Mathematical substantiation of the efficiency of sunflower cultivation in the conditions of the southern forest-steppe of the Central Black Earth Region

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Abstract. Sunflower is one of the strategic crops of the agro-industrial complex not only in Russia, but also around the world: sunflower seeds are used not only for food products and feed from production waste, but also for energy carriers. In recent years, the cost of sunflower oil has shown high growth dynamics, and we believe that against the background of the general growth in the consumption of "green" renewable energy, it will also show growth. The high demand for sunflower oilseeds both in the domestic and foreign markets is due to the wide range of products produced from this raw material, and this trend has persisted for many years due to an increase in the population and an increasing demand for high-quality food products. In addition, an increasing number of consumers in Russia have a negative attitude towards the widespread palm oil on the international market, preferring sunflower oil or its processed products. Sunflower oilseeds are cultivated everywhere both in the Russian Federation and in the world. However, the high variability of soil-climatic conditions, the emergence of new varieties, hybrids and plant protection products with high attention to zero soil treatment technologies require research and justification of mass production. The high price of the crop made it possible not to touch on the issues of the effectiveness of sunflower cultivation and ensuring its high quality, this article is designed to fill in these gaps. The authors of the article investigate the hypothesis of the dependence of sunflower quality on the technology of its cultivation. Mathematical methods were used to substantiate the conclusions, which made it possible to identify significant and secondary factors of cultivation technology and obtain an assessment model.

1. Introduction

It is known that the oiliness of sunflower seeds depends both on the biological features of the variety or hybrid, and on the techniques of cultivation. Academician L.A. Zhdanov notes that the oiliness of sunflower seeds varies greatly mainly depending on the reserves of soil moisture and the distribution of precipitation during its flowering and filling. Even relatively small precipitation during seed formation has a beneficial effect on oil accumulation in seeds. This happens not only due to an improvement in the supply of plants with moisture, but also due to a decrease in air temperature, since even with a large amount of precipitation, but under conditions of high air temperature there is a sharp decrease in the oil content in the seeds. Also, the content of oil in the seeds, as a rule, increases in the absence of dried animals in the fruiting phase and excessively high temperatures [1].
Some researchers note the dependence of the oil content in sunflower seeds on the food area of plants. As a rule, on cut crops, the seed core contains oils 1.5-2.0% less than with optimal plant standing density. This is due to the fact that in sparse crops, each plant receives more water along with nutrients dissolved in it than in thickened crops [2].

We will check these provisions by laying down scientific production experiments.

2. Materials and methods

In our studies, the sunflower hybrids used had fairly good initial indicators of the oil content of the seeds - 43.93-49.17%:

NK Brio is a medium-ripened (112-116 days) classic sunflower hybrid. Hybrid of intensive type, responds well to soil fertility. It has an average growth energy at the initial stages of organogenesis. It is resistant to the infection of races A - E. It has a good tolerance to phomopsis, phomosis, basket and stem forms of white and gray rot. The use of classical tillage is recommended. It is recommended to observe crop rotation.

NC Neoma is medium-ripe (112-116 days). Hybrid intensive type. It has an average growth energy at the initial stages of its development. It is resistant to the infection of races A - E. It is tolerant to fomosis, fomopsis, stem and basket forms of white and gray rot. Genetically close to NK Brio. It is not recommended to place after legumes. Compliance with classical cultivation technology is recommended.

PR64E83 is a medium-ripened hybrid adapted to ExpressSun technology. Selection of the Pioneer company. A hybrid of simple crossing. High-yielding, stable, one of the most drought-resistant of the registered hybrids. A good self-pollinator. The hybrid is tolerant to the contagion of race E (Spanish classification). It has genetic resistance to peronosporosis of race 304 – the most common in the Russian Federation. Tolerant to phomopsis. It has a powerful root system, is resistant to lodging, is tall, well-leafed, leaves are dark green. The basket is large, convex shape, well filled with seeds. The size of the seeds is average (weight 1000 pcs. the average is 55-65 g), the oil content is in the range of 48-49%.

During the study, three-factor field experiments were conducted according to the following scheme.

Factor A - seeding rates:
1) 50 thousand germinating seeds per hectare (row spacing 70 cm);
2) 60 thousand germinating seeds per hectare (row spacing 70 cm) - control;
3) 70 thousand viable seeds per hectare (row spacing 70 cm).

Factor B - weed control schemes:
1) traditional: hybrid Brio + herbicide Dual Gold (1.6 l / ha) - control;
2) Clearfield production technology: Neoma hybrid + Euro-Lightning herbicide (1.2 l / ha).
3) production technology ExpressSun: hybrid PR64E83 + Express herbicide (40 g / ha) + Fuzilad Forte herbicide (1 l / ha).

Factor C – method and depth of basic tillage:
1) plowing at 25-27 cm - control;
2) plowing by 30-32 cm;
3) deep drying by 25-27 cm;
4) deep drying by 30-32 cm;
5) disking to a depth of 10-12 cm.

The predecessor of sunflower was winter wheat.

After harvesting of the precursor, stubble was discarded to a depth of 6-8 cm. Depending on the test options, the main soil treatment was carried out after 2-3 weeks. Fertilizers were introduced in the fall for the main tillage in the form of azofosca at a rate of 4 c/ha. Pre-harvest tillage consisted of moisture closure and pre-harvest cultivation on sowing day. Sowing was carried out in the optimal time. Sunflower harvesting was performed in a direct manner.

In experiments, they studied the technology of protecting sunflower from weeds in three versions:
1) traditional - hybrid Brio + herbicide Dual Gold (1.6 l/ha). The herbicide was introduced immediately after sowing with MTZ -80 Belarus tractor + OP-2000 aggregate, followed by sealing into the soil;

2) Clearfield - Neom hybrid + Euro-Lightning herbicide (1.2 l/ha), which was introduced into the phase of the 4th sheet by spraying;

3) ExpressSun - hybrid PR64Ye83 + herbicide Express (50 g/ha) + herbicide Fuzilad Forte (1 l/ha). The herbicide Express was introduced in the 4th leaf phase, the Fuzilad Forte in the 6th leaf phase.

The study used field and laboratory methods. When laying the experiments, we were guided by the method of conducting field agrotechnical experiments with oilseeds [3].

The repetition is threefold. The total area of the plot is 240 sq.m, the accounting area is 200 sq.m, the placement of the plots is systematic in one tier.

The experiments were accompanied by a number of observations and analyzes accepted in agronomic research, which were carried out according to the corresponding approved methods.

The sowing quality of seeds was determined in a certified laboratory of the regional seed inspection according to the relevant GOSTs (State Standard System):
- germination energy and laboratory germination - according to GOST 12038-84;
- 1000 seeds weight - according to GOST 12042-80.

The phenology of sunflower development, the density of plant standing, the dynamics of height and mass of plants according to the phases of crop development, the diameter and alignment of the basket, as well as the elements of the crop structure were determined using the methodology of conducting field agrotechnical experiments with oilseeds [4].

The leaf area was determined by the method of die-cutting in phases according to the methods of A A Nichiporovich [5].

The aboveground mass of weed vegetation was accounted for by quantitative and weight method by superimposing stationary sites, taking into account the species composition, number and mass of weeds.

When calculating the harvest, the method of continuous threshing was used with the conversion of the seed mass to 100% purity and 7% humidity.

During harvesting, average samples of seeds weighing 0.5 kg were taken, in which:
- humidity - as per GOST 10856-64;
- purity - as per GOST 10854-88;
- mass of 1000 grains - as per GOST 12042-80;
- oiliness of seeds - as per GOST 10857-64;
- Seed fluidity - as per GOST 10855-64.

Physicochemical indices of oils were determined by the following GOST:
- color number - GOST 5477;
- acid number - GOST R 52110;
- iodine number - GOST 5475;
- number of saponification - GOST 5478;
- peroxide number - GOST 26593.

Mathematical processing of the research results was carried out on a personal computer by the method of analysis of variance according to B A Dospekhov [6] using the works of other authors [7].

Economic efficiency was calculated using standard flow charts [8, 9].

3. Research question
The highest oil content of achenes was formed by sunflower in 2013 - 46.93–49.17%. This indicator was somewhat less in 2014 - 44.10–47.43%, and the lowest in 2012 - from 43.90 to 46.17%. On average, over 3 years of research on the variants of the experiment, the oil content varied in the range from 45.13 to 47.51%.

When studying the influence of seeding rates on the oil content of sunflower seeds, minor differences were revealed – less than 1.0%. A clear dependence of the oil content in the seeds on the
seeding rates has not been established. Nevertheless, some authors note that the oil content of large seeds obtained from plants grown in sparse crops is less than in thickened ones.

On average, for 3 years, Neoma and Brio hybrids had almost the same indicators of oil content of seeds. Achenes of the hybrid PR64E83 with the ExpressSun weed protection system contained 1.5–2.0% less oil compared to the Neoma and Brio hybrids (Table 1-3). The results of statistical data processing indicate the importance of the factor of the weed protection system. In addition, the lower oil content in sunflower seeds may be due to the genetic characteristics of the hybrid.

In the Brio hybrid, with the traditional system of protecting sunflower crops from weeds, the oil content in the seeds, depending on different methods of soil cultivation, varied slightly - within 1.0%.

| Method and depth of tillage | Seed seeding rate, thousand pieces/ha | Oil content of hemicarps, % | On average for 3 years |
|-----------------------------|--------------------------------------|-----------------------------|-----------------------|
|                             |                                      | 2012 | 2013 | 2014 |                              |
| **Brio Hybrid, Traditional Technology – Control** |                                      |      |      |      |                              |
| Plowing 25-27 cm Control 50 | 45.97                                | 48.90 | 47.00 | 47.29 |
|                             | 60 (Control)                         | 45.87 | 49.07 | 47.07 | 47.34 |
|                             | 70                                   | 45.80 | 49.83 | 47.10 | 47.28 |
| Plowing 30-32 cm 50         | 46.00                                | 49.07 | 46.97 | 47.35 |
|                             | 60 (Control)                         | 45.93 | 49.83 | 47.50 | 47.45 |
|                             | 70                                   | 46.00 | 49.17 | 46.93 | 47.37 |
| Deep loosening by 25-27 cm 50 | 46.07                              | 49.13 | 47.10 | 47.43 |
|                             | 60 (Control)                         | 45.97 | 48.87 | 47.33 | 47.39 |
|                             | 70                                   | 45.87 | 49.00 | 47.27 | 47.38 |
| Deep loosening by 30-32 cm 50 | 46.10                              | 48.97 | 47.47 | 47.51 |
|                             | 60 (Control)                         | 45.70 | 48.93 | 47.20 | 47.28 |
|                             | 70                                   | 45.97 | 48.83 | 47.27 | 47.36 |
| Disking 10-12 cm 50         | 46.03                                | 49.07 | 47.43 | 47.51 |
|                             | 60 (Control)                         | 46.10 | 48.93 | 46.97 | 47.33 |
|                             | 70                                   | 45.93 | 48.90 | 46.97 | 47.27 |
| **Hybrid Neoma, Clearfield technology** |                                      |      |      |      |                              |
| Plowing 25-27 cm Control 50 | 45.97                                | 49.17 | 47.13 | 47.42 |
|                             | 60 (Control)                         | 45.80 | 49.03 | 47.07 | 47.30 |
|                             | 70                                   | 46.17 | 48.90 | 46.93 | 47.33 |
| Plowing 30-32 cm 50         | 46.10                                | 48.97 | 47.30 | 47.46 |
|                             | 60 (Control)                         | 45.90 | 48.93 | 47.27 | 47.37 |
|                             | 70                                   | 45.97 | 48.83 | 46.97 | 47.26 |
| Deep loosening by 25-27 cm 50 | 45.80                              | 48.67 | 46.87 | 47.11 |
|                             | 60 (Control)                         | 45.97 | 49.10 | 47.30 | 47.46 |
|                             | 70                                   | 45.80 | 48.87 | 46.97 | 47.21 |
| Deep loosening by 30-32 cm 50 | 46.03                              | 49.07 | 46.97 | 47.36 |
|                             | 60 (Control)                         | 45.60 | 48.93 | 46.97 | 47.17 |
|                             | 70                                   | 46.00 | 49.10 | 47.50 | 47.53 |
| Disking 10-12 cm 50         | 45.83                                | 47.13 | 46.93 | 46.63 |
|                             | 60 (Control)                         | 45.97 | 47.07 | 47.20 | 46.75 |
|                             | 70                                   | 45.87 | 46.93 | 45.07 | 45.96 |

Table 1. Oil content of sunflower seeds depending on seeding rates, weed control system and soil treatment.
In the Neoma hybrid with the Clearfield weed control system, a decrease in oil content by 1.1–2.0% was observed in all years of the study when disking as the main method of soil cultivation.

For further assessment, it is necessary to assess the influence of factors on the oil content of seeds of sunflower hybrids, depending on factors such as yield, method and depth of soil cultivation, seed seeding rate, duration of the growing season, plant height at the stage of technical ripeness, weed mass before harvesting, plant safety and etc.

To substantiate the influence of factors on the efficiency of sunflower cultivation, mathematical modeling was applied.

Table 2. Oil content of sunflower seeds depending on seeding rates, weed control system and soil treatment (Hybrid PR64E83, ExpressSun technology).

| Method and depth of tillage | Seed seeding rate, thousand pieces/ha | Oil content of hemicarps, % |
|----------------------------|--------------------------------------|----------------------------|
|                            | 2012 | 2013 | 2014 | On average for 3 years |
| Plowing 25-27 cm - Control | 50   | 44.10| 47.30| 45.93 | 45.78 |
|                            | 60 (Control) | 43.90| 47.40| 45.97 | 45.76 |
|                            | 70   | 44.20| 47.10| 44.10 | 45.13 |
| Plowing 30-32 cm           | 50   | 44.03| 47.00| 44.97 | 45.33 |
|                            | 60 (Control) | 44.10| 47.07| 44.97 | 45.38 |
|                            | 70   | 43.93| 47.10| 44.93 | 45.32 |
| Deep loosening by 25-27 cm | 50   | 43.97| 47.10| 46.97 | 46.01 |
|                            | 60 (Control) | 43.93| 47.07| 44.93 | 45.31 |
|                            | 70   | 44.13| 47.10| 45.00 | 45.41 |
| Deep loosening by 30-32 cm | 50   | 44.93| 47.07| 45.13 | 45.71 |
|                            | 60 (Control) | 44.07| 46.93| 44.93 | 45.31 |
|                            | 70   | 44.13| 46.93| 45.07 | 45.38 |
| Disking 10-12 cm           | 50   | 44.07| 47.13| 45.07 | 45.42 |
|                            | 60 (Control) | 44.00| 47.07| 44.97 | 45.35 |
|                            | 70   | 44.03| 46.93| 44.93 | 45.30 |

The regression model used in this work is plural. In such models, the variable $Y$ is considered as a function of several independent variables $x_i$. For example, oil content can be assessed from the standpoint of the influence of many factors on it: the depth of plowing and the method of soil cultivation, standing density, acidity, and more.

1. Estimation of the vector of regression coefficients:

$$\hat{b} = (X'X)^{-1} X'Y$$

2. The standard error of the k-th regression coefficient, equal to the square root of the corresponding diagonal element of the covariance matrix of the vector estimate:

$$S_{\hat{b}}^2 = \hat{\sigma}^2 (X'X)^{-1}$$
where \( \hat{\sigma}^2 = \frac{\textbf{e}'\textbf{e}}{n - m - 1} \) is calculated by balances \( \textbf{e} = \textbf{Y} - \textbf{X}\hat{\textbf{b}} \).

3. Multiple correlation index:

\[
R_{y,x_1,x_2,\ldots,x_m} = \sqrt{1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2}}
\]  

(3)

4. Beta odds:

\[
\beta_i = b_i \frac{\sigma_{x_i}}{\sigma_y}
\]

(4)

5. Paired correlation coefficients:

\[
r_{xy} = b_i \frac{\sigma_x}{\sigma_y} = \frac{\bar{x}_y - \bar{x} \bar{y}}{\sigma_x \sigma_y} = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sigma_x \sigma_y (n-1)}
\]

(5)

6. Multiple correlation coefficient:

\[
R_{y,x_1,x_2,\ldots,x_m} = \sqrt{\sum \beta_j r_{y,x_j}}
\]

(6)

7. Adjusted coefficient of multiple determination:

\[
D = \hat{R}^2 \cdot 100 = \left[ 1 - (1 - \hat{R}^2) \frac{(n-1)}{(n-m-1)} \right] \cdot 100
\]

(7)

8. Private F-test:

\[
F_{x_i} = \frac{R^2_{y,x_1,x_2,\ldots,x_m} - R^2_{y,x_1,\ldots,x_i-1,x_{i+1},\ldots,x_m}}{1 - R^2_{y,x_1,x_2,\ldots,x_m}} \cdot \frac{n - m - 1}{1}
\]

(8)

9. The standard error of the forecast of the mean:

\[
S_{\hat{y}} = \sqrt{\hat{\sigma}^2 x_n + (\textbf{X}'\textbf{X})^{-1} x'_{n+1}} = \sqrt{x_{n+1} S^2_{\hat{b}} x'_{n+1}}
\]

(9)

10. To test the hypothesis of equality of the forecast of the mean value of a given value, the t-statistic is calculated:

\[
t_p = \frac{\hat{y}_{n+1} - \bar{y}_{n+1,0}}{\sqrt{S^2_{\hat{y}}}}
\]

(10)
For the analysis, indicators were selected that characterize the parameters of each applied technology in order to obtain a model of the form:

\[ Y = F(x) + b_0, \]  

where \( F(x) \) is a function of several variables; 
\( b_0 \) is a free term that takes into account the residual effects of the factors included in the model.

To solve the problem of investigating the dependence of factors, the Microsoft Excel package was used.

After analyzing the data, excluding side and insignificant factors, the following results were obtained. The resulting indicator \( Y \) is the oil content parameter, and the role of the factor variables \( x_3 \), \( x_{15} \) is played by the formation turnover and acidity. The multiple correlation coefficient \( R \) is quite high, which indicates a significant dependence of oil content (\( Y \)) on the factors included in the model: formation turnover (\( x_3 \)) and acidity (\( x_{15} \)), while formation turnover is considered as a negative factor. The multiple correlation coefficient \( R \) is quite high, which indicates a significant dependence of oiliness on the factors included in the model: formation turnover and acidity:

1. **Hybrid Brio, traditional technology (Figure 1):**

\[ Y = -0.18 \cdot x_3 + 4.8827 \cdot x_{15} + 42.1793 \]

| Regression statistics |
|-----------------------|
| **Multiple R**        | 0.892841 |
| **R-square**          | 0.797165 |
| **Normalized R-square** | 0.787506 |
| **Standard error**    | 0.583069 |
| **Observations**      | 45      |

| ANOVA                  |
|------------------------|
| **df** | **SS** | **MS** | **F**  |
| Regression | 2 | 56.11701157 | 28.05850578 | 82.5324817 |
| Remainder | 42 | 14.27870843 | 0.339969248 |
| Total | 44 | 70.39572 |

| Coefficients | Standard error | Coefficients | Standard error | t-statistic | P-Value       |
|--------------|----------------|--------------|----------------|-------------|---------------|
| Y-intersection | 42.17983 | 0.420411723 | 100.3298044 | 1.1989E-51 |
| Variable X 3 | -0.18141 | 0.177766028 | -1.020470708 | 0.3133476 |
| Variable X 15 | 4.882721 | 0.380101387 | 12.84583736 | 3.8607E-16 |

**Figure 1.** Sunflower Oil Regression Analysis Parameters - Brio Hybrid, Traditional Technology.

2. **Neoma Hybrid, Clearfield Technology (Figure 2):**

\[ Y = 0.438867 \cdot x_3 + 3.7732 \cdot x_{15} + 42.9303 \]
Regression statistics

| Parameter       | Value         |
|-----------------|---------------|
| Multiple R      | 0.743068794   |
| R-square        | 0.552151233   |
| Normalized R-square | 0.530825101 |
| Standard error  | 0.849067612   |
| Observations    | 45            |

ANOVA

|          | df   | SS       | MS       | F       |
|----------|------|----------|----------|---------|
| Regression | 2    | 37.33021599 | 18.665108 | 25.89082906 |
| Remainder | 42   | 30.27846401 | 0.72091581 |         |
| Total     | 44   | 67.60868  |          |         |

| Coefficients Standard error | Coefficients Standard error | t-statistic | P-Value |
|-----------------------------|-----------------------------|-------------|---------|
| Y-intersection              | 42.93027385                 | 0.600458621 |         |
| Variable X 3                | 0.438866867                 | 0.258764884 | 1.696006275 | 0.097286223 |
| Variable X 15               | 3.773158101                 | 0.533169274 | 7.076848362 | 1.12884E-08 |

Figure 2. Sunflower Oil Regression Analysis Parameters - Neoma Hybrid, Clearfield Technology

3. Hybrid PR64YE83, technology ExpressSun (Figure 3):

\[ Y = 0.7550 \cdot x_3 + 3.4559 \cdot x_{15} + 40.0005 \]

The multiple correlation coefficient R is quite high, which indicates a significant dependence of oilfield on the factors included in the model, in particular on: the method of soil tillage.

Thus, regression analysis showed that sunflower’s oiliness is directly dependent on the method of soil treatment. The various weed protection systems of the hybrids studied and their associated sunflower growing technologies were not properly reflected in the model, since for comparison there was no zero option without their application.

The range of changes in the seeding rate from 50 to 70 thousand germinating seeds per 1 ha is not representative, since it does not have a noticeable effect on fluctuations in oilseeds.

The remaining factors that were excluded from the model reflected the biological development of plants, as well as their adaptation to different plant densities and experience conditions.

The collection of oil with 1 hectare is a summing indicator of oiliness and yield and reflects the effectiveness of oil production as a whole.

It is this indicator that determines the amount of oil produced by each creamery and in general the level of its production in the country.

Table 3-4 shows the collection of sunflower's seed oil during the study years. The largest oil collection from 1 ha (13.33 c/ha) in an average of 3 years was provided by the Neoma hybrid (Clearfield technology) on the application of plowing to a depth of 30-32 cm with a seed sowing rate of 60 thousand pcs. /ha.
Regression statistics

|                |       |
|----------------|-------|
| Multiple R     | 0.842172555 |
| R-square       | 0.709254613 |
| Normalized R-square | 0.695409594 |
| Standard error | 0.723065132 |
| Observations   | 45    |

ANOVA

|             | df | SS           | MS           | F             |
|-------------|----|--------------|--------------|---------------|
| Regression  | 2  | 53.56652398  | 26.78326199  | 51.2281451    |
| Remainder   | 42 | 21.95857379  | 0.522823186  |               |
| Total       | 44 | 75.52509778  |              |               |

| Coefficients | Standard error | Coefficients | Standard error | t-statistic | P-Value    |
|--------------|----------------|--------------|----------------|-------------|------------|
| Y-intersection | 40.00054766    | 0.55115779   | 72.57549182   | 8.9536E-46  |
| Variable X 3  | 0.075037094    | 0.026729734  | 2.807251835   | 0.00754569  |
| Variable X 15 | 3.455927971    | 0.635941079  | 5.434352466   | 2.573E-06   |

Figure 3. Parameters of regression analysis of sunflower oil - Neom hybrid, ExpressSun technology.

The sowing rate of 60 thousand pcs./ha, all other things being equal, ensured the largest oil harvest with a sunflower seed crop, a little less this indicator was noted at a sowing rate of 70 thousand pcs./ha, and the smallest - at a sowing rate of 50 thousand pcs./ha.

Production weed protection systems also influenced the overall yield and oiliness of sunflower seeds. The largest oil collections were obtained from the Neom hybrid (Clearfield technology) - 7.59-13.33 c/ha, then from the Brio hybrid (traditional technology) - 7.70-12.87 c/ha, and the smallest - from the hybrid PR64Ye83 (technology ExpressSun) - 6.70-11.62 c/ha.

The main tillage system also affected the collection of sunflower oil from 1 ha. In all years of the study, the largest oil collection from 1 hectare was obtained on the ploughing application option to a depth of 30-32 cm, a little less on the ploughing application option to a depth of 25-27 cm, then on the deep-drying application option by 30-32 cm and 25-27 cm. The smallest oil collection is obtained on soil discing options.

An important feature of the quality of sunflower seeds is the acid number of oil, which shows the content of free fatty acids in it. The value of the acid number of the oil is directly dependent on the activity of hydrolytic enzymes in the seeds, mainly lipase. The acid number of the oil is a standardized indicator of sunflower quality and is defined as the amount of mg KOH required to neutralize free fatty acids in 1 g of oil.

The acid number of vegetable oil of the same origin may vary considerably depending on the quality of the feedstock and especially the storage conditions. Under-mature seeds contain a significant amount of free fatty acids, and the oil from them is characterized by a high acid number. As the culture matures, the concentration of free fatty acids decreases and, as a result, the acid number decreases. The amount of free acids may increase with prolonged and improper storage of oils. Depending on the acid number of oil, sunflower seeds are divided into classes:

- up to 1.5 mg KOH/g belongs to the upper class;
- from 1.5 to 4.0 - to the first;
- from 4.0 to 6.0 - to the second;
- more than 6.0 - to the technical class.

Sunflower oil with a high acid number has unsatisfactory organoleptic properties and is unsuitable for nutrition, and is also oxidized faster during storage and heating, so it is subjected to alkaline
refining. However, the technological reduction of the acid number by 1 mg KOH/g is accompanied by a loss of about 1.0% oil [10].

Table 3. Oil harvesting with sunflower seeds harvest depending on sowing standards, weed protection system and soil tillage.

| Method and depth of tillage | Seed seeding rate, thousand pieces/ha | Oil collection, c/ha | 2012 | 2013 | 2014 | On average for 3 years |
|-----------------------------|-------------------------------------|----------------------|------|------|------|----------------------|
|                             | Brio Hybrid, Traditional Technology – Control |
| Plowing 25-27 cm - Control  | 50                                   | 8.96                 | 12.86| 12.17| 11.33 |
|                             | 60 (Control)                         | 9.82                 | 13.89| 12.80| 12.17 |
|                             | 70                                   | 9.43                 | 13.46| 11.54| 11.48 |
| Plowing 30-32 cm            | 50                                   | 9.43                 | 13.69| 12.63| 11.92 |
|                             | 60 (Control)                         | 10.20                | 15.07| 13.35| 12.87 |
|                             | 70                                   | 9.84                 | 14.60| 11.83| 12.09 |
| Deep loosening by 25-27 cm  | 50                                   | 7.79                 | 12.53| 10.74| 10.35 |
|                             | 60 (Control)                         | 8.23                 | 13.59| 11.26| 11.03 |
|                             | 70                                   | 8.03                 | 13.08| 10.54| 10.55 |
| Deep loosening by 30-32 cm  | 50                                   | 8.21                 | 12.88| 11.11| 10.73 |
|                             | 60 (Control)                         | 8.45                 | 13.41| 11.75| 11.20 |
|                             | 70                                   | 8.37                 | 13.14| 11.01| 10.84 |
| Disking 10-12 cm            | 50                                   | 7.04                 | 9.47 | 6.59 | 7.70  |
|                             | 60 (Control)                         | 7.61                 | 10.28| 6.95 | 8.28  |
|                             | 70                                   | 7.90                 | 11.39| 7.14 | 8.84  |
|                             | Hybrid Neoma, Clearfield technology |
| Plowing 25-27 cm - Control  | 50                                   | 9.61                 | 14.46| 11.69| 11.92 |
|                             | 60 (Control)                         | 10.35                | 15.93| 12.00| 12.76 |
|                             | 70                                   | 9.88                 | 15.45| 11.36| 12.23 |
| Plowing 30-32 cm            | 50                                   | 10.37                | 15.28| 12.39| 12.68 |
|                             | 60 (Control)                         | 10.88                | 16.49| 12.62| 13.33 |
|                             | 70                                   | 10.53                | 16.07| 11.98| 12.86 |
| Deep loosening by 25-27 cm  | 50                                   | 8.15                 | 13.87| 10.36| 10.79 |
|                             | 60 (Control)                         | 8.96                 | 14.58| 10.74| 11.43 |
|                             | 70                                   | 8.47                 | 14.22| 10.10| 10.93 |
| Deep loosening by 30-32 cm  | 50                                   | 8.47                 | 14.08| 10.66| 11.07 |
|                             | 60 (Control)                         | 9.35                 | 14.97| 10.85| 11.72 |
|                             | 70                                   | 9.02                 | 14.68| 10.55| 11.41 |
| Disking 10-12 cm            | 50                                   | 7.52                 | 9.52 | 5.73 | 7.59  |
|                             | 60 (Control)                         | 7.95                 | 11.67| 6.04 | 8.56  |
|                             | 70                                   | 8.35                 | 12.25| 6.00 | 8.86  |

Oils with a high acid number are used only for technical purposes. The high acidity of oil in seeds significantly increases its losses during industrial processing, the cost of obtaining finished products, reduces the profitability of oil plants.

Table 4. Oil harvesting with sunflower seeds harvest depending on sowing standards,
Over the years of the study, the acid number of sunflower seed oil ranged from 0.73 to 1.51 (Table 5-6), which gives reason to attribute the oil to the highest class.

Table 5. Indicators of the acid number of sunflower oil depending on sowing standards, weed protection system and soil tillage (Brio Hybrid, Traditional Technology– Control).

| Method and depth of tillage | Seed seeding rate, thousand pieces/ha | Acid number, mg KOH | Oil collection, c/ha, % On average for 3 years |
|-----------------------------|--------------------------------------|---------------------|-----------------------------------------------|
|                             | 2012 | 2013 | 2014 |
| Plowing 25-27 cm - Control  | 50   | 7.98 | 13.53 | 9.92 | 10.48 |
|                             | 60 (Control) | 8.87 | 13.89 | 10.44 | 11.06 |
|                             | 70   | 8.53 | 13.66 | 9.26  | 10.48 |
| Plowing 30-32 cm            | 50   | 8.45 | 13.77 | 10.25 | 10.83 |
|                             | 60 (Control) | 9.08 | 15.25 | 10.52 | 11.62 |
|                             | 70   | 8.65 | 14.98 | 9.97  | 11.20 |
| Deep loosening by 25-27 cm  | 50   | 6.86 | 12.86 | 8.13  | 9.28  |
|                             | 60 (Control) | 7.07 | 13.46 | 8.36  | 9.63  |
|                             | 70   | 7.02 | 13.24 | 7.86  | 9.27  |
| Deep loosening by 30-32 cm  | 50   | 7.19 | 13.41 | 8.35  | 9.65  |
|                             | 60 (Control) | 7.40 | 14.60 | 8.58  | 10.19 |
|                             | 70   | 7.28 | 14.17 | 8.20  | 9.89  |
| Disking 10-12 cm            | 50   | 6.08 | 9.47  | 4.55  | 6.70  |
|                             | 60 (Control) | 6.64 | 10.87 | 5.04  | 7.52  |
|                             | 70   | 6.96 | 12.01 | 4.31  | 7.76  |

The lowest indicator of the acid number of oil was in 2012, and the largest in 2013, due to weather conditions during the formation and filling of seeds.
Table 6. Indicators of the acid number of sunflower oil depending on sowing standards, weed protection system and soil tillage.

| Method and depth of tillage | Seed seeding rate, thousand pieces/ha | Acid number, mg KOH | 2012 | 2013 | 2014 | On average for 3 years |
|-----------------------------|--------------------------------------|---------------------|------|------|------|------------------------|
| **Brio Hybrid, Traditional Technology – Control** | | | | | | |
| Plowing 25-27 cm | 50 | 1.12 | 1.38 | 1.06 | 1.19 |
| Control | 60 (Control) | 0.95 | 1.31 | 0.78 | 1.01 |
| Plowing 30-32 cm | 50 | 1.04 | 1.35 | 0.86 | 1.08 |
| 60 (Control) | 0.94 | 1.29 | 0.75 | 0.99 |
| Deep loosening by 25-27 cm | 50 | 0.85 | 1.31 | 0.95 | 1.04 |
| 60 (Control) | 0.78 | 1.41 | 1.21 | 1.13 |
| Deep loosening by 30-32 cm | 50 | 0.86 | 1.38 | 1.01 | 1.08 |
| 60 (Control) | 0.75 | 1.31 | 0.89 | 0.98 |
| Disking 10-12 cm | 50 | 0.91 | 1.38 | 0.98 | 1.09 |
| 60 (Control) | 0.88 | 1.45 | 0.89 | 1.07 |
| **Hybrid Neoma, Clearfield technology** | | | | | | |
| Plowing 25-27 cm | 50 | 0.93 | 1.34 | 0.87 | 1.05 |
| Control | 60 (Control) | 1.12 | 1.37 | 0.94 | 1.14 |
| Plowing 30-32 cm | 50 | 0.85 | 1.43 | 0.94 | 1.07 |
| 60 (Control) | 0.78 | 1.32 | 0.88 | 0.99 |
| Deep loosening by 25-27 cm | 50 | 0.85 | 1.40 | 0.86 | 1.04 |
| 60 (Control) | 1.08 | 1.31 | 0.87 | 1.09 |
| Deep loosening by 30-32 cm | 50 | 0.94 | 1.41 | 0.85 | 1.07 |
| 60 (Control) | 0.88 | 1.29 | 0.78 | 0.98 |
| Disking 10-12 cm | 50 | 0.78 | 1.35 | 0.96 | 1.03 |
| 60 (Control) | 0.85 | 1.42 | 1.01 | 1.09 |
| On average, during the three years of the study, the indicators of oil acidity varied slightly - in the range from 0.99 to 1.19%, that is, within 0.2%.

With a seed sowing rate of 60 thousand pcs./ha, all other things being equal, on average, for three years the lowest indicator of the acid number of oil obtained from sunflower seeds was noted.

As the results of calculations show, the most effective way of cultivating the soil when growing three hybrids is the traditional deep plowing with a seam turnover. When growing the Brio hybrid, the level of profitability on the option of using plowing at different depths was 91.2–115.2%, which is 4.4–10.8 percentage points higher than on the options for using deep loosening, and by 41.3–51.8% - than on disc options. When growing Hybrid Neoma, the level of profitability on the options for plowing was in the range from 95.9 to 117.1%, which is 7.8–9.5 percentage points higher than the
indicators of the option of using deep loosening and by 49.6–57.3 % indicators of the disk option. When growing a hybrid PR64E83, the level of profitability on the options for plowing was 89.0–109.5%, which exceeded the indicators of the options for deep loosening and disking.

4. Conclusion
There were no significant differences in the applications of different technologies for protecting crops from weeds. Also, there was no noticeable effect on the acidity of sunflower seeds by various methods and the depth of soil treatment.

When growing sunflower with different seeding rates and different weed control systems, the best indicators were obtained when using autumn plowing at a depth of 30–32 cm, as well as 25–27 cm in comparison with moldboard loosening at the same depth and minimal processing with discs on depth 10–12 cm.

Production verification and implementation of the results was carried out in the farms of Pavlovskaya Niva CJSC of the Pavlovsky District of the Voronezh Region and Agrosoyuz Agro-Industrial Complex JSC of the Bogucharsky District of the Voronezh Region.

According to the economic assessment, the option of growing the Neoma hybrid sunflower using the Clearfield technology with a seeding rate of 60 thousand viable seeds per hectare by plowing the soil to a depth of 30–32 cm showed the greatest economic effect - an increase in income by 4238 rubles per hectare, in comparison with the technology used on the farm.

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