Chapter 14

SUNFLOWER: STRATEGIES AND TECHNOLOGIES FOR ADAPTIVE CULTIVATION UNDER CLIMATE CHANGE CONDITIONS

Revto O. Ya., Maliarchuk A. S.
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INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the most important oilseed crops in the world, playing a key role in ensuring food security and contributing to the economic development of many countries. High-quality sunflower oil is considered one of the healthiest, and its seeds contain a wide range of nutrients, making them not only a tasty snack but also a nutritious ingredient in various food products such as health bars, salad toppings, and spreads.

However, under the conditions of global climate change – characterized by rising temperatures, altered precipitation patterns, and an increased frequency of extreme weather events – sunflower cultivation faces new challenges. This is particularly true for the southern regions of Ukraine, where temperature increases and prolonged droughts can reduce the crop's resilience, negatively affecting both yield and production stability.[1].

Climate change is evident in Ukraine, especially in the steppe zone, through rising average annual temperatures and shifts in precipitation patterns, leading to more frequent and intense droughts. Moisture deficiency is becoming one of the key limiting factors for the productivity of many agricultural crops. Sunflower, as a primary oilseed crop in the region, is especially vulnerable to these changes. A lack of moisture and increased temperatures during critical growth stages can significantly reduce both yield and product quality.[2].

Research conducted by scientists at the Odesa State Environmental University[3] indicates that an increase in photosynthetically active radiation

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[1] Домарацький Є. О., Добровольський А. В., Базалій В. В., Пічура В. І. Соняшник: екологічні шляхи оптимізації його живлення. Олді-плюс, 2020

[2] Sunflower crop and climate change: vulnerability, adaptation, and mitigation potential from case-studies in Europe / P. Debaeke et al. OCL. 2017. Vol. 24, no. 1. P. D102. URL: https://doi.org/10.1051/ocl/2016052.

[3] Вплив змін клімату на урожайність соняшнику в Північному Степу України: аналіз і прогноз / О. Л. Жигайло та ін. Вісник Полтавської державної аграрної академії. 2021. № 1. С. 180–186. URL: https://doi.org/10.31210/visnyk2021.01.22

(PAR), as projected under both climate scenarios (RCP2.6 and RCP4.5), will have a positive impact on the potential yield of sunflower. Agro-climatic conditions outlined in the RCP2.6 scenario – particularly favorable temperature regimes and sufficient moisture – are expected to promote growth in both the meteorologically possible yield and the realistically achievable yield of the crop. In contrast, the RCP4.5 scenario, which involves higher temperatures during the sunflower flowering period, may lead to a slight reduction in both the maximum meteorologically possible yield (MMPY) and the realistically possible yield (RPY).

Sunflower is traditionally considered a drought-tolerant crop, suitable for cultivation in regions with limited water resources – especially under increasing soil moisture deficits. However, climate change poses new threats even to such resilient crops.

Sunflower has a high-water demand throughout its entire growing season, particularly during the flowering and seed formation stages. A shortage of soil moisture during these critical phases leads to reduced photosynthetic activity, disruption of pollination processes, and impaired head development, all of which directly contribute to lower yields and decreased seed quality (especially oil content). Recent trends toward prolonged dry periods and increased evaporation further exacerbate this issue, threatening the stability of sunflower production in affected regions.

Under increasing moisture deficit conditions, traditional soil tillage methods may prove ineffective or even counterproductive. Intensive tillage practices, including deep plowing, can lead to moisture loss through enhanced evaporation and the destruction of soil structure, which is vital for water retention.

The use of moisture by sunflower crops can be regulated to some extent by optimizing sowing dates. Specifically, shifting sowing to earlier periods can improve plant growth and development conditions by enhancing moisture availability and avoiding critical temperature stress during key developmental phases.[4].

In light of these climatic challenges, it is essential to adapt agronomic management practices to minimize the risks of drought stress. This includes the implementation of new, adaptive soil tillage systems aimed at conserving and efficiently utilizing available moisture; selecting optimal sowing methods and seeding rates of viable seeds per hectare; and adjusting sowing dates based on weather forecasts. Such adjustments can help avoid the crop's critical

[4] Піньковський Г. В., Танчик С. П. Продуктивність та водоспоживання середньоранніх гібридів соняшника залежно від строків сівби та густоти стояння рослин у Правобережному Степу України. *Зрошуване землеробство*. Херсон: ОЛДІ-ПЛЮС. 2019. Т. 72. С. 47–52. URL: https://doi.org/10.32848/0135-2369.2019.72.11.

growth stages coinciding with periods of peak temperature and moisture deficit.

The objective of this study was to determine the effectiveness of primary soil tillage systems, optimal sowing dates, sowing methods, and seeding rates for sunflower cultivation in the southern regions of Ukraine. The goal is to achieve the efficient use of solar radiation and nutrient elements, thereby enhancing yield, improving seed quality, and increasing the economic and energy efficiency of production.

1. Retrospective and current trends in sunflower production in Ukraine and Kherson region

Sunflower is one of the most important oilseed crops in Ukraine, playing a vital role in the country's agriculture and economy.

Kherson Region, with its favorable climatic conditions, has traditionally been one of the main sunflower-growing areas in Ukraine.

Between 2001 and 2024, Ukraine experienced a significant increase in sunflower production volumes (Table 1). Starting from 2.25 million tonnes in 2001, the gross sunflower harvest has shown an overall upward trend, reaching peak levels in 2019 (14.92 million tonnes) and 2021 (16.44 million tonnes).

The area cultivated with sunflower has also expanded, growing from 2.50 million hectares in 2001 to over 5 – 6 million hectares in recent years. The largest areas were recorded in 2020 (6.38 million ha) and 2021 (6.52 million ha).

The average sunflower yield in Ukraine also shows a clear upward trend. From 9.4 centners per hectare in 2001, the yield increased to 25.9 c/ha in 2019 and 25.2 c/ha in 2021. Yield fluctuations over the period can be attributed to climatic conditions, agronomic practices, and other influencing factors. In 2024, a decline in yield was recorded, dropping to 21.0 c/ha.

The nationwide development trend of sunflower production up to 2021 was marked by significant growth in gross output, cultivated area, and yields. The Kherson region also showed an increase in yield during this period, although at a slower pace compared to the national average (Table 2).

Table 1

Dynamics of gross harvest, harvested area, and sunflower yield in Ukraine (2001–2024)[5]

Year	Gross yield, thousand tonns	Harvested area, thousand hectares	Yield, centners per 1 hectare of harvested area
2001	2250.6	2502	9.4
2002	3270.5	2834	12.0
2003	4254.4	4001	11.2
2004	3050.1	3521	8.9
2005	4706.1	3743	12.8
2006	5324.3	3964	13.6
2007	4174.4	3604	12.2
2008	6526.2	4306	15.3
2009	6364.0	4232	15.2
2010	6771,5	4572	15.0
2011	8670.5	4739	18.4
2012	8387.1	5194	16.5
2013	11050.5	5051	21.7
2014	10133.8	5257	19.4
2015	11181.1	5105	21.6
2016	13626.9	6073	22.4
2017	12235.5	6034	20.2
2018	13882.7	5923	23.4
2019	14923.4	5760	25.9
2020	13135.8	6381	20.6
2021	16439.8	6524	25.2
2022	11328.7	5238	21.6
2023	12759.7	5202	24.5
2024	10221.0	5400	21.0

Table 2

Dynamics of sunflower seed yield in Kherson region (2018–2024)[6]

Year	Yield, centners per 1 hectare of harvested area
2018	16.5
2019	18.1
2020	16.1
2021	19.5
2022*	-
2023*	-
2024	8.0

*Data for 2022 and 2023 are unavailable.

[5] Площі, валові збори та урожайність сільськогосподарських культур за їх видами. Державна служба статистики. URL: https://www.ukrstat.gov.ua/

[6] Площі, валові збори та урожайність сільськогосподарських культур за їх видами. Державна служба статистики. URL: https://www.ukrstat.gov.ua/

From 2018 to 2021, Kherson region exhibited a general upward trend in sunflower yield. Starting at 16.5 c/ha in 2018, the yield gradually increased to a peak of 19.5 c/ha in 2021.

It is important to note the absence of data for 2022 and 2023, which prevents a complete yield assessment for that period.

In 2024, however, a sharp decline in yield to 8.0 c/ha was recorded. This decrease may be attributed to various factors such as adverse weather conditions, changes in agronomic practices, pest and disease pressures, and – most critically – the direct consequences of the ongoing russian occupation in Kherson region. These include field contamination with landmines, destruction of infrastructure, and significant disruption to agricultural operations.

Just a few years ago, sunflower was predominantly a crop of the Steppe zone. However, over the past 3-5 years, its expansion has extended into the Forest-Steppe zone and even reached Western Ukraine.

2. Analysis of weather conditions in Ukraine: trends, risks, and challenges

Global climate change has had a significant impact on weather conditions in Ukraine, manifesting in a noticeable increase in temperatures and a growing frequency and intensity of extreme meteorological events.[7]. An analysis of temperature data over recent decades reveals a clear warming trend, with each successive decade since 1991 marked by higher average temperatures compared to the previous one. The warming has been especially pronounced since 2000, and the period from 2011 to 2019 was the warmest on record.

Seasonal changes also reflect the overall warming trend. Summer months have seen rising average temperatures, an increase in the number of hot days, and more frequent tropical nights. Winters have become milder, with fewer frost days and days with stable snow cover, along with an increased frequency of rainfall and freezing rain.

Despite the nationwide trends of warming and more frequent extreme events, the Kherson region – geographically located in the Steppe zone – is particularly vulnerable to climate risks such as droughts, hot dry winds, and potential desertification. The growing number of hot days also negatively affects agricultural productivity and the state of the region's water resources.

The current difficult situation in the Kherson region, caused by occupation, active hostilities, and the threat of landmines, significantly complicates the comprehensive analysis of weather conditions. However, the prevailing

[7] Ревтьо О.Я., Набока В.В. Соняшник в Україні – стан, проблеми, перспективи (оглядова). *Таврійський науковий вісник*. 2022. Вип. 128. С. 23. DOI: https://doi.org/10.32851/2226-0099.2022.128.23.

general climate trends are likely to exacerbate an already critical situation in the region's agricultural sector and ecological sphere.

Overall, weather conditions in Ukraine are marked by a pronounced warming trend and an increase in extreme meteorological events, which pose significant risks to various sectors of the economy and to the population's livelihoods. An analysis of average annual temperatures reveals considerable interannual variability, indicating climatic instability in the country (Fig. 1). Certain years have shown abnormally low (e.g., 1929, 1942, 1954) and abnormally high (e.g., 2020) temperature values.

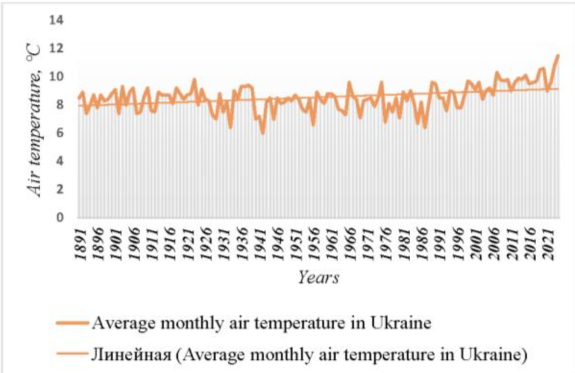

Fig. 1. Average Monthly Air Temperature in Ukraine (1981–2024)[8]

Analysis of temperature data over recent decades confirms the presence of a statistically significant trend toward increasing average annual temperatures, consistent with the concept of global warming.

According to meteorological observations, the year 2024 in Ukraine was marked by abnormally high temperature levels. The average annual temperature reached 11.5°C, which is 0.7°C higher than the corresponding figure for 2023.

In some regions of Ukraine in 2024, prolonged periods of precipitation deficit were observed. In particular, in the Dnipropetrovsk, Kharkiv, and Mykolaiv regions, dry spells lasted 70-80 days (June–September), leading to drought conditions.

Overall, climate instability in Ukraine – evidenced by significant interannual temperature variability, the abnormally high temperatures in 2024, and extended dry periods in certain regions – presents serious challenges for various sectors of the economy. Further research is essential for developing

[8] Кліматичні дані по Україні. Головна. URL: http://cgo-sreznevskyi.kyiv.ua/uk/diialnist/klimatolohichna/klimatychni-danni-po-ukraini.

effective adaptation strategies and mitigating the impacts of climate change in Ukraine, especially in the most vulnerable regions.

Weather conditions play a key role in determining the effectiveness of conducted research.

Table 3 presents the average monthly air temperature and total precipitation recorded by the iMETOS 3.3 weather station on experimental plots (Kherson region) during the years 2019 – 2021.

The temperature regime over the study years was characterized by typical seasonal dynamics. The lowest average monthly temperatures were observed in January and February, while the highest occurred in July and August. The annual average temperatures fluctuated only slightly, demonstrating relative stability in the region's temperature regime during the observed period.

As for precipitation, its distribution throughout the year was uneven. Most precipitation in most years occurred in the summer months (May–June), as well as at the beginning of winter (December–January). The driest periods were usually in the autumn and early spring months. The annual precipitation totals varied significantly from year to year, with the lowest amount recorded in 2020 and the highest in 2021.

Analysis of average annual temperatures for the period 2019-2021 revealed certain differences between nationwide indicators and data recorded in the Kherson region (iMETOS 3.3 weather station).

According to available data, the average annual temperature in Ukraine was 10.5 °C in 2019, 10.6 °C in 2020, and 9.0 °C in 2021. Meanwhile, in the Kherson region, slightly higher average annual temperatures were observed over the same period: 12.4 °C in 2019, 12.4 °C in 2020, and 10.9 °C in 2021.

Table 3

Temperature and precipitation indicators for the study period in Kherson region (iMETOS 3.3 weather station data)

Month	**Temperature, °C**			**Precipitation, mm**		
	2019	*2020*	*2021*	*2019*	*2020*	*2021*
January	-1.6	0.6	-0.4	44.6	17.2	65.8
February	1.5	2.8	-0.8	15.4	67.0	15.0
March	8.5	7.5	3.2	6.6	8.0	28.8
April	10.6	9.9	8.7	44.8	3.3	41.8
May	17.9	14.5	15.9	55.6	63.5	49.6
June	24.8	22.1	20.9	21.2	101.6	115.4
July	23.3	24.5	25.7	57.8	12.6	68.4
August	23.5	23.8	24.1	61.6	4.0	27.4
September	18.0	20.6	16.0	5.8	22.0	22.6
October	11.7	15.9	9.7	36.8	31.2	26.2
November	6.8	4.6	6.5	19.6	7.2	30.0
December	4.2	1.8	1.8	21.8	20.0	38.4
Annual	***12.4***	***12.4***	***10.9***	***391.6***	***357.6***	***529.4***

As shown, in 2019 and 2020 the average annual temperature in the Kherson region exceeded the national average by 1.9 °C and 1.8 °C, respectively. In 2021, this difference slightly decreased, but the average annual temperature in Kherson still surpassed the national figure by 1.9 °C.

These differences are expected and are due to the geographical location of the Kherson region, which lies in the southern part of Ukraine, characterized by a more continental and arid climate compared to many other parts of the country.

Overall, the presented data confirm the trend of higher average annual temperatures in the Kherson region compared to the national average during the study period.

3. Optimization of soil tillage technology for effective sunflower cultivation under climate change conditions

Soil tillage is one of the most critical aspects of increasing agricultural production, especially under climate change conditions, where there is a constant struggle to conserve soil moisture. To solve the issue of maximum moisture accumulation and rational use, there is a need to move away from traditional tillage systems. Conventional plowing turns the soil into large clods, requiring additional leveling of the field and moisture sealing. Therefore, changing soil tillage technology is a relevant issue today for agricultural enterprises of all ownership types. The development and implementation of moisture-conserving primary tillage methods and direct seeding technologies without prior soil preparation are highly relevant and require an objective ecological and economic assessment.

Modern crop production technologies are designed to generate higher profits per hectare while reducing material and energy inputs. One of the technological solutions for efficient resource use is the minimization of tillage. Reduced tillage shortens the production cycle, saving not only material and energy resources but also labor–an important factor considering the declining rural workforce.

Tillage minimization involves replacing conventional moldboard plowing with various shallow loosening methods or direct seeding into untilled soil using wide-coverage equipment.

Studies on the impact of different primary tillage methods on soil processes and crop productivity in rotations have been conducted by Medvedev V.V., Bulygin S.Yu., Balaiev A.D., Havrylyuk M.V., Hrechkosii V.D., Shatrov R.V., Tsiliuryk O.I., Horbatenko A.I., Sudak V.M., Shevchenko M.S., Rybka V.S., Shevchenko O.M., among others.

In the context of modern agriculture, the issue of optimizing soil tillage technology for sunflower cultivation is becoming increasingly important to ensure resource conservation, improve crop profitability, and minimize the loss of organic and mineral compounds from the soil. However, there is currently no scientific consensus regarding the effectiveness of different primary tillage methods for sunflower.

To evaluate the impact of different soil tillage systems and seeding methods on sunflower yield, a two-factor field experiment was conducted. The study was carried out on slightly solonetzic, heavy loam, dark chestnut soils in the Kherson region (GPS coordinates: 46.746794, 32.355702).

Two soil tillage systems were tested:

– Conventional tillage – moldboard plowing to a depth of 28–30 cm;
– No-till – direct seeding without prior soil cultivation.

Two seeding methods were applied:

– Wide-row spacing (45 cm) – row spacing of 45 cm;
– Wide-row spacing (70 cm) – row spacing of 70 cm.

The experiment followed a full factorial design including four treatments in four replicates. The plot size was 50 m², with randomized plot placement.

During the sunflower growing season, agronomic practices recommended for the research zone were applied, including weed, pest, and disease control. Fertilization followed standard recommendations for the crop.

Yield data were collected by harvesting all plants from the sample plots at the stage of full seed maturity. The harvested material from each plot was weighed. To calculate yield at standard moisture (8%), average seed samples were taken from each plot to determine actual moisture content using standard methods.[9]

Table 4 presents the results of the study on the impact of different soil tillage systems and seeding methods on sunflower yield in 2020–2021. Experimental data show that the choice of tillage method and row spacing significantly affects crop productivity.

In 2020, the highest yield (3.24 t/ha) was recorded using the No-till system with a 45 cm row spacing, while conventional plowing combined with the same row spacing resulted in a slightly lower yield of 3.18 t/ha. Increasing the row spacing to 70 cm led to somewhat lower yields in both tillage systems, highlighting the importance of optimal plant placement in the field.

In 2020, abnormally low soil moisture reserves and high temperatures created significant stress for the plants. Despite these challenging conditions, the No-till system with a 45 cm row spacing provided the highest yield (3.24 t/ha), demonstrating the effectiveness of moisture conservation under this technology.

In 2021, a more favorable year in terms of moisture availability, the yield under the conventional tillage system with 45 cm row spacing increased to

[9] ДСТУ ISO 10565:2003. Насіння олійних культур. Одночасне визначання вмісту олії та вологи. Метод спектрометрії з використовуванням імпульсного ядерного магнітного резонансу (ISO 10565:1998, IDT). Чинний від 2005-07-01. Вид. офіц. 2003.

3.54 t/ha, while the yield under the No-till system remained almost unchanged at 3.28 t/ha. This highlights the stability of the No-till system under drought conditions, whereas the conventional tillage system may outperform in years with adequate moisture.

Table 4

Sunflower yield depending on primary tillage systems and sowing methods, 2020–2021

No.	**Primary Tillage System (Factor A)**	**Sowing Method (Factor B)**	**Yield, t/ha (adjusted to 8% moisture)**	
			2020	2021
1	Conventional (plowing 28–30 cm)	Wide-row (45 cm)	3.18	3.54
2		Wide-row (70 cm)	2.90	3.14
3	No-till	Wide-row (45 cm)	3.24	3.28
4		Wide-row (70 cm)	3.05	2.87
LSD_{05}, t/ha		for main effects:		A-0.03 B– 0.04
		for partial differences:		A-0.04 B– 0.06

Expanding the row spacing to 70 cm, regardless of the tillage system, resulted in a decrease in yield, indicating a negative effect of lower plant density on the efficient use of limited water resources.

According to the analysis of variance results, both primary tillage system and sowing method had a statistically significant effect on sunflower seed yield.

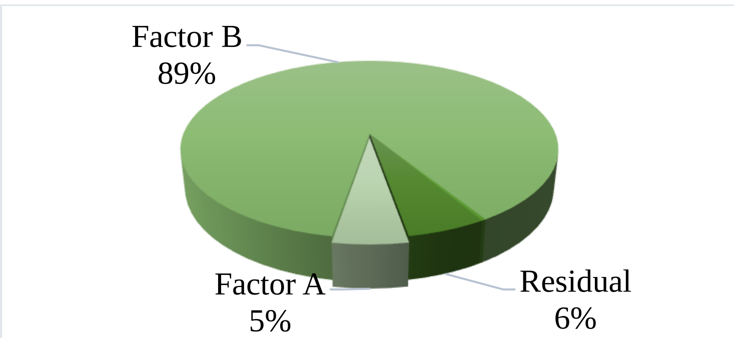

Fig. 2. Proportion of Factor Influence

The results obtained underscore the importance of adapting agrotechnologies to weather conditions. The No-till system shows high potential for stable productivity in dry years, while traditional plowing may have advantages under sufficient moisture conditions. Optimization of sowing methods and choice of tillage technology can minimize the negative impact of climate change on sunflower productivity.

To evaluate the impact of different soil tillage systems and seeding methods on sunflower yield, a two-factor field experiment was conducted. The study was carried out on slightly solonetzic, heavy loam, dark chestnut soils in the Kherson region (GPS coordinates: 46.746794, 32.355702).

4. Sowing dates and seeding rates as factors in sunflower yield formation

The research was conducted during 2019–2021 at the experimental field (GPS coordinates: 46.71031905923212, 32.68489405206296) within a grain-fallow-row crop rotation system. The field is located in the Dry Steppe soil-ecological zone of the Inhulets irrigated area. The terrain is flat, and groundwater lies deeper than 10 meters.

The soil is dark chestnut, medium loamy, and coarse-silty-loamy by granulometric composition. The humus horizon is 38 – 40 cm deep. The humus content in the 0 – 40 cm soil layer is 2.15%; the minimum field moisture capacity in the 0 – 100 cm layer is 21.5%; wilting point – 9.1%; water-stable aggregates – 34.1%; equilibrium bulk density – 1.39–1.42 g/cm^3; porosity – 49.2%; water permeability – 1.25 mm/min.

The content of water-soluble salts varied little between layers. The pH of the aqueous extract was 6.8 in the 0–20 cm layer and 7.2 in the 20–40 cm layer.

The sum of exchangeable bases was 21.12 in the 0–20 cm layer and 19.35 meq in the 20 – 40 cm layer. The absorbed bases consisted of Ca and Mg: in the 0–20 cm layer, Ca made up 80.99%, and Mg – 19.01%; in the 20–40 cm layer – 80.1% and 19%, respectively.

The research methodology was designed to achieve the study's objectives and included field, laboratory-field, and laboratory experiments, as well as a set of phenological, biometric, and analytical observations.

The early-maturing sunflower hybrid *Carlos 105* (originator – LLC VNIS) was sown after winter wheat in wide rows (row spacing of 70 cm) using the Vega-6 seeder (manufacturer: PJSC Elvorti, Kropyvnytskyi). The sowing depth was 5 cm.

The sunflower cultivation technology followed generally accepted practices recommended for the Southern Steppe at the time of research, except for the studied factors. The experiment was laid out in three replications. The total sowing area was 1.760 m^2; the accounting plot area – 50 m^2. Treatments were arranged using the split-plot method.[10].

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[10] Ушкаренко В. О., Нікішенко В. Л., Голобородько С. П., Коковіхін С. В. Дисперсійний і кореляційний аналіз у землеробстві та рослинництві : навч. посіб. Херсон:

The wheat straw was evenly spread over the field surface. Then disking was performed with a heavy disk harrow (BDVP-6.3) in two perpendicular directions to a depth of 6 – 8 and 8 – 10 cm. Plowing was carried out to a depth of 25 – 27 cm.

In early spring, heavy tooth harrowing was performed. Pre-sowing cultivation, with simultaneous application of soil herbicides, was done on the day of sowing using a steam cultivator (KPS-4A) combined with harrows and the OP-2000 sprayer.

In all years of the study, sunflower seedlings emerged uniformly and in a timely manner. Due to herbicide application, there was no need for pre– or post-emergence harrowing. However, even minor rainfall after sowing led to the formation of a soil crust that suppressed sunflower growth and development. Therefore, in the 4–5 leaf phase, inter-row cultivation to a depth of 4 – 5 cm was carried out annually using the USMK-5.4 row-crop cultivator.

The research was conducted using standard Ukrainian methodologies and methodological recommendations based on national standards (DSTU) and other regulatory documents.[11]

Field trials were laid out using the split-plot method. The experimental scheme involved studying the influence of two factors:

Factor A – Sowing dates:

– Early – when soil temperature at a depth of 10 cm reaches 6-8°C
– Recommended – 10-12°C
– Late – 14-16°C

Factor B – Seeding rate of viable seeds per hectare:

– 30,000 seeds/ha
– 40,000 seeds/ha
– 50,000 seeds/ha

In the tables and text, the least significant difference (LSD) is given at a 5% level of significance.

The onset of phenological phases was determined by observing 50 plants in two non-adjacent replications. The beginning of a phase was defined when 10% of the plants exhibited its signs; full onset – when 75% showed signs.

Phenological and biometric observations were conducted during the main growth phases according to the methodology.[12] Plant height was measured on 10 typical plants per variant at the budding, flowering, and physiological maturity stages. Head diameter was measured at the end of the growing season, during physiological seed maturity.

Айлант, 2008. 272 с.

[11] Ушкаренко В.О., Голобородько С.П., Вожегова Р.А., Коковіхін С.В. Методика польового досліду (зрошуване землеробство). Херсон: Грінь Д.С., 2014. 448 с.

[12] Єщенко В. О., Копитко П. Г., Опришко В. П., Костогриз П. В. Основи наукових досліджень в агрономії: підручник / за ред. В. О. Єщенка. Вінниця: ПП «ТД «Едельвейс і К», 2014. 332 с.

Yield structure was determined during full seed maturity by sampling 10 typical plants per treatment plot. After biometric measurements, the seeds were threshed and weighed to assess mass parameters.

Chemical treatments were carried out mechanically using the OP-2000 sprayer coupled with an MTZ-82 tractor.

Harvesting and accounting of sunflower yield were done by threshing all plants within the accounting plots, adjusting to a standard moisture content of 8%, and recalculating to per hectare values.[13]

Statistical processing, summarizing, and analysis of experimental results from field and laboratory studies, as well as various observations and analyses, were carried out using modern methods of variance and correlation analysis on a PC.

Temperature, moisture regime, nutrient availability, and use of adapted varieties and hybrids significantly influence vegetative mass formation, duration of the growing season, yield, and seed quality. In regions with a short growing season, sowing date is critically important, as early spring frosts or late summer cooling can negatively affect plant growth and reproductive processes.

Plant height is considered a key morpho-biological trait reflecting the crop's response to changes in agri-ecological conditions. The flowering phase is decisive in growth and development, as during this period, plants reach maximum height and generate the most above-ground biomass.[14]

According to the results of the study, major biometric indicators of sunflower plants significantly varied depending on sowing dates and the seeding rates of viable seeds per hectare.

Thus, under early sowing conditions, the highest values for plant height, stem diameter at 5 cm above ground, and number of leaves were observed at a seeding rate of 40.000 seeds/ha during the end of the flowering phase (Table 5).

Under recommended sowing dates, a clear trend was observed: the highest biometric indicators – plant height of 155.6 cm, stem diameter of 2.9 cm, and number of leaves at 21.2 per plant – were recorded at a seeding rate of 40 thousand seeds/ha. A decrease or increase in seeding rate to 30 or 50 thousand/ha led to reduced indicators: height decreased by 3.4–4.9 cm, stem diameter by 0.2 cm, and leaf number by 2.0–2.8 per plant.

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[13] Насіння олійних культур. Визначення вмісту вологи та летких речовин: ДСТУ ISO 665:2008. Київ: Держспоживстандарт України, 2008.

[14] Мельник А. В. Агробіологічні основи формування врожаю соняшнику та ріпаку ярого в лівобережному лісостепу України: автореф.дис. на здобуття наукового ступеня д-ра с.-г. наук: 06.01.09 / НУБІП. Київ, 2013. 43 с.

Table 5

Biometric indicators of sunflower plants under different sowing dates and seeding rates of viable seeds per hectare (average for 2019–2021)

Sowing date (Factor A)	Seeding rate, thousand seeds/ha (Factor B)	Plant height, cm		
		Plant height, cm	Stem diameter, cm	Number of leaves, pcs/plant
Early	30	150.0	2.6	17.8
	40	152.2	2.7	18.9
	50	149.6	2.5	16.5
Recommended	30	152.2	2.7	19.2
	40	155.6	2.9	21.2
	50	150.7	2.7	18.4
Late	30	149.1	2.5	17.0
	40	151.7	2.7	18.3
	50	148.9	2.4	16.2

Notably, stem diameter peaked between the beginning and end of flowering, gradually decreasing by physiological maturity.

Biometric characteristics also depended on sowing time in the southern region of Ukraine. The highest indicators were observed under recommended sowing dates (April 20–30, depending on the year), compared to early (April 1-10) and late (May 1-10) sowing. Late sowing significantly reduced sunflower development parameters compared to early and optimal sowing times.

Thus, overly early or late sowing, combined with an increased seeding rate, reduced biometric traits – particularly the number of leaves and stem diameter – compared to recommended sowing conditions.

One key efficiency indicator in sunflower cultivation is dry matter accumulation, which reflects the intensity of growth processes and the crop's ability to utilize agro-climatic resources. This metric largely depends on agronomic practices, notably sowing dates and seeding rates. In the southern Steppe of Ukraine, identifying optimal combinations of these factors is crucial to maximize biomass accumulation – a prerequisite for high yield.

According to various scientific studies, both over-densification and under-densification of crops negatively impact sunflower yield due to intensified competition among plants. In dense plantings, mutual suppression increases, adversely affecting vegetative growth – these effects become evident from the budding phase.[15]

Table 6 presents data on the accumulation of dry matter by sunflower crops at harvest time based on average values from 2019 to 2021, depending on the

[15] Effect of Planting Density on the Growth and Yield of Sunflower under Mulched Drip Irrigation. *Li et al. Water*. 2019. Vol. 11, no. 4. P. 752. URL: https://doi.org/10.3390/w11040752.

studied factors. The highest accumulation of dry matter – 7.70 t/ha – was recorded under recommended sowing dates with a seeding rate of 40 thousand viable seeds per hectare. This indicates favorable conditions for plant growth during this period and optimal plant density. Under early sowing conditions, the maximum value was 7.09 t/ha, and under late sowing – 6.45 t/ha, indicating reduced biological productivity in these cases. Overall, a trend was observed: at all sowing dates, the best results were achieved with a seeding rate of 40 thousand seeds per hectare.

Table 6

Dry matter accumulation in sunflower crops at harvest time, t/ha (average for 2019–2021)

Sowing date (Factor A)	**Seeding rate, thousand seeds/ha (Factor B)**		
	30	40	50
Early	6.15	7.09	6.76
Recommended	7.00	7.70	7.15
Late	5.78	6.45	6.26

Sunflower productivity under climate change and in various agro-ecological zones heavily depends on several factors, with agronomic practices – especially sowing dates and seeding rates – playing a decisive role. Deviations from optimal sowing dates reduce yield potential and necessitate adaptation of cultivation systems, including new breeding strategies.[16]

Our research showed that yield indicators were significantly affected by both sowing date and seeding rate (Fig. 3).

The highest yield for the Carlos 105 hybrid in southern Ukraine – 2.64 t/ha – was achieved under recommended sowing dates and a seeding rate of 40 thousand viable seeds/ha. Early sowing produced yields between 1.95 and 2.38 t/ha, depending on seeding rate. Late sowing resulted in lower yields – from 1.82 to 2.30 t/ha.

Increasing seeding rate from 30 to 40 thousand viable seeds/ha significantly improved yield, whereas a further increase to 50 thousand led to only minor increases or stabilization.

A comparative assessment of different sowing times confirms the advantage of recommended dates, with yields ranging from 2.11 to 2.64 t/ha, depending on the seeding rate.

[16] Ahmed B., Sultana M., Zaman J., Paul S.K., Rahman Md. M., Islam Md. R., Majumdar F. Effect of sowing dates on the yield of sunflower. *Bangladesh Agronomy Journal*. 2015. Vol. 18, no. 1. P. 1–5.

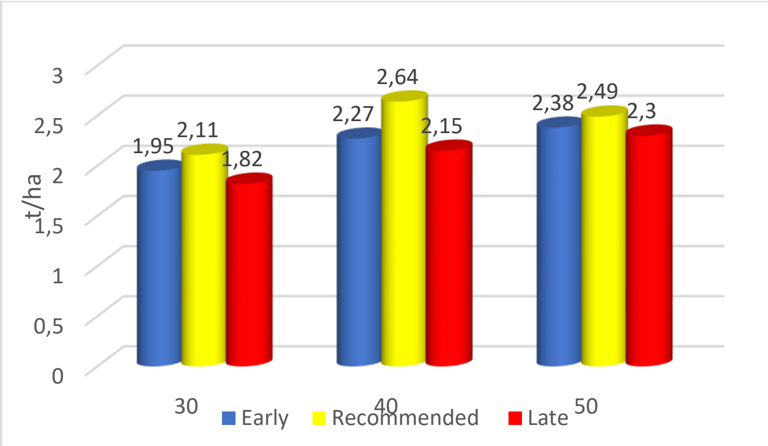

Fig. 3. Sunflower yield under different sowing dates and seeding rates (average for 2019–2021), t/ha

Based on the research results, it was established that sowing dates and seeding rates significantly affect sunflower yield. A significant yield difference was observed between the recommended and late sowing dates. Among the seeding rates, significant differences were recorded between the 30 and the 40 – 50 thousand viable seeds per hectare. The difference between the 40 and 50 thousand seed rates was found to be insignificant.

CONCLUSIONS

The conducted research confirms the significance of sunflower as a key oilseed crop for Ukraine, especially in its southern regions, while highlighting the growing challenges related to climate change. An analysis of sunflower production trends in Ukraine and the Kherson region shows a positive increase in acreage and yield up to 2021, but a sharp decline in 2024, likely due to both weather anomalies and the complex geopolitical situation in the region.

A thorough analysis of weather conditions in Ukraine reveals a clear warming trend and an increase in the frequency of extreme meteorological events, which pose considerable risks for stable sunflower cultivation. The Kherson region, located in the steppe zone, is particularly vulnerable to drought and dry winds, underscoring the need to develop adaptive agronomic technologies.

Experimental research results confirm the effectiveness of optimizing soil tillage technologies and sowing methods as adaptation strategies to changing climatic conditions. In particular, the No-till system demonstrated more stable yields during the dry year of 2020 compared to traditional plowing, indicating its potential in conserving soil moisture. An optimal row spacing of 45 cm contributed to higher yields under both tillage systems.

Studies on the effects of sowing dates and seeding rates on sunflower biometric indicators and yield revealed that the recommended sowing dates (at a soil temperature of 10–12 °C at a depth of 10 cm) and a seeding rate of 40 thousand viable seeds per hectare provided better plant growth and development, and hence, higher yields. Deviations from these optimal parameters – whether through earlier or later sowing, or by increasing or decreasing the seeding rate – led to reduced biometric indicators and lower potential yields.

Therefore, to ensure sustainable and efficient sunflower cultivation under climate change conditions in southern Ukraine, it is necessary to implement adaptive agronomic technologies that include: the use of moisture-preserving tillage systems such as No-till, especially in high-drought-risk regions; optimization of sowing methods taking into account row spacing for effective resource use; selection of optimal sowing dates based on soil temperature to ensure favorable early growth conditions; and adjustment of seeding rates to achieve optimal plant density, enhancing the use of solar radiation and nutrients.

Further research should focus on comprehensively studying the interactions of various agronomic factors under changing climatic conditions and on developing and implementing innovative approaches that improve sunflower resilience and productivity in southern Ukraine. Considering the current socio-economic and environmental challenges is critically important for forming effective adaptive sunflower cultivation strategies.

SUMMARY

This article addresses the pressing issues of sunflower (*Helianthus annuus L.*) cultivation under the conditions of global climate change, characterized by rising temperatures and altered precipitation patterns, particularly in the southern region of Ukraine. It provides a retrospective analysis of sunflower production in Ukraine and the Kherson region, highlighting key trends and current challenges. The impact of weather conditions on crop productivity is examined in detail. The study experimentally substantiates the effectiveness of optimizing primary tillage systems (traditional plowing and No-till) and sowing methods (row spacing of 45 and 70 cm) on sunflower yield under the conditions of the Kherson region during 2020–2021. Optimal sowing dates (at soil temperatures of 10–12 °C) and seeding rates (40 thousand viable seeds/ha) were determined to provide the best biometric parameters and yield.

Based on the obtained results, conclusions are drawn regarding the necessity of implementing adaptive agronomic technologies aimed at moisture conservation, optimization of plant placement, and sowing dates to

minimize the negative impact of climate change and ensure sustainable sunflower production in southern Ukraine.

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Information about the authors:
Revto Olesia Yaroslavivna,
Candidate of Agricultural Sciences,
Associate Professor at the Department of Plant Growing and Agroengineering,
Kherson State Agrarian and Economic University
23, Stritenska str., Kherson, 73006, Ukraine

Maliarchuk Anastasiia Serhiivna,
Candidate of Agricultural Sciences,
Associate Professor at the Department of Plant Growing and Agroengineering,
Kherson State Agrarian and Economic University
23, Stritenska str., Kherson, 73006, Ukraine