QUANTITATIVE AND QUALITATIVE EVALUATION OF AUTUMN-SOWN SUNFLOWER GROWTH

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Abstract. Under warm climate conditions it is possible, and this has been proved by the results of multiple field experimental studies, to grow the winter varieties of sunflower. Considering that sunflower is the most widespread and important technical (oil) crop, widely used in the production of oil for food and technical purposes, its cultivation should be of the utmost importance and perspective. However, in general, successful cultivation of sunflower, both regular varieties and winter crops, depends on many natural and climatic factors, such as temperature, amount of heat during the growing season, availability of moisture, soil type and crop rotation used, as well as the required plant nutrition rate. Our experimental agronomic field studies have shown positive results, allowing us to recommend this particular type of crop, i.e. autumn-sown sunflower, for mass production. However, the technology of growing the winter sunflower has a number of its own features. Thus, there is a need for pre-sowing treatment of its seeds with a water-repellent preparation at a soil temperature, not exceeding 2-3 ºC. Sowing should exclude the process of soil compaction by a seed drill rolling devices, which eliminates rapid seed germination. The results of the field measurements showed that, in contrast to the conventional varieties, the autumn-sown sunflower plants do not have significant differences in the uniformity of their arrangement in the rows of crops, which indicates almost the same germination, as well as in the height of the plants themselves. The results of statistical evaluation showed that at a statistical significance level of 0.05 it was established that the null hypothesis about the equality of the mean values and variances of the fluctuations of these parameters for both types of sunflowers is not significantly rejected. Yet, other measurements showed that the diameter of the autumn-sown sunflower heads is on average 1.32 cm larger than that of the regular ones. Therefore, it has been established that the dispersion and frequency of oscillations of this parameter are higher. On the whole, according to the results of the conducted field experimental study, it turned out that the yield of the autumn-sown sunflower, recorded at a statistical significance level of 0.05, was 2.6 cwt·ha^{-1} higher. If we take into account the fact that the harvesting period for the autumn-sown sunflower is earlier, on average by 40 days, then the efficiency of its production is more than obvious.

Keywords: front chopper; surface longitudinal profile; plough draft resistance; ploughing depth.

Introduction

Sunflower is the most widespread and highly important oilseed crop in many countries of the world. The production of high-quality sunflower oil from the seeds of this crop is a fairly effective and well-developed technological process (with a high percentage of a finished food product output), which is why sunflower is considered one of the most important and profitable agricultural crops. The technology of growing sunflowers is also widely known, and its application does not cause any particular difficulties for producers. The complexes of agricultural machinery and combines used in sunflower cultivation are also well known and have a fairly high efficiency. However, sunflower cultivation technology is constantly being improved; high-yielding hybrids and varieties are being developed and introduced in order to obtain maximum yield and minimize losses [1-3].

Despite this, modern developments by geneticists and breeders around the world are aimed at finding varieties of sunflower that would not only increase yields but also be resistant to diseases and pests. As it turned out, in warm climate conditions (and in Ukraine these are the southern regions), it is possible to vary the cultivation periods of this oilseed crop within wide limits. Thus, the possibilities of sowing sunflowers for autumn-sown crops are currently being studied at the testing stage. This was made possible also by the fact that at the initial stage of vegetation, sunflower plants do not require a significant amount of heat.

There are currently only a few published scientific articles in this area of research. From the few published scientific literature sources available, attention should be paid to studies on the effect of treating sunflower seeds with water-repellent preparations before sowing, which is important for the autumn-sown sunflower seed varieties since there is a need to delay the time of their soaking and germination during the winter period. The use of the agricultural chemical "dimethyl sulphate" as a surfactant to treat sunflower seeds sown in the autumn before sowing has already been shown to be very effective.

With medium doses of dimethyl sulphate, mutagenic lines of the sunflower variety VNIIMK 8931 were obtained [4]. During the experimental field studies, special attention was paid to mutations of the autumn-sown sunflower and its resistance to low temperatures. In addition, the influence of low temperatures during sunflower cultivation, sometimes reaching as low as -30 ºC, was studied, as well as the efficiency of plant growth at increased planting density, reaching 500 thousand plants per hectare.

The study of the influence of timing the application of mineral fertilizers for autumn-sown sunflower crops upon the growth and yield is devoted to the work of [5]. The specified indicators were studied for the autumn-sown sunflower variety "*Helianthus annuus* L." The authors of the publication studied various rates of application of mineral fertilizers for autumn-sown sunflower crops, such as nitrogen (N), phosphorus (P), potassium (K), and sulphur (S). The influence of specified mineral fertilizers upon the height of the plants, their dry matter mass, and the mass of 1000 seeds, etc. was established. Further research examined the cultivation of autumn-sown sunflower in different crop rotations [6]. These studies resulted in the establishment of the fact that the cultivation system "sunflower-groundnut-greengram" is the most stable (sustainable yield index 70%) in comparison with other systems. The authors conducted these studies continuously for 4 years.

It is also worth noting the works [7; 8] devoted to the research of new methods to determine the physiological maturity of autumn-sown sunflower plants, based on the assessment of the colour of its heads, as well as the maximum ripeness before harvesting. The same autumn-sown sunflower variety, *Helianthus annuus* L., was used in these studies.

There are also investigations among the literary sources, devoted to the degree of influence of irrigation of autumn-sown sunflower crops upon the properties of its seeds – the yield and oil content [8; 9]. These authors found, for example, that three-fold irrigation of autumn-sown sunflower crops ensures an increase in the yield by an average of 17.4-18.0 $cwt \cdot ha^{-1}$. In this case, a necessary condition is also the application of nitrogen fertilizers at a dose of 40 $kg \cdot ha^{-1}$.

The study of the degree of influence of predecessors upon the yield of autumn-sown sunflower is reflected in the work [10]. In this case, the results of the study are presented where rapeseed was used as a precursor. Conditions were also agreed upon for the use of irrigation in the form of a subsurface drainage system, located at a depth of 0.30 m. According to the results of the field study, conducted by these authors, the autumn-sown sunflower harvest was obtained 1.5 months earlier than in the case of using conventional cultivation technology.

The above studies, conducted by various authors, cover a wide range of conditions in which autumn-sown sunflower can be successfully grown. In almost all cases, there is an improvement in the yield indicators, a reduction in the cultivation time, and other indicators.

Based on the study of this issue and the publications by other authors, it is possible to formulate the main disadvantages and advantages that arise when growing autumn-sown sunflower.

The main disadvantages may be considered the following:

- the risk of freezing of autumn-sown sunflower crops, especially when there are frequent changes in negative temperatures in the winter-spring periods;
- even under the condition that autumn-sown sunflower successfully survives the winter, in the spring during its growing season the plants may be suppressed by weeds since at the initial stages it grows rather slowly. In such a case, it is important that the sunflower is resistant to the herbicides used to control the weeds.

At the same time, there are obvious advantages to growing autumn-sown sunflower, the main ones being:

- sufficient supply of moisture to the sunflower crops (early spring and early summer);
- harvesting can be carried out almost a month earlier, which allows for timely and high-quality further cultivation of the soil on its plantations;
- if ripening is early, more favourable conditions are created for pollination during the flowering period of this crop, which contributes to better seed filling.

Thus, the earlier harvest allows for earlier and more even loading of products into the oil extraction plants. The producers of autumn-sown sunflower can sell their products at higher prices. In addition, early sowing of autumn-sown sunflower practically before autumn-sown will make it possible to reduce the stress of the spring sowing campaign next spring. And early harvesting of autumn-sown sunflowers in the following will make it possible to carry out autumn fieldwork in these areas more efficiently, i.e. to prepare the soil well for the cultivation of other agricultural crops.

However, the following issues in the production of autumn-sown sunflower can still be considered insufficiently researched:

- which of the hybrids and varieties of autumn-sown sunflower are the most priority for certain cultivation zones with a warm climate;
- what water-repellent preparations should be used to treat the autumn-sown sunflower seeds before sowing, depending on the mechanical and technological properties of the soil;
- what is the degree of soil moisture in which the autumn-sown sunflower will be sown;
- what should the optimal timing be for sowing the autumn-sown sunflower in the autumn-winter period, depending on the zone of its cultivation.

In such a way, the aim of this study is to determine the main quantitative indicators, primarily of the soil and climatic conditions in which autumn-sown sunflower is grown and quality indicators using statistical methods for processing measurement results.

Materials and methods

A testing ground was selected as the research object for studying the technological process of growing autumn-sown sunflower in southern Ukraine, where the soil and climatic conditions were suitable. This research was conducted in partnership with the Latvia University of Life Sciences and Technologies. The experimental field was located in Melitopol (46°50′56″ north latitude, 35°21′55″ east longitude, altitude: 37 m). The soil characteristics were as follows: medium loamy soil with a humus content of 3.1% in the 0-20 cm layer, containing total nitrogen – 23.8 $mg \cdot kg^{-1}$, phosphorus – 36.8 $mg \cdot kg^{-1}$, and potassium – 289.0 $mg \cdot kg^{-1}$ of soil. The field capacity was 18-20%, and the wilting point moisture was 9.6%.

For the experimental field studies, the widely distributed autumn-sown sunflower hybrid “Logos” was used (Table 1).

Table 1

Characteristics of the “Logos” hybrid

Index	Value
Reproduction	F-1
Varietal purity, %	99.8
Germination rate, %	94
Humidity, %	6.5
Weight of 1000 seeds, g	78.2
Protectant	Apron XL

To create a water-repellent effect, the autumn-sown sunflower seeds were treated with a film-forming agent of the “Mars” brand at a rate of 250 $ml \cdot t^{-1}$.

During the experimental field investigations, the field designated for the study of autumn-sown sunflower cultivation was divided into two adjacent plots of equal size, each measuring 5 hectares. One plot was designated for sowing the autumn-sown sunflower, while the other served as the control plot for sowing regular sunflower. Prior to the sowing of the autumn-sown sunflower, temperature measurements were taken in the surface layer of the soil (up to 8 cm deep) using an electronic thermometer with a DS18B20 sensor (Dallas Semiconductor), manufactured in China. The electrical signal from the sensor was transmitted and recorded using an Arduino Uno, made in Italy. The absolute error in measuring soil temperature with this electronic device did not exceed 0.5%.

In both plots, soil moisture was determined at a depth of 8 cm. The autumn-sown sunflower was sown in mid-December, while the regular sunflower was sown in the following spring, at the beginning of May.

To maintain the consistency of the field experiments conducted at different times of the year (with a 5-month interval), the seed sowing was performed using the same machine-tractor unit, consisting of an 89 HP tractor and a Vega-8 row drill manufactured by Elvorti (Ukraine). In both cases, the same seeding rate of 5 $kg \cdot ha^{-1}$ was carefully observed. The Vega-8 seeder was set to a seeding depth of 6 cm, and the row spacing for the sunflower sowing was maintained at 70 cm.

An exception was made when sowing the autumn-sown sunflower, as the soil was not rolled due to the noted conditions. Additionally, when the first sunflower shoots appeared, only one inter-row treatment was conducted in both cases. This was performed using the same machine-tractor unit, which included a row-crop tractor with an 89 HP engine and an ALTAIR-5.6 cultivator. The cultivator was set to a working depth of 6 cm, ensuring high precision in driving and copying the rows of plants [11].

At each of the designated sites, identical measurements were taken to assess:

- the distance between the plants;
- the height of the plants;
- the size of the sunflower heads (their diameters) at the time of harvesting.

Additionally, linear measurements were conducted at different locations within the plots, randomly selecting more than 250 measurement points. The measurements were performed using a ruler with an error margin not exceeding ± 0.5 cm. The distances between the plants were measured from the same sides of the sunflower plants, the height was measured from the soil surface to the upper leaves, and the diameters of the heads were measured along their outer contours.

Results and Discussion

Since it was established that the autumn-sown sunflower sowing should be carried out under the condition that the soil temperature (both on the surface and at a sowing depth of up to 8 cm) is not lower than 2–3 ºC, constant monitoring of the temperature regime of the experimental field with two sections was performed. The results of these measurements enabled the construction of a graph showing changes in the soil temperature at the expected sowing date, presented as a broken curve in Fig. 1.

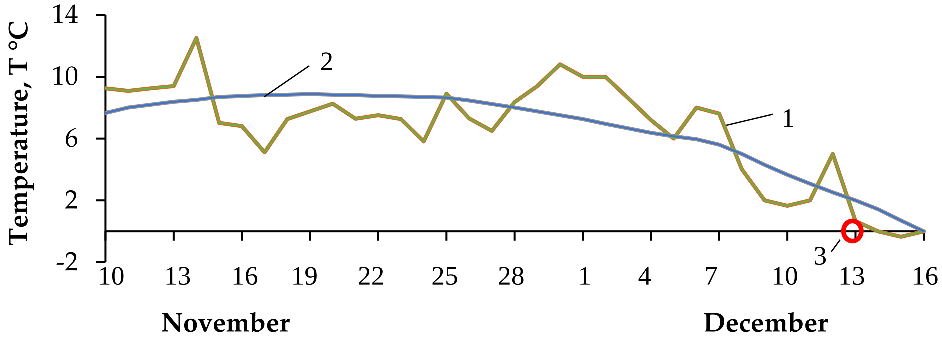

Fig. 1. **Change in soil temperature at the expected time of sowing the autumn-sown sunflower:** 1 – measured value; 2 – approximated value; 3 – rain

Based on the statistical analysis of soil temperature measurements over the required period, an equation for the approximating function was derived, and its graph was constructed. Thus, it was determined that the optimal sowing period for the autumn-sown sunflower in this region is the end of the first ten days of December and, effectively, the middle of this month. Additionally, it is possible that during this same period, sudden and sharp drops in ambient air temperature may occur. However, in this case, the decrease in the soil temperature will occur more slowly. Under such conditions, it is feasible to use direct seeding row crop drills for sowing the autumn-sown sunflower, with coulters capable of efficiently breaking up the upper frozen soil crust. This will not affect the quality of sowing or the placement of the autumn-sown sunflower seeds at the required planting depth.

According to the program and methodology for conducting the experimental field study, on December 15, we sowed the autumn-sown sunflower in one of the areas designated for different technologies. The second plot remained unused until the following spring. At this time, soil moisture at the seeding depth was measured at 16.8%. Control measurements of temperature during sowing indicated that at the required seed placement depth in the soil, up to 8 cm, the temperature was not lower than 1-3 ºC.

The sowing of sunflower seeds using conventional technology on the second plot was conducted in the spring of the following year, specifically on May 4, 2021. During sowing, special attention was given to the uniform movement of the working body in the vertical plane, accounting for vibrations transmitted from the field surface [12; 13].

It should also be noted that during the period between the sowing of the autumn-sown sunflower and the sunflower grown using the conventional technology, the ambient air temperature dropped to negative values (in January-February) and briefly reached as low as -10 ºC. There was practically no precipitation in the form of snow. These temperature fluctuations did not affect the integrity of the experimental field study.

Observations also revealed significant differences in the development of the two types of sunflowers studied in this experiment. At the time of flowering of the sunflower grown using the conventional technology, the autumn-sown sunflower was already in the full ripening phase. This is clearly visible in the photographs presented in Fig. 2.

a)  b) 

Fig. 2. **Field sections with the autumn-sown sunflower**, sown (a) and the sunflower, sown using conventional technology (b) – the beginning of August

Based on the results of measurements and their statistical processing, comparative indicators were obtained for both types of the grown sunflower, which are shown in Table 2.

Table 2

Comparative indicators of the plant measurements, performed for the autumn-sown sunflower and the sunflower, grown using the conventional technology

Indicator	Sunflower sowing time	
	conventional	autumn-sown
Plant density, cwt·ha^{-1}	56.6	56.4
Height of the plants:		
– mean, cm	123.93 ± 0.69	124.78 ± 0.65
– variance, cm^2	28.73	25.30
– standard deviation, ± cm	5.36	5.03
– coefficient of variation, %	4.3	4.0
– sample mean error, cm	0.35	0.33
– LSD_{05}, cm	0.95	
Basket (head) diameter:		
– mean, cm	19.85 ± 0.28	21.17 ± 0.34
– variance, cm^2	3.97	5.78
– standard deviation, ± cm	2.00	2.40
– coefficient of variation, %	10.1	11.4
– sample mean error, cm	0.14	0.17
– LSD_{05}, cm	0.44	

Table 2 (continued)

Indicator	Sunflower sowing time	
	conventional	autumn-sown
Distance between plants:		
– mean, cm	35.18 ± 0.35	35.42 ± 0.33
– variance, cm	6.22	5.46
– standard deviation, ± cm	2.49	2.34
– coefficient of variation, %	7.1	6.6
– sample mean error, cm	0.18	0.17
– LSD_{05}, cm	0.48	

The statistical analysis of the measurements indicated that the height of the autumn-sown sunflower plants was 0.85 cm greater than that of the sunflowers grown using the conventional technology. However, at a statistical significance level of 0.05, this difference in height is considered random because LSD05 = 0.95 cm, as shown in Table 2.

Additionally, the difference between the variances of height fluctuations in the autumn-sown sunflower plants and the sunflowers grown using the conventional technology is also random. When comparing these statistical characteristics using the Fisher's *F*-test, the actual value of 1.13 is less than the critical value of 1.39. Therefore, with a 95% confidence level, we cannot reject the null hypothesis that the variances of height fluctuations in the autumn-sown sunflower plants and the sunflowers grown using the conventional technology are equal. Both variances represent the same overall sample.

Furthermore, as seen in Table 2, the coefficients of variation for the plant height parameter do not exceed 10%. This suggests that the height fluctuations of the autumn-sown sunflower plants and the sunflowers grown using the conventional technology are low-variance [14-16]. Additionally, the height fluctuation processes in both variants are of low frequency. This is indicated by the normalized correlation functions of the height fluctuations in the sunflower plants, presented in Fig. 3. The analysis shows that for both processes, the correlation length does not exceed 0.4 m. This is the value of the abscissas at which the normalized correlation functions first reach zero for both variants.

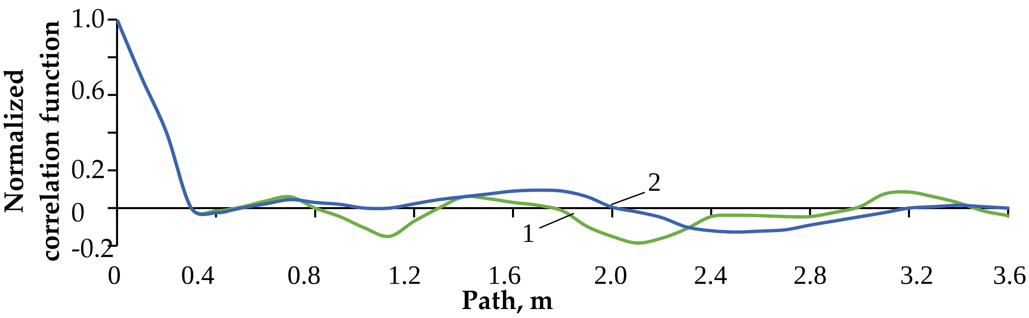

Fig. 3. **Normalized correlation functions of the plant stem height fluctuations in the middle of the growing season:** 1 – autumn-sown sunflower; 2 – sunflower, grown using the conventional technology

The analysis of the measurements of the distance between the plants in the compared variants (which indicates the plant germination rate) showed that the null hypothesis about the equality of the mean values and the dispersion of fluctuations of this parameter at the accepted statistical significance level of 0.05 is not rejected. As shown in Table 1, the difference between the average values of this measurement parameter is actually two times smaller than in the previous case, with LSD_{05} = 0.48 cm. The actual value of the Fisher's *F*-test, equal to 1.14, for the compared variances of the same parameter, is less than the critical value of 1.39. Additionally, the values of the variation coefficients are at the same level and do not exceed 10%.

As evident from the behaviour of the curves presented in Fig. 4, which display the normalized correlation functions of the fluctuations in the distance between the autumn-sown sunflower plants and the sunflowers grown using the conventional technology, the correlation relationship is practically the same in both variants. Moreover, the length of the correlation link in both variants is approximately 0.5 m.

It should be noted that, as with the height of the sunflower plants, the hidden periodic components of the correlation functions of the fluctuations in the distance between the shoots are insignificant in amplitude and very weakly expressed in period.

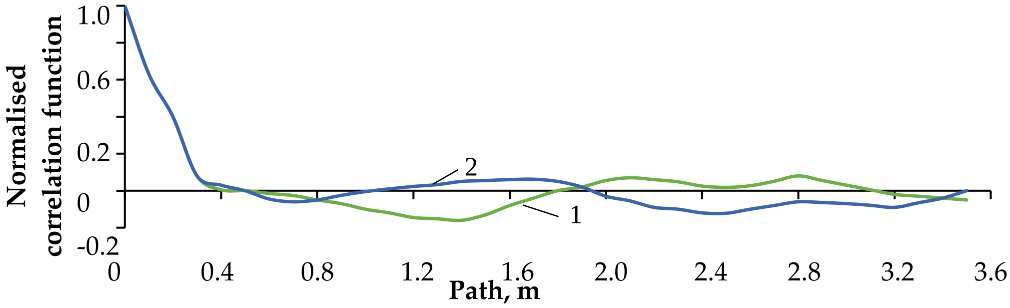

Fig. 4. **Normalized correlation functions of fluctuations in the distance between the plants in a row of crops**: 1 – autumn-sown sunflower; 2 – sunflower, grown using the conventional technology

Next, the results of measurements of the diameters of the heads (baskets) of the autumn-sown sunflower and the sunflower grown using the conventional technology are analysed based on their statistical assessment. It was established that the average values for this indicator are significantly higher in the autumn-sown sunflower compared to the conventionally grown sunflower. Specifically, the difference in the diameters of the autumn-sown sunflower heads is 1.32 cm greater than that of the conventionally grown sunflower heads, which is three times higher than LSD_{05}, equal to 0.44 cm, as shown in Table 2.

A similar pattern is observed in the variance of fluctuations in the diameter of the sunflower heads. The variance for the autumn-sown sunflower is 1.45 times higher than that of the conventionally grown sunflower. This excess is considered natural since the actual value of the Fisher's *F*-test, 1.45, is greater than the critical value of 1.39.

When comparing the values of the variation coefficients for this parameter, as shown in Table 2, they are approximately the same for both options. According to [14-16], since their values are between 10 and 20%, they are characterized as processes of medium variability.

Analysing the basic nature of the fluctuations in the diameter of the sunflower heads in both studied variants, based on the obtained normalized correlation functions, reveals different lengths of the correlation relationship. For the fluctuations in the diameters of the autumn-sown sunflower heads, it is 0.75 m, and for the conventionally grown sunflower it is 1.1 m. A larger value of the correlation length characterizes a low-frequency process. As shown in Fig. 5, such properties are characteristic of the oscillations in the diameter of the conventionally grown sunflower heads.

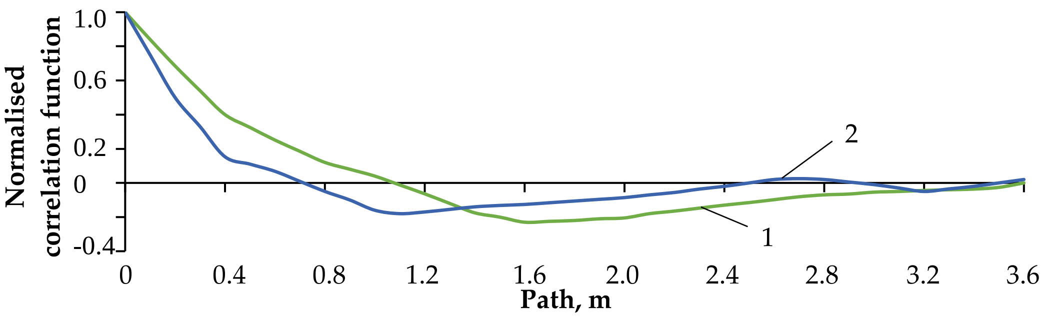

Fig. 5. **Normalized correlation functions of oscillations of the head (basket) diameters at the moment of full ripeness before harvesting**: 1 – autumn-sown sunflower; 2 – sunflower, grown using the conventional technology

During this experimental field study, tillering events were discovered, which were observed only in some sunflower seedlings sown in autumn. An example of such tillering is shown in Fig. 6. It should be noted that this phenomenon, which is most characteristic (or obligatory) for other winter crops, was observed in sunflower for the first time. Additionally, in this experimental field study, absolutely identical seeds with the same varietal purity were used for sowing both the autumn-sown sunflower and the sunflower sown using the conventional technology. A thorough examination of the sunflower crops grown using the conventional technology revealed no evidence of tillering.

It is evident that this feature, observed during the cultivation of the autumn-sown sunflower, requires more thorough and additional study.

Fig. 6. **Phenomenon of tillering of the autumn-sown sunflower plants**

The results of the measurements and subsequent statistical evaluation established that the yield of the autumn-sown sunflower is higher, amounting to 22.4 $cwt \cdot ha^{-1}$, compared to the yield of 19.8 $cwt \cdot ha^{-1}$ for the sunflower grown using the conventional technology. The difference of 2.6 $cwt \cdot ha^{-1}$ is significant and not random, as it is greater than the least significant difference (LSD_{05}) value of 2.2 $cwt \cdot ha^{-1}$. This advantage in yield is likely due to the higher amount of moisture received by the autumn-sown sunflower plants during their early (spring) stage of development. In contrast, the sunflower seeds sown using the conventional technology may not receive such water saturation or may not have been sown at this time.

In warm climates, the sunflower plants sown in the autumn are quite resistant to climate changes towards colder temperatures. Being in the soil at a predetermined sowing depth, they do not freeze during the winter and maintain high germination rates in early spring. The key is to create conditions to prevent the plant seeds from germinating in winter or during early spring when significant temperature fluctuations occur. For this purpose, the water-repellent agricultural chemicals used to treat the seeds before sowing the autumn-sown sunflower must exert their effect reliably and be completely neutralized in spring.

Conclusions

1. The conducted experimental field studies have demonstrated that in the warm climate and favourable soil and climatic conditions present in the south of Ukraine, the cultivation of autumn-sown sunflower is feasible and effective.
2. To successfully implement the new technology for growing autumn-sown sunflower under these specified conditions, the following measures are essential:
3. Use of sunflower hybrids and varieties that can tolerate low temperatures and temperature fluctuations during the germination period and the initial stage of vegetation.
4. Pre-sowing treatment of autumn-sown sunflower seeds with water-repellent chemicals to prevent moisture absorption when seeds are at the required depth.
5. The sowing process should be conducted at positive temperatures no lower than 2-3 ºC.
6. Rolling of crops is not permitted to avoid germination in the initial period after sowing.
7. The experimental field studies, including numerous measurements and their statistical analysis, showed no significant differences between the autumn-sown sunflower seedlings and those sown using the conventional technology. Comparison of plant height and arrangement in rows (indicating germination) supports the null hypothesis with a 95% confidence probability that the mean values and variances of these indicators are equal for both sunflower types.
8. The measurements indicated that the diameters of the heads (baskets) of the autumn-sown sunflowers are, on average, 1.32 cm larger than those of the sunflowers grown using the conventional technology, with higher variance and frequency of oscillations for this parameter.
9. It has been established that the ripening period of the autumn-sown sunflower is, on average, 40 days earlier, indicating the clear operational and technological advantages of this method.

10. The measured yield of the autumn-sown sunflower was 2.6 $cwt \cdot ha^{-1}$ higher at a statistical significance level of 0.05, further indicating the potential of this technology.

Author contributions

Conceptualization, V.B., I.H. and V.N., methodology, V.B., V.N. and I.H., software, O.T., validation, V.B., A.A., O.T. and V.N., formal analysis, A.A. and A.R., investigation, V.B. and A.R., resources, V.B. and I.H., data curation, O.T., writing – original draft preparation, V.B., A.A. and A.R., writing – review and editing, A.A. and A.R., visualization, O.T., supervision, O.T., project administration, V.B., funding acquisition, A.R. All authors have read and agreed to the published version of the manuscript.

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