months. According to long-term averages – 61.3 mm in 2022, 38.4 mm fell in 2023, 29.8 mm in 2024, and 19.8 mm in 2025. June was characterised by precipitation close to the long-term average (68.1 mm), while in 2023 it significantly exceeded the average and amounted to 104.6 mm. July was characterised by a similar pattern, with precipitation exceeding the long-term average in 2024 (93.3 mm compared to 53.9 mm). In August, precipitation was close to the long-term average, ranging from 51.2 to 63.6 mm. In September, precipitation was below normal (70.3 mm) in 2022 and 2023, amounting to 48.4 and 33.3 mm, respectively. In 2024, precipitation in September amounted to 124.1 mm, which complicated the harvesting of crops.

An analysis of the calculated coefficients of significance of precipitation deviations showed that 54% of the months analysed belonged to the category of "conditions close to normal". Meanwhile, 33% were characterised as "conditions that differ significantly from long-term indicators" and 13% as "conditions close to rare" (Fig. 3).

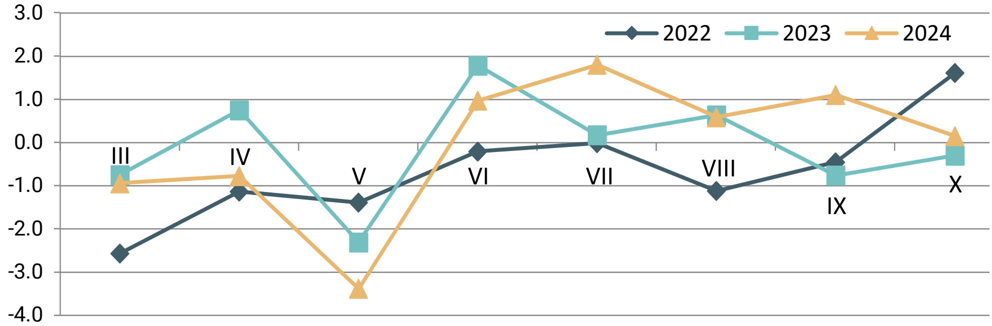

Figure 3. *Significance coefficients of precipitation deviations, 2022-2024*
Source: developed by the authors

Calculations to determine the significance coefficients of temperature deviations and their analysis indicate significant deviations between the long-term average data and the actual temperature readings during the years of research. It should be noted that a significant upward deviation in temperature indicators brings certain periods of plant growth and development closer to "rare conditions" (Fig. 4).

Analysis of the calculated coefficients of significance of temperature deviations showed that they varied in the range from 2.6 to minus 1.5. The following results were obtained when calculating the coefficients of deviation of temperature indicators: the percentage of months with "conditions close to normal" was 58, and "conditions that differ significantly from long-term indicators" was 25, while "conditions close to rare" was 17%.

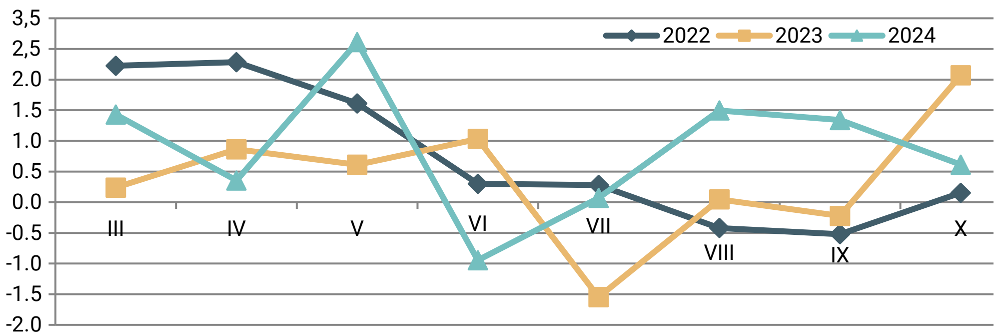

Figure 4. *Materiality coefficients of deviations in average monthly temperature indicators, 2022-2024*
Source: developed by the authors

Air temperature indicators are unregulated factors. And in the context of climate change, when there is a significant increase in these indicators, their significant impact on certain processes in plants becomes apparent, which is reflected in the formation of their productivity. There are a number of indicators that can be calculated based on temperature data to draw conclusions about their impact on plant growth and development. The calculation of heat units by month showed that April was characterised by the highest deviations from the average value. The sum of heat units in 2023 was the lowest, at 127.9°C, while in 2024 the indicator was 309.7°C. In other words, April in the region where the research was conducted was characterised by rather unstable temperature indicators during the day and night, which was reflected in the sum of heat units per month. In all other months of the sunflower growing season, no such significant differences were found between the years of research (Table 1).

Table 1. *Total heat units for sunflower vegetation in 2022-2024*

Month, period	CHU			Deviation from the average			Average for 2022-2024
	2022	2023	2024	2022	2023	2024	
April	189.4	127.9	309.7	-19.6	-81.1	100.7	209.0
May	495.2	471.4	512.1	2.3	-21.5	19.2	492.9
June	657.1	634.5	730.7	-17.0	-39.6	56.6	674.1
July	789.6	770.2	830.8	-7.3	-26.7	33.9	796.9
August	786.1	814.7	812.9	-18.5	10.1	8.3	804.6
September	694.6	664.2	636.1	29.6	-0.8	-28.9	665.0
Σ April-August	2,917.4	2,818.7	3,196.2	-60.0	-158.7	218.8	2,977.4
Σ April-September	3,612.0	3,482.9	3,832.3	-30.4	-159.5	189.9	3,642.4
Σ May-August	2,728.0	2,690.8	2,886.5	-40.4	-77.6	118.1	2,768.4
Σ May-September	3,422.6	3,355.0	3,522.6	-10.8	-78.4	89.2	3,433.4

Note: CHU – Crop Heat Units
Source: developed by the authors

The calculation of the average number of heat units during the years of research during the sunflower growing season indicates their significant importance and dependence on weather conditions during the year. It should be noted that the number of heat units depended not only on the average daily temperature, but also on its minimum and maximum values. Thus, for the period from April to August, the sum of heat units was 2,917.4 in 2022, 2,818.7 in 2023, and 3,196.2°C in 2023. The April-September growing season was characterised by the following indicators: 3,612.0 in 2022, 3,482.9 in 2023, and 3,832.3°C in 2024. During the period from May to August, plants accumulated the smallest amount of heat units, which varied from 2,690.8 to 2,886.5°C during the study period. The sum of heat units for the May-September growing season ranged from 3,355.0 (2023) to 3,522.6 (2024). It should be noted that the highest average number of heat units per year was obtained for the growing season covering April-September, with an indicator of 3,642.4. A slightly lower indicator was obtained for the period May-September – 3,433.4.

The next criteria determining the conditions for growing crops are the sums of active and effective temperatures during the growing season. For sunflowers, the sums of these temperatures at biological minimums of 5 and 10°C are relevant. As shown by the calculations, the sums of active and effective temperatures for the corresponding periods were significantly lower than the sums of heat units (Table 2).

Table 2. *Indicators of the sum of active and effective temperature indicators at a biological minimum of 5°C*

Month	Decade	Sum of active temperatures, °C			Average value	Sum of effective temperatures, °C			Average value
		2022	2023	2024		2022	2023	2024	
April	1	47.5	29.9	129.5	69.0	4.9	10.5	79.5	31.6
	2	91.5	88.7	100.9	93.7	41.5	38.7	55.9	45.4
	3	90.1	90.5	101.3	94.0	40.1	40.5	51.3	44.0

***Table 2.** Continued*

Month	Decade	Sum of active temperatures, °C			Average value	Sum of effective temperatures, °C			Average value
		2022	2023	2024		2022	2023	2024	
May	1	103.4	99.7	145.9	116.3	53.4	49.7	95.9	66.3
	2	127.0	149.6	130.7	135.8	77	99.6	80.7	85.8
	3	197.1	190.7	209.1	199.0	147.1	133.1	154.1	144.8
June	1	184.1	179.4	193.9	185.8	134.1	129.4	143.9	135.8
	2	171.3	168.9	190.1	176.8	121.3	111.9	140.1	124.4
	3	199.2	190.6	223.3	204.4	149.2	140.6	173.3	154.4
July	1	215.2	204	210.3	209.8	165.2	154.0	160.3	159.8
	2	235.4	207.4	260.3	234.4	185.4	157.4	210.3	184.4
	3	223.1	217.8	222.1	221.0	173.1	162.8	167.1	167.7
August	1	203.1	208.1	198.2	203.1	153.1	158.1	148.2	153.1
	2	217.0	221.8	220.7	219.8	167.0	171.8	170.7	169.8
	3	260.1	258.0	256.9	258.3	210.1	203.0	201.9	205.0
September	1	201.8	171.5	207.9	193.7	151.8	121.5	157.9	143.7
	2	189.2	181.1	165	178.4	139.2	131.1	115	128.4
	3	168.4	182.6	155.4	168.8	118.4	132.6	105.4	118.8
Σ April-August		2,565.1	2,505.1	2,793.2	2,621.2	1,822.5	1,761.1	2,033.2	1,872.3
Σ April-September		3,124.5	3,040.3	3,321.5	3,162.1	2,231.9	2,146.3	2,411.5	2,263.2
Σ May-August		2,336.0	2,296.0	2,461.5	2,364.5	1,736.0	1,671.4	1,846.5	1,751.3
Σ May-September		2,895.4	2,831.2	2,989.8	2,905.4	2,145.4	2,056.6	2,224.8	2,142.2

Source: developed by the authors

The sum of active temperatures (biological minimum 5°C) for the period April-September was the highest and amounted to the following for the years of research: in 2022, 3,124.5; in 2023, 3,040.3; in 2024, 3,321.5°C. The indicators for the period May-September were slightly lower: in 2022, 2,895.4; in 2023, 2,831.2; in 2024, 2,989.8°C. The growing seasons from April to August and May to August were characterised by significantly lower values. The maximum sum of active temperatures at a biological minimum of 5°C – 3,162.1°C – was obtained for the period from April to September on average over the years of research. Analysis of the sum of effective temperatures at a biological minimum of 5°C indicates similar trends between indicators depending on the growing seasons and years of research. The sum of active temperatures for the period April-September had the highest values, varied depending on the year of research and amounted to 2,231.9 in 2022, 2,146.3 in 2023, and 2,411.5°C in 2024. The sum of effective temperatures for the same period averaged 2,263.2°C over the years. The calculation of the sum of active temperatures at a biological minimum of 10°C showed significantly lower values than those in the previous table, but the trends between the indicators remained the same (Table 3).

***Table 3.** Indicators of the sum of active and effective temperature indicators at a biological minimum of 10°C*

Month	Decade	Sum of active temperatures, °C			Average value	Sum of effective temperatures, °C			Average value
		2022	2023	2024		2022	2023	2024	
April	1	0	0	111.9	37.3	0	0	31.1	10.4
	2	11.5	0	81.6	31.0	0	0	21.6	7.2
	3	30.1	65.8	52.3	49.4	0	5.8	12.3	6.0

Table 3. *Continued*

Month	Decade	Sum of active temperatures, °C			Average value	Sum of effective temperatures, °C			Average value
		2022	2023	2024		2022	2023	2024	
May	1	33.4	61.5	145.9	80.3	0	11.5	45.9	19.1
	2	103.0	139.8	130.7	124.5	3	49.8	30.9	27.9
	3	197.1	190.7	209.1	199.0	97.1	80.7	109.1	95.6
June	1	184.1	179.4	193.9	185.8	84.1	79.4	93.9	85.8
	2	171.3	169.9	190.1	177.1	71.3	61.9	90.1	74.4
	3	199.2	190.6	223.3	204.4	99.2	90.6	123.3	104.4
July	1	215.2	204.0	210.3	209.8	115.2	104.0	110.3	109.8
	2	235.4	207.4	260.3	234.4	135.4	107.4	160.3	134.4
	3	223.1	217.8	222.1	221.0	123.1	107.8	122.1	117.7
August	1	203.1	208.1	198.2	203.1	103.1	108.1	98.2	103.1
	2	217.0	221.8	220.7	219.8	117.0	121.8	120.7	119.8
	3	260.1	258	256.9	258.3	160.1	148.0	146.9	151.7
September	1	201.8	171.5	207.9	193.7	101.8	71.5	107.9	93.7
	2	189.2	184.1	165	179.4	89.2	81.1	65.0	78.4
	3	168.4	182.6	155.4	168.8	68.4	82.6	58.1	69.7
Σ April-August		2,283.6	2,314.8	2,707.3	2,435.2	1,108.6	1,076.8	1,316.7	1,167.3
Σ April-September		2,843.0	2,853.0	3,235.6	2,977.1	1,368.0	1,312.0	1,547.7	1,409.1
Σ May-August		2,242.0	2,249.0	2,461.5	2,317.5	1,108.6	1,071.0	1,251.7	1,143.7
Σ May-September		2,801.4	2,787.2	2,989.8	2,859.4	1,368.0	1,306.2	1,482.7	1,385.5

Source: developed by the authors

The sum of active temperatures (biological minimum 10°C) for the period April-September had the highest values and amounted to the following for the years of research: in 2022, 2,843.0; in 2023, 2,853.0; in 2024, 3,235.6°C, which indicates the possibility of growing hybrids with longer growing seasons than those studied in the research region. The calculation of the sum of effective temperatures (biological minimum 10°C) shows similar dependencies between the indicators and their lower values. The period from April to September was characterised by the highest values of the sum of effective temperatures at a biological minimum of 10°C, with indicators ranging from 1,312.0 to 1,547.7°C over the years of research. On average for the years of research, the sum of active temperatures at a biological minimum of 10°C was at its maximum during the April-September growing season at 2,977.1°C, and the sum of effective temperatures was 1,409.1°C. The results obtained, according to the calculations, indicate the possibility of growing the hybrids studied under the conditions of the research.

Moisture is one of the limiting factors in the formation of crop productivity, in particular sunflower. Analysis of moisture reserve indicators under the conditions of the research indicates a significant influence of the meteorological characteristics of each growing season. The total moisture reserves for sunflower cultivation depend on the moisture reserves in the metre-deep soil layer at the time of sowing, the amount of precipitation during the growing season, and the duration of the growing season for a particular hybrid. Due to the fact that all hybrids were sown simultaneously, soil moisture reserves did not change in terms of maturity group (Table 4).

Table 4. *Characteristics of moisture supply indicators for sunflower hybrids, m3/ha*

Year	Hybrid maturity group	Soil moisture reserves, sowing, m³/ha	Precipitation during vegetation, m³/ha	Total moisture reserves, m³/ha	Moisture reserves, harvesting, m³/ha	Moisture consumption, total, m³/ha
2022	Early	1,295	1,815	3,110	796	2,314
	Mid-early	1,295	1,839	3,134	748	2,386
	Mid-season	1,295	1,879	3,174	715	2,459
2023	Early	1,489	1,843	3,332	832	2,500
	Mid-early	1,489	2,262	3,751	811	2,940
	Mid-season	1,489	2,277	3,766	774	2,992
2024	Early	1,645	2,163	3,808	841	2,967
	Mid-early	1,645	2,593	4,238	827	3,411
	Mid-season	1,645	3,137	4,782	801	3,981

Source: developed by the authors

Thus, soil moisture reserves at the time of sowing amounted to 1,295 m³/ha in 2022, 1,489 m³/ha in 2023, and 1,645 m³/ha in 2024. The amount of precipitation depended on the maturity group of the hybrids and the duration of their vegetation period, ranging from 1,815 m³/ha (in 2022, for the early maturity group) to 3,137 m³/ha (in 2024, for the mid-season group). The total moisture reserves in the one-metre soil layer during the vegetation period varied depending on the research year – from 3,110 m³/ha in 2022 when cultivating early-maturing sunflower hybrids to 4,782 m³/ha in 2024 for mid-season hybrids. Calculations showed that total moisture reserves depended more on precipitation during the vegetation period than on the productive moisture reserves in the one-metre soil layer at sowing time. It is worth noting that 2024 was characterised by the highest soil moisture reserves at sowing and the greatest amount of precipitation during the sunflower vegetation period. Moisture consumption by sunflower plants depended on the total moisture reserves and the resulting crop yield. The yield of sunflower hybrids was influenced by the genetic characteristics of the hybrids, their maturity group, the impact of uncontrolled environmental factors, and the elements of cultivation technology. Therefore, moisture consumption depended on the growth and development features of each hybrid under the combined influence of all factors. It varied according to maturity group and amounted to between 2,314 and 2,459 m³/ha in 2022, between 2,500 and 2,992 m³/ha in 2023, and between 2,967 and 3,981 m³/ha in 2024. As the duration of the vegetation period increased, moisture consumption also increased.

Sunflower, like other field crops, have different moisture requirements at different stages of their growth and development. They have the greatest need for water during the period of laying and formation of generative organs. Insufficient moisture leads to a decrease in crop productivity. The calculation of water consumption coefficients for sunflowers within maturity groups depended primarily on the established yield of the main product, and only then on the duration of their growing season and, accordingly, moisture availability (Table 5).

***Table 5.** Water consumption coefficient indicators for sunflower hybrid maturity groups, m3/t per 1 t of seeds*

Year	Maturity group					
	Early		Mid-early		Mid-season	
	1	2	1	2	1	2
2022	1,146	972	1,015	871	931	851
2023	1,116	965	1,200	1,024	1,092	962
2024	1,257	1,099	1,297	1,156	1,276	1,154
average	1,173	1,012	1,171	1,017	1,100	989

Note: 1 – $N_{60}P_{60}K_{80}$; 2 – $N_{80}P_{80}K_{120}$
Source: developed by the authors

The analysis of indicators demonstrates their dependence on yield, the maturity group of sunflower hybrids (vegetation duration), and the moisture supply available to plants during the growing season. The amount of fertiliser applied in sunflower cultivation also influenced these indicators. As the fertiliser application rates increased, crop yield rose, while the water consumption coefficient decreased. On average over the years of study, the water consumption coefficient for early-maturing hybrids under the influence of fertilisers ranged from 1,173 to 1,012 m^3/t per tonne of seed; for mid-early hybrids, from 1,171 to 1,017 m^3/t; and for mid-season hybrids, from 1,100 to 989 m^3/t per tonne of seed. Correlation analysis between sunflower yield and soil moisture reserves revealed a direct relationship with a correlation coefficient of 0.8456.

Similar results were obtained by D. Baranskyi (2024) from studies conducted in 2022-2023 in the Western Forest-Steppe zone, which demonstrated a dependence of sunflower yield on soil moisture reserves within the root zone. However, that research also emphasised the importance of moisture accumulation during the autumn and winter periods. Studies by O.I. Polyakov & A.D. Shcherbak (2022) showed that sunflower yield depends on the water supply available to plants of different hybrids throughout the entire vegetation period. The authors also highlighted the influence of fertiliser application rates on water consumption and crop yield. In variants without fertiliser application, the lowest total plant water use was recorded. Under the influence of the genetic characteristics of each variety, the indicators varied from 359.2 to 372.8 mm. When phosphorus and potassium fertilisers were applied in sunflower cultivation, the lowest water consumption coefficient was recorded, ranging from 1,039 to 1,177 m^3/ha depending on the studied factors.

Research by A. Haj Sghaier *et al.* (2023), dedicated to studying the impact of temperature indicators and moisture on the rate of sunflower seed germination, highlighted the importance of considering the duration of the vegetation period and the ability of plants to form seedlings when planning technological processes. These results make it possible to determine the optimal sowing dates, ensuring proper growth, development, and productivity formation of sunflower plants. The study by S. Matskova and A. Gumanyuk (2025), aimed at analysing uncontrolled environmental factors (average annual temperatures and spring soil moisture reserves) over the period 2006-2024, showed that spring soil moisture reserves have a weak correlation with sunflower yield indicators ($r = 0.145$), indicating an insignificant influence of this factor on crop productivity formation. When considering the combined effect of spring soil moisture and precipitation during April-May, the correlation coefficient was $r = 0.298$. A higher correlation coefficient ($r = 0.505$) was obtained when taking into account both spring soil moisture and precipitation during April –July, indicating the importance of moisture availability during the critical period of sunflower growth and development, corresponding to the formation of the crop's generative organs.

Research by J. Mu *et al.* (2025), conducted in the 10th Division of Xinjiang at three representative stations, focused on examining the relationship between meteorological factors and the growth and development characteristics of sunflower varieties of different maturity groups. The study revealed distinct regional adaptation patterns among sunflower varieties. Varieties differing in vegetation duration demonstrated specific adaptive responses to environmental conditions. The obtained results enable the proper selection of varieties and the development of appropriate cultivation strategies (including technological elements) that enhance the resilience and stability of sunflower yields under various climatic conditions. The study of the effects of fertilisation and growth-regulating substances on sunflower productivity conducted by O.V. Nikitenko *et al.* (2021) revealed the influence of these factors on the total water consumption required to form the yield. The lowest water consumption coefficient obtained in the study was 832 m^3/t under the conditions of a conventional tillage system, the application of $N_{60}P_{60}K_{60}$, and the use of growth-regulating substances during the vegetation period.

Research by Ye.O. Domaratskyi *et al.* (2021) carried out in the Southern Steppe of Ukraine, which focused on the impact of growth-regulating preparations on the productivity of sunflower hybrids and the optimisation of water consumption under critical climate change conditions, showed that the lowest water consumption coefficient (1,283 m^3/t) was obtained when cultivating the hybrid P64GE133 with seed treatment using the preparation Helafit Combi. The studied preparations promoted efficient use of soil moisture, reducing the water consumption coefficient across all hybrids involved in the experiment. The subsequent research by Ye.O. Domaratskyi *et al.* (2022), aimed at studying the influence of fertiliser application and growth-regulating substances on sunflower water use, confirmed their positive effect. The authors established that both fertilisation and the use of growth regulators contributed to improved crop productivity formation. The minimum water consumption coefficient was recorded for the sunflower hybrid P64GE133, amounting to 1,283 m^3/ha when treated with Helafit Combi.

Studies conducted at the College of Agriculture, University of Wasit by D.N.J. Al-Waili *et al.* (2025), which aimed to investigate the effects of several factors on sunflower water consumption, demonstrated that the amount of water absorbed by plants increased as growth and development progressed, while the need for moisture declined during the ripening phase. Field research by K. Farrag *et al.* (2025), focused on examining the impact of fertilisers, soil amendments, and moisture availability on sunflower productivity indicators, revealed a positive influence of fertilisation on the physical properties of soil and, consequently, on its water-holding capacity. A positive effect of fertilisers and soil amendments on the productive use of moisture was established. Under modern sunflower cultivation conditions, attention is focused not only on crop adaptation to weather conditions but also on the optimisation of agrotechnological practices. In particular, studies by V. Bolokhovsky *et al.* (2024) demonstrated that integrated plant nutrition technologies incorporating biopreparations enhance the efficiency of soil and water resource use, which is especially important under variable climatic conditions and agrometeorological risks.

According to the findings of S.M. Kalenska & A.S. Ryzhenko (2020), who investigated the relationship between heat and moisture resources and the biological characteristics of sunflower hybrids under the conditions of the Sumy region, yield was found to depend on these factors. The sum of active temperatures above 10°C for the development cycle of the studied sunflower hybrids ranged from 2,306.4 to 2,401.3°C, while the sum of effective temperatures varied between 1,056.9

and 1,109.1°C. The total heat units during the vegetation period (April-August), averaged across the study years, ranged from 2,868 to 3,258°C, significantly exceeding the sums of active and effective temperatures. However, I. Gintsioudis *et al.* (2024) emphasised that under equal total heat unit sums, plants grown under different environmental conditions exhibit distinct distributions of heat units across growth and development stages. Therefore, heat unit models must account for the fact that plants require varying amounts of thermal energy at different growth stages. Further research is needed to refine baseline and threshold temperature values to more accurately determine the timing of specific developmental phases. The obtained research results comprehensively characterise the agrometeorological conditions for sunflower cultivation in the Ternopil region and partially contribute to understanding their influence on the adaptability and productivity formation of the studied hybrids.

Conclusions

The analysis of weather conditions in the study region indicates that the conditions are suitable for growing sunflower hybrids of all maturity groups examined, in terms of both heat resources and moisture availability. During the vegetation period (April-September), the average values across the research years showed a maximum sum of active temperatures of 3,162.1°C and effective temperatures of 2,263.2°C, based on a biological minimum of 5°C. With a biological minimum of 10°C, the sum of active temperatures was 2,977.1°C and effective temperatures 1,409.1°C (for the April-September period). The highest total number of heat units during the sunflower vegetation period was recorded for April–September, amounting to 3,642.4°C. For the vegetation period from May to September, the value was 3,433.4°C. The total moisture reserves in the one-metre soil layer during the vegetation period varied from 3,110 m^3/ha in 2022 (early maturity group) to 4,782 m^3/ha in 2024 (mid-season group). Moisture consumption depended on total moisture reserves and the yield achieved, ranging from 2,314 to 2,459 m^3/ha in 2022, from 2,500 to 2,992 m^3/ha in 2023, and from 2,967 to 3,981 m^3/ha in 2024. As the duration of the vegetation period increased, moisture consumption by sunflower plants also increased.

The water consumption coefficient for early-maturing hybrids under the influence of fertilisers ranged from 1,173 to 1,012 m^3/t per tonne of seed, for mid-early hybrids from 1,171 to 1,017 m^3/t, and for mid-season hybrids from 1,100 to 989 m^3/t per tonne of seed. The correlation analysis between sunflower yield indicators and soil moisture reserves revealed a direct correlation with a correlation coefficient of 0.8456. Prospects for further research lie in studying the influence of both controlled and uncontrolled factors on the growth, development, and productivity formation of hybrids belonging to different maturity groups, with the aim of identifying levers to enhance the realisation of their genetic potential under atypical growing conditions for sunflower.

Acknowledgements

None.

Funding

None.

Conflict of Interest

None.

References

[1] Al-Waili, D.N.J., Abdul Rahman, J.N., & Al-Maliki, R.J.M. (2025). Moisture depletion, soil improvers and antitranspiration and its effect on water consumption of sunflower (*Helianthus annus* L.). *IOP Conference Series: Earth and Environmental Science*, 1449, article number 14. doi: 10.1088/1755-1315/1449/1/012114.

[2] Baranskyi, D. (2024). Managing sunflower growth in the changing climate and fluctuating moisture levels of the Western Forest-Steppe. *Bulletin of Lviv National Environmental University. Series Agronomy*, 28, 57-66. doi: 10.31734/agronomy2024.28.057.

[3] Bolokhovsky, V., Bolokhovska, V., Khomenko, T., Datsko, A., & Litvinova, O. (2024). Optimisation of plant nutrition under the influence of biopreparations in integrated sunflower cultivation technologies. *Plant and Soil Science*, 15(4), 64-75. doi: 10.31548/plant4.2024.64.

[4] Convention on Biological Diversity. (1992, June). Retrieved from https://zakon.rada.gov.ua/laws/show/995_030#Text.

[5] Domaratskyi, Ye., Kozlova, O., Dobrovolskyi, A., & Bazaliy, V. (2022). Optimization of water consumption of high-oleic sunflower hybrids under non-irrigated conditions of the steppe zone of Ukraine. *Journal of Ecological Engineering*, 23(6), 14-21. doi: 10.12911/22998993/148150.

[6] Domaratskyi, Ye.O., Dobrovolskyi, A.V., Kozlova, O.P., Dobrovolskyi, P.A., & Lavryshyna, O.Ye. (2021). Ways of optimization of high oolein type sunflower consumption under climate change. *Agrarian Innovations*, 10, 34-41. doi: 10.32848/agrar.innov.2021.10.6.

[7] Farrag, K., Abdel-Hakim, S.G., El-Sesy, M.E., El-Sayed, E.S. el-Bastamy, & Abdrabbo, M.A. (2025). Promotion of sunflower growth and water productivity using soil amendments under saline conditions. *Water Science*, 39(1), 336-345. doi: 10.1080/23570008.2025.2507456.

[8] Furmanets, O.A. (2022). Development and productivity of sunflower on sod-podzolic soils of Western Polissia with the application of various types of complex fertilizers. *Agrarian Innovations*, 16, 80-84. doi: 10.32848/agrar.innov.2022.16.13.

[9] Gintsioudis, I., Danalatos, G.J., Bartzialis, D., Giannoulis, K.D., & Danalatos, N.G. (2024). Accumulated thermal units method for predicting development stages, and potential seed yield of sunflower (*Helianthus annuus*) under Mediterranean conditions. *Industrial Crops and Products*, 221, article number 119383. doi: 10.1016/j.indcrop.2024.119383.

[10] Haj Sghaier, A., Khaeim, H., Tarnawa, Á., Kovács, G.P., Gyuricza, C., & Kende, Z. (2023). Germination and seedling development responses of sunflower (*Helianthus annuus* L.) seeds to temperature and different levels of water availability. *Agriculture*, 13(3), article number 608. doi: 10.3390/agriculture13030608.

[11] Huz, M., Chukhlib, A., & Symonenko, O. (2024). Predictive assessment of the impact of climate change on sunflower production: Analysis of dynamic series and modeling of trends. *Herald of Khmelnytskyi National University,* 331(1), 438-445. doi: 10.31891/2307-5732-2024-331-67.

[12] Ivanyuta, S.P., Kolomiyec, O.O., Malinovska, O.A., & Yakushenko, L.M. (2020). *Climate change: Impacts and adaptation measures*. Kyiv: NISD .

[13] Kalenska, S.M., & Ryzhenko, A.S. (2020). Evaluation weather conditions for growing sunflower (*Helianthus annuus* L.) in the northern part of the Left-bank Forest Steppe of Ukraine. *Plant Varieties Studying and Protection*, 16(2), 162-172. doi: 10.21498/2518-1017.16.2.2020.209229.

[14] Matskova, S., & V Gumanyuk, A. (2025). Reserves of soil productive humidity are the key to high yield of sunflower. *Research Journal of Agricultural Science*, 57(1), 161-165. doi. 10.59463/RJAS.2025.1.19.

[15] Mu, J., Wang, J., Ma, R., Lv, Z., Dong, H., Liu, Y., Duan, W., Liu, S., Wang, P., & Zhang, X. (2025). Optimizing sunflower cultivar selection under climate variability: Evidence from coupled meteorological-growth modeling in arid northwest China. *Agronomy*, 15(7), article number 1724. doi: 10.3390/agronomy15071724.

[16] Nikitenko, O.V., Poliakov, O.I., & Litoshko, S.V. (2021). Optimal growing regulations – guarantee of high productivity of sunflower. *Scientific and Technical Bulletin of the Institute of Oilseed Crops NAAS*, 31, 72-87. doi: 10.36710/ioc-2021-31-07.
[17] Polyakov, O.I., & Shcherbak, A.D. (2022). Productivity of sunflower under the influence of mineral fertilizers and growth regulators. *Scientific and Technical Bulletin of the Institute of Oilseed Crops NAAS*, 35, 101-113. doi: 10.36710/IOC-2023-35-09.
[18] Rozhkov, A.O., Puzik, V.K., Kalenskaya, S.M., Puzik, L.M., Popov, S.I., Muzafarov, N.M., Bukhalo, V.Ya., & Kryshtop, E.A. (2016). *Research in agronomy. Book 1: Theoretical aspects of research.* Kharkiv: Maidan
[19] Tomashuk, I.V., & Horobchuk R.O. (2024). Socio-economic potential of the agrarian sector of Ukraine: prospects for development and opportunities for improving the efficiency of its use. *Taurida Scientific Herald*, 138, 193-201. doi: 10.32782/2226-0099.2024.138.24.
[20] Totskyi, V.M., Hanhur, V.V., & Poliakov, I.A. (2024). Yield and quality of seed of sunflower hybrids (*Helianthus annuus L.*) depending on the fertilizer system. *Scientific Progress & Innovations*, 27(3), 5-11. doi: 10.31210/spi2024.27.03.01.
[21] Trembitska, O., Sorochuk, M., Serhiienko, T., Zinkevych, V., & Konovchuk, M. (2021). Sunflower productivity at various norms of mineral fertilizers. *Science of Europe*, 2(82), 12-14. doi: 10.24412/3162-2364-2021-82-2-12-14.
[22] Zhygailo, O.L., Volvach, O.V., Tolmachova, A.V., & Kostiukievych, T.K. (2021). The influence of climate change on sunflower yield in the Northern Steppe of Ukraine: Analysis and forecast. *Bulletin of Poltava State Agrarian Academy*, 1, 180-186. doi: 10.31210/visnyk2021.01.22.

Оцінка агрометеорологічних умов вирощування гібридів соняшнику

Леся Гарбар
Кандидат сільськогосподарських наук, доцент
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.ord/0000-0003-4249-0434
Максим Ванджура
Аспірант
Національний університет біоресурсів і природокористування України
03041, вул. Героїв Оборони, 15, м. Київ, Україна
https://orcid.org/0009-0001-6372-0641

Анотація. Мета досліджень полягала у аналізі погодних умов періоду вегетації, їх відповідності морфобіологічним особливостям гібридів та виявленні більш адаптованих гібридів соняшнику для регіону проведення досліджень. Дослідження проводили впродовж 2022-2024 рр. в умовах Тернопільської області. Аналіз агрометеорологічних показників років досліджень показав значну відмінність періодів вегетації між собою, як за аналізу температурних показників, так і сумарної кількості опадів щомісячно. За результатами температурних показників виявлено їх перевищення відносно середніх багаторічних даних. Аналіз погодних умов регіону проведення досліджень, свідчить про придатність умов для вирощування гібридів соняшнику всіх груп стиглості, які ми вивчали за тепловими ресурсами та забезпеченістю вологою. Сума активних температур за період квітень–вересень становила 3162,1 °С (біологічний мінімум 5 °С, за суми ефективних температур – 2263,2 °С. За біологічного мінімуму 10 °С показники відповідно склали 2977,1 °С та 1409,1 °С. За зазначений період було отримано і найвищу суму теплових одиниць – 3642,4 °С. Сума теплових одиниць за період травень-вересень відповідала показнику 3433,4 °С. запаси вологи у метровому шарі ґрунту залежали від погодних умов року та змінювалися у розрізі років від Коефіцієнт водоспоживання для гібридів ранньої групи стиглості за впливу добрив змінювався від 1173 до 1012 м3/т на 1 т насіння, середньоранньої – 1171-1017 та середньостиглої – 1100-989 м3/т на 1 т насіння. Кореляційний аналіз між показниками урожайності соняшнику та запасами вологи в ґрунті показав пряму кореляційну залежність із коефіцієнтом кореляції 0,8456. Результати дослідження можна використати для оптимізації строків сівби та збирання врожаю відповідно до прогнозованих агрометеорологічних умов

Ключові слова: *Helianthus annuus*; температурні показники; вологозабезпеченість; теплові одиниці; група стиглості