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The impact of environmentally balanced agricultural systems on changes in the agrophysical state of typical chernozem soil and the energy management of sunflower cultivation

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ABSTRACT

The relevance of the studies lies in developing methods for primary tillage of soil under sunflower that significantly affect agrophysical indicators. This task acquires special importance under conditions of unstable and insufficient moisture. It is expected to improve the agrophysical properties that would impact the soil's moisture balance and control of crop weeds, which would subsequently allow obtaining high yields. Therefore, the need to develop such methods of primary tillage under row crops, primarily under sunflower, becomes urgent. The study took place in the left-bank forest-steppe zone of Ukraine (Sumy region), utilizing typical low-humus chernozem soil throughout the years 2023–2024. It was found that the largest reserves of productive moisture in the arable horizon at the time of sunflower sowing with plowing at 20–22 cm were 16.9 mm, and the smallest at no-till disc cultivation were 16.4 mm. At the time of harvest, the moisture reserves significantly reduced to a critical level, namely to 0.6–1.0 mm in the arable horizon and to 24.0–25.8 mm in the meter horizon. During the sunflower's germination period, the density of the arable layer soil remained within the optimal range across all soil treatment methods, with values for plowing ranging from 1.14 to 1.24 g/cm^3, deep loosening – 1.17–1.26 g/cm^3, no-till treatment with a heavy cultivator at 12–14 cm – 1.22–1.28 g/cm^3, and disc cultivation at the same depth – 1.20–1.27 g/cm^3. The density of the arable horizon under sunflower increased more significantly at plowing than at no-till treatments from plant emergence to harvest. The yield of sunflower seeds in the variant with plowing was the highest – 3.28 t·ha^{-1}. Soil treatments without turning the soil, both deep at 35–40 cm and shallow at 12–14 cm, led to a significant decrease in sunflower seed yield by 0.40–0.71 t·ha^{-1} at LSD_{05} – 0.04 t·ha^{-1}. The coefficient of energy efficiency was lowest at plowing under sunflower – 2.6. As the energy intensity of the sunflower yield decreased at no-till soil treatments without turning the soil, it increased to 3.0–3.3.

Keywords: productive moisture, soil density, energy assessment, crop structure, bulk soil mass, water-physical properties, management, biological activity.

INTRODUCTION

The main and unchanging natural resource upon which the success in agriculture depends is soil. Therefore, in modern conditions, the question of the necessity to introduce new methods of primary tillage under row crops, which would regulate its agrophysical parameters, is very acute. Purposeful regulation of the physical state of the soil, water, air, thermal, and nutritional regimes ensures the necessary conditions for the growth and development of agricultural plants

[Jursík et al., 2015; Baylis and Dicks, 2020; Kolisnyk, 2024].

In recent years, significant changes in weather and climatic conditions have occurred, the number of extreme, drought years has increased, and the dependence on them of the quantity and quality of the harvest of agricultural crops, especially in the Forest-Steppe zone of Ukraine, has intensified [Voitovyk et al., 2023; Datsko et al., 2024a].

The ways to increase the yield in modern conditions of agricultural production should be based on the comprehensive implementation of technological operations within set timelines with strict compliance with agronomic requirements [Yankov and Drumeva, 2021; Datsko et al., 2025].

Sunflower (*Helianthus annuus* L.) is one of the most important and widespread oil crops in the world, the cultivation of which largely depends on water supply. Its cultivation depends on many factors, among which the provision of plants with moisture is crucial. The effectiveness of water consumption determines the yield, seed quality, and the expediency of using resources. Moisture conditions, climatic factors, methods of soil cultivation, and agronomic measures directly affect the water consumption of sunflower [Gulya et al., 2019; Hryhoriv et al., 2022; Dehodiuk et al., 2024].

Research has determined that insufficient soil moisture not only negatively affects plant development but also significantly reduces the effectiveness of individual agronomic measures [Tsyliuryk, 2017]. Ground moisture reserves are the main reason for fluctuations in sunflower productivity levels. Scientists have substantiated that better-moisturized crops form a higher yield of seeds. Precipitation that falls in autumn, winter, and at the beginning of the vegetative period plays an important role in this process [Tanchyk and Salnikov, 2013; Tsylyuryk and Sudak, 2014; Litvinov et al., 2020].

In the complex of agronomic measures aimed at increasing the productivity of agricultural crops, the primary tillage of the soil occupies an important place. The main task of its under sunflower is to maximize the destruction of perennial and annual weeds, accumulate and preserve as much moisture as possible from autumn-winter and early spring precipitation in the root zone, and mobilize nutrients [Markell et al., 2015; Mishchenko et al., 2024a; Kolisnyk et al., 2024a].

Primary tillage of the soil improves the agro physical properties of the arable layer, regulates biochemical processes occurring in the soil environment. Only through mechanical action on the soil by the working bodies of machines and implements can optimal conditions be created for the development of the roots of cultural plants, the realization of the high efficiency of ameliorants, fertilizers, and uniform water consumption [Spitzer et al., 2018; Kolisnyk et al., 2020; Karbivska et al., 2022a].

When determining the method of soil cultivation under row crops, particularly sunflower, it is necessary to consider the type of soil, weather-climatic conditions, biological properties of plants, and their requirements for the cultivation technology in crop rotation. The effective impact of mechanical action on the soil is intensified when the depth, methods, and measures of cultivation are carried out in a scientifically justified sequence and in close interaction with all links of the agricultural system. At the same time, it should be considered that excessive cultivation can lead to soil degradation, loss of its fertility, and increased unnecessary costs. The soil cultivation system needs to be constantly refined in connection with the improvement of zonal crop cultivation technologies [Voytovyk et al., 2024; Kolisnyk et al., 2024b].

In regions of unstable and insufficient moisture of the Forest-Steppe, the main task of primary tillage is to create conditions for the maximum accumulation and preservation of moisture in the soil and the destruction of weeds. The timing and technology of soil cultivation are determined by the time of harvesting the predecessor [Kvitko et al., 2021; Kovalenko et al., 2024].

In different soil-climatic zones of Ukraine under sunflower, autumn differentiated tillage is applied, namely, plow (plowing) and no-till (chisel, flat-cut, combined) methods of cultivation. Each of the above methods has its advantages. However, giving a definitive answer when choosing them is quite difficult, which largely depends on the preferences of the farm, soil-climatic conditions, type of soils, and available equipment [Zając et al., 2020; Karbivska et al., 2022b; Mishchenko et al., 2022].

Quality and timely primary tillage of the soil is one of the most important stages in the formation of future yields. Since sunflower has a taproot system, it should be considered that for its development the soil should be well structured, with the absence of harmful compactions (for example, “plow sole”), which during the growth and development of the root system can hinder its penetration into deeper soil layers for moisture assimilation. Technological operations in the autumn period should be aimed at the distribution of post-harvest residues and maximum leveling of the field, good soil structuring, so that in the spring period it is possible to reduce the number of its treatments and moisture losses [Legris et al., 2017; Sikora et al., 2020; Mishchenko et al., 2024b].

The relevance of the research lies in developing methods of primary tillage of the soil under sunflower, which significantly affect agrophysical indicators. This task acquires special importance under conditions of unstable and insufficient moisture. There are no universal solutions when choosing technology for primary tillage of the soil, but the main goal is expected to improve the agrophysical characteristics, which are anticipated to influence the soil's moisture conditions and the control of weeds in the crops, which would subsequently allow obtaining high yields. Therefore, nowadays, the need to develop such methods of primary tillage of the soil under row crops, primarily under sunflower, becomes urgent.

MATERIAL AND METHODS

Field experiments were carried out at the Institute of Agriculture of the north-east of Ukraine (left-bank forest-steppe) during 2023 and 2024. Coordinates of the experimental plots 50°53'22.3"N latitude, 34°42'34.1"E longitude, 137.7 m above sea level (Map data© 2025 Google).

Soil cover – typical chernozem with little humus. The humus content was from 4.2 to 4.8%. The acidity index of the soil environment (saline pH) was at the level of – 6.0 and 7.9 (aqueous pH). The granulometric composition of the soil (according to Kaczynski) was coarse-grained and medium loamy. In the volume of the soil 0–20cm, physical clay (size from 0.05 to 0.01) was 49.1–52.1%, silt (particles less than 0.001 mm) was 23.4–25.5%.

The weather over the past years has changed significantly. The average daily air temperature has noticeably increased and reduced the effectiveness of plant utilization of precipitation due to its evaporation, leading to drought conditions. The average annual air temperature during the years of the study was 9.8 °C. This is 2.4 °C higher than the multi-year average of 7.4 °C. The maximum temperature of 36.0 °C was recorded in the second decade of July, and the lowest temperature was from January 1 to 10 (-21.0 °C). The amount of precipitation for 2023–2024 was 491 mm, which was 102 mm less than the multi-year average (593 mm).

The experimental design includes four variants of primary soil cultivation under sunflower: 11. Plowing to 20–22 cm (Control); 2. Deep soil loosening to 35–40 cm; 3. No-till treatment using a complex cultivator to depth of 12–14 cm; 4. No-till disc cultivation also to depth of 12–14 cm.

The study was carried out using a field crop rotation system: buckwheat (*Fagopýrum esculéntum*), winter wheat (*Triticum aestivum*), sunflower (*Heliantus annuus*), and spring barley (*Hordeum vulgare*). The arrangement of variants and replications was systematic, with each being replicated three times. Except for primary soil cultivation, the agronomic practices employed for crop cultivation were standard for this region.

Phenology of sunflower development in the experiment (average for 2023–2024): Sowing – May 24, June 04 – seedlings, June 07 – the first pair of true leaves, June 18 – phase 4–6 leaves, July 10 – star phase, July 23 – flowering, September 23 – ripening. The duration of the growing season is 122 days. No significant difference in the passage of sunflower development phases was observed across the experiment variants (deviation by year ± 1 day).

Research methods: to achieve the set goal, we use generally recognized research methods: field and visual to establish phenological phases of plant development, biometric records and measurements; laboratory – to determine the agrophysical properties of the soil, determine the structure of the crop; calculation – to assess the economic and energy efficiency of soil cultivation methods; mathematical and statistical – to assess the reliability of differences between experimental variants.

Phenological observations, studying the peculiarities of growth and development of plants were conducted according to the "Methodology for conducting expertise of plant varieties of the group of cereals, groats, and legumes for suitability for dissemination in Ukraine" [Maliyenko et al., 2017, 2020]. The bulk soil mass (soil compaction) was determined by the cutting ring method by Kachinsky [1965]. The actual soil moisture was determined by the thermostatic-gravimetric method, which meets the requirements of DSTU B V.2.1-17:2009 [Altukhova et al., 2010]. The processing of research results and evaluation of their reliability were carried out using the standard statistical approach based on the ANOVA model.

RESULTS AND DISCUSSION

Moisture is one of the main factors of life. It is critically important for the growth and development of plants, but to a large extent, it affects the growth and size of the harvest. Both excessive and insufficient moisture adversely affect plants, as in both cases they cannot fully utilize heat resources to accumulate their mass and create an optimal harvest.

Moisture reserves in the soil depend on many factors, especially its permeability and the degree of evaporation from its surface. These properties of the soil depend on its structure, which can be altered by methods of soil cultivation [Maslak and Radchenko, 2010; Gulya et al., 2019].

Moisture reserves during the period of sunflower sowing, primarily depended on the weather conditions of the year and agronomic practices and were crucial for obtaining uniform emergence and further development of the cultivated plants. Thanks to spring atmospheric precipitation, soil moisture reserves were replenished in all experiment variants. At the same time, at the beginning of the vegetation period, the availability of moisture in the soil had significant differences (Table 1).

During the sunflower sowing period, the maximum amount of available moisture in the 0–100 cm soil layer was recorded in the control variant at 118.2 mm. In other plots, depending on the soil cultivation, the moisture content was 0.4–6.7 mm less than the control. Additionally, it is important to mention that at the time of sowing, the levels of available moisture in the 0–20 cm soil layer were favorable, varying between 16.4 and 16.9 mm across different experimental variants. Moisture reserves in the layer 0–50 cm in the variant with cultivation with delta NT tines were 60.4 mm and were at the level with the control variant – plowing. In the variants with no-till treatments with heavy cultivators and discs, they decreased relative to plowing by 2.5 and 3.0 mm respectively.

At harvest time, the available moisture reserves in the one-meter soil layer showed no significant differences among the tested variants. Specifically, the variant with deep loosening had 0.2 mm less moisture compared to the control, the no-till heavy cultivator variant at a depth of 12–14 cm had 1.5 mm less, and the discing variant at the same depth had 1.8 mm less than the control.

The bulk soil mass is important indicators of its agrophysical state and serves as the primary agronomic characteristic, reflecting its structure, water-physical properties, and biological activity. The water, air, thermal, and nutrient regimes, as well as the life activities of soil flora and fauna, entirely depend on the magnitude of the soil's bulk mass [Zając et al., 2020; Mishchenko et al., 2025].

The process of soil cultivation is primarily directed towards regulating its bulk mass. The assessment of the soil's bulk mass in our studies was conducted according to Kachinsky [1965].

One of the conditions for achieving high and stable yields of field crops is the optimal density of the arable layer (bulk mass), which significantly depends on the method and intensity of mechanical soil cultivation [Mathew et al., 2018; Datsko et al., 2024b].

In Table 2, data are presented on the soil compaction density in the sunflower field depending on

Table 1. Impact of initial soil cultivation techniques on moisture levels in a sunflower field, mm (2023–2024)

Variant	Time of sampling											
	Sowing						Harvesting					
	Horizon (cm)											
	0 to 20	To control	0 to 50	To control	0 to 100	To control	0 to 20	To control	0 to 50	To control	0 to 100	To control
Plowing to 20–22 cm (control)	16.9	–	61.7	–	118.2	–	1.0	–	12.4	–	25.8	–
Deep soil loosening to 35–40 cm	16.6	-0.3	60.4	-1.3	117.8	-0.4	0.9	-0.1	11.9	-0.5	25.6	-0.2
No-till treatment using a complex cultivator to depth of 12–14 cm	16.6	-0.3	59.2	-2.5	112.0	-6.2	0.8	-0.2	11.6	-0.8	24.3	-1.5
No-till disc cultivation to depth of 12–14 cm	16.4	-0.5	58.7	-3.0	111.5	-6.7	0.6	-0.4	11.4	-1.0	24.0	-1.8

the methods of primary soil cultivation. The density of soil compaction in the arable layer during the sunflower germination period was within optimal values for growing this crop across all variants of primary soil cultivation and varied within the following ranges: plowing – 1.13–1.22g/cm³, deep loosening – 1.16–1.26 g/cm³, no-till treatment with a heavy cultivator – 1.18–1.26 g/cm³, and disc cultivation – 1.17–1.25 g/cm³.

With no-till treatment using a heavy cultivator and discs, due to the reduced depth of loosening to 12–14 cm, compaction of the 10–20 cm layer was noted compared to turning the sod under sunflower, respectively by 0.07 and 0.05 g/cm³. The least compacted layer across all variants was the surface 0–10 cm layer of soil, because the methods of soil cultivation ensured its sufficient loosening. It should be noted that all studied methods of primary soil cultivation under sunflower provided optimal density, which did not exceed the optimal indicators (1.3 g/cm³).

In sunflower crops, the soil compaction density increased from germination to harvesting across all primary cultivation methods and the studied soil layers. Reducing the depth of cultivation led to an increase in the soil compaction density in the untreated layers. Thus, at the end of the vegetation, the maximum soil density in the 20–30 cm layer was recorded after cultivation with a complex cultivator to a depth of 14 cm (respectively 1.29 and 1.3 g/cm³). The minimum soil density in the top 0–10 cm layer was observed in fields where plowing to a depth of 20–22 cm was conducted, with densities of 1.19 g/cm³ in maize and 1.2 g/cm³ in sunflower.

In the lower horizon of the 30–40 cm layer, a trend towards decreasing soil density was observed. On average, over the vegetation period, the soil density of the arable layer under sunflower increased after no-till cultivation with heavy cultivators and discs compared to plowing.

From the above material, it can be concluded that in the sunflower field, the soil compaction density increased from germination to harvesting across all variants of the experiment, but remained within optimal values.

The total porosity of the soil in the studies was evaluated according to Kachinsky [1965]. Corresponding to the density indicators, the soil porosity was also determined. For tillage to a depth of 20–22 cm, in the 0–10 cm soil layer, it was 55.3% at the beginning of the sunflower

Table 2. Effects of basic soil cultivation techniques on soil compaction in a sunflower field, 2023–2024

Soil layer (cm)	Soil density, g/cm³			Total porosity, %		
	Germination	Harvesting	Average for vegetation period	Germination	Harvesting	Average for vegetation period
	Plowing to 20–22 cm					
0–10	1.14	1.20	1.17	55.3	53.8	54.6
10–20	1.20	1.24	1.22	53.6	51.7	52.7
20–30	1.24	1.26	1.25	51.9	50.4	51.2
30–40	1.18	1.24	1.21	52.5	51.5	52.0
Deep soil loosening to 35–40 cm						
0–10	1.17	1.22	1.20	54.8	52.3	53.6
10–20	1.22	1.26	1.24	52.5	51.2	51.9
20–30	1.25	1.27	1.26	51.0	50.8	50.9
30–40	1.26	1.28	1.27	50.8	49.7	50.3
No-till treatment using a complex cultivator to depth of 12–14 cm						
0–10	1.22	1.24	1.23	52.8	52.7	52.8
10–20	1.27	1.28	1.28	50.5	50.9	50.7
20–30	1.28	1.30	1.29	49.6	50.0	49.8
30–40	1.24	1.27	1.26	51.0	51.2	51.1
No-till disc cultivation to depth of 12–14 cm						
0–10	1.20	1.22	1.21	53.9	53.5	53.7
10–20	1.25	1.27	1.26	51.2	51.4	51.3
20–30	1.27	1.28	1.28	51.8	50.8	51.3
30–40	1.22	1.26	1.24	52.3	52.0	52.2

vegetation period and 53.8% before harvesting. The lowest porosity was found in no-till cultivation with heavy cultivators and discs to a depth of 14 cm in the 10–20 cm soil layer.

The generative development and productivity of sunflower plants were entirely dependent on the methods of primary soil cultivation. The mass of seeds from the head showed significant variations among the studied variants. The highest seed mass from the head formed in plants from the plot where the primary soil cultivation was plowing to a depth of 20–22 cm – 58.6 g, and the lowest was with no-till disc cultivation at 12–14 cm – 45.4 g (Table 3).

No-till disc cultivation to a depth of 12–14 cm led to a reduction in seed mass from the head to 45.9 g, which is 12.7 g less than the control.

Seed yield is the main criterion characterizing the effectiveness of the studied methods of primary soil cultivation. Table 4 presents the levels of sunflower seed yield for the experimental variants.

In the reporting year, a good sunflower harvest was formed. For this crop, plowing was an appropriate method of soil cultivation, which provided the highest level of yield productivity – 3.28 t ha^{-1}. A decrease in seed yield of 0.4 t ha^{-1} was noted for cultivation with a heavy cultivator at a depth of 12–14 cm. A lower yield relative to plowing was observed in the no-till disc cultivation variant at a depth of 12–14 cm, which was 2.57 t ha^{-1}, 0.71 t less than the control variant (plowing up to a depth of 20–22 cm).

Thus, the methods of primary soil cultivation under sunflower without turning the sod led to an increase in soil density in the 0–20 cm horizon and the subsoil horizon, where the main mass of the plant's root system is located, which significantly reduced the yield by 0.4–0.71 t compared to plowing, with an LSD_{05} of 0.04 t ha^{-1}.

In today's market conditions of agriculture, it is important that the elements of cultivation technology developed and implemented in production reduce energy costs, lower the cost of production per unit, and increase productivity. Modern, scientifically based cultivation technologies for field crops, including the cultivation of maize for grain and sunflower, should be energy-efficient and economically viable.

Efficiency reflects the final result from the utilization of all production resources and is determined by comparing the outcomes obtained to the costs of production resources. It is well-known that one of the most energy-intensive stages of mechanized work in the cultivation of row crops is the primary soil cultivation, which accounts for up to 50% of the fuel and energy costs [Malienko et al., 2020; Radchenko et al., 2023].

The evaluation of sunflower cultivation technology with different primary soil cultivation methods was conducted using a commonly accepted methodology that allows for the assessment of technology variants based on yield levels, cost of production per unit, profitability per hectare of sown area, and profitability level (Table 5).

Efficiency calculations demonstrated that the highest profit indicator – €1161.0 per hectare and profitability – 193.0% were achieved with

Table 3. Structure of sunflower seed yield depending on the main soil cultivation methods, 2023–2024

No.	Methods of main soil cultivation	Head diameter, cm	Seed mass from head, g
1	Plowing to 20–22 cm	15.0	58.6
2	Deep soil loosening to 35–40 cm	14.9	48.7
3	No-till treatment using a complex cultivator to depth of 12–14 cm	14.8	53.3
4	No-till disc cultivation to depth of 12–14 cm	14.3	45.9

Table 4. Sunflower seed yield productivity in dependence on the methods of main soil cultivation, 2023–2024

No.	Methods of main soil cultivation	Yield, t ha^{-1}	Difference from control, t ha^{-1}
1	Plowing to 20–22 cm (control)	3.28	-
2	Deep soil loosening to 35–40 cm	2.63	-0.65
3	No-till treatment using a complex cultivator to depth of 12–14 cm	2.88	-0.4
4	No-till disc cultivation to depth of 12–14 cm	2.57	-0.71
LSD_{05}, t ha^{-1}		0.04	

Table 5. Metrics of performance in sunflower production across various primary soil cultivation techniques, 2023–2024

No.	Methods of primary soil cultivation	Total costs, € ha^{-1}		Profit, € ha^{-1}	Calculated profitability level, %
		For the entire technology	Including for primary cultivation		
1	Plowing to 20–22 cm	601.1	46.4	1161.0	193.0
2	Deep soil loosening to 35–40 cm	603.8	49.1	809.1	134.0
3	No-till treatment using a complex cultivator to depth of 12–14 cm	586.3	31.7	960.8	164.0
4	No-till disc cultivation to depth of 12–14 cm	580.1	25.5	800.5	138.0

plowing up to a depth of 20–22 cm due to higher grain yield.

Energy analysis is necessary to evaluate cultivation technologies with the aim of ensuring rational use of energy types: consumed and reproduced by the crop. Soil cultivation units used in the experiment for primary cultivation at various depths under row crops in a four-field crop rotation significantly differed in labor productivity and the use of materialized non-renewable energy. Therefore, an evaluation of the energy intensity of the methods of primary cultivation under sunflower was conducted. Based on the calculations carried out, the energy costs per hectare were determined (Table 6).

Determining the energy intensity of sunflower cultivation technology, based on different methods and depths of primary soil cultivation, made it possible to establish that reducing the costs of carrying out primary cultivation in various experimental variants had a minor impact on the overall energy intensity of the cultivation technology.

Labor, material, and financial resources used in the production of sunflower grain have a single energy basis, which allows for the use of energy analysis of the technologies applied.

The variant involving plowing demonstrated the greatest energy intensity for the sunflower crop, registering 5848 MJ ha^{-1}. Energy intensity was reduced by 1159 MJ ha^{-1} with deep loosening down to 35–40 cm, and by 713 and 1266 MJ ha^{-1} with no-till cultivation using heavy cultivators and discs at depths of 12–14 cm, respectively. The energy efficiency coefficient was lower with plowing under sunflower, at 2.6. As the energy intensity of the crop decreased with no-till cultivation methods without turning the sod, it increased to 3.0–3.3.

CONCLUSIONS

From our research, it was established that the highest reserves of productive moisture in the plow layer at the time of sunflower sowing with plowing at 20–22 cm were 16.9 mm, and the lowest were with no-till disc cultivation at 16.4 mm. By the time of harvest, moisture reserves significantly decreased to a critical level, namely to 0.6–1.0 mm in the plow layer and to 24.0–25.8 mm in the meter layer. The soil compaction density in the plow layer during the sunflower germination period was within optimal values for all variants of soil cultivation and was 1.14–1.24 g/cm^3 for plowing, 1.17–1.26 g/cm^3 for deep loosening, 1.22–1.28 g/cm^3 for no-till cultivation with a heavy cultivator at 12-14 cm, and 1.20–1.27 g/cm^3 for disc cultivation at the same depth. The soil compaction density in the 20–40 cm horizon tended to increase and was

Table 6. Energy efficiency of sunflower cultivation depending on the methods of primary soil cultivation, 2023–2024

Methods of primary soil cultivation	Yield, t ha^{-1}	Energy input per crop, MJ ha^{-1}	Energy input per technology, MJ ha^{-1}	EEC*
Plowing to 20–22 cm	3.28	5848	15407	2.6
Deep soil loosening to 35–40 cm	2.63	4689	15410	3.3
No-till treatment using a complex cultivator to depth of 12–14 cm	2.88	5135	15194	3.0
No-till disc cultivation to depth of 12–14 cm	2.57	4582	15157	3.3

Note: * Energy efficiency coefficient.

more intense in no-till treatments at a depth of 12–14 cm, from 1.24–1.26 g/cm³ with plowing to 1.26–1.30 g/cm³. Thus, the compaction density of the plow layer under sunflower increased more significantly with plowing than with no-till treatments from plant emergence to harvest.

Analysis of the impact of the main tillage options on the structure of sunflower yield showed that the mass of seeds per cob was 58.6 g when plowing at 20–22 cm, which is 12.7 g more than with no-till disc cultivation at 12–14 cm. Accordingly, the sunflower seed yield in the variant with plowing was the highest – 3.28 t ha^{-1}. Soil treatments without turning the sod, both deep at 35–40 cm and shallow at 12–14 cm, led to a significant decrease in sunflower seed yield by 0.40–0.71 t ha^{-1} with LSD_{05} – 0.04 t ha^{-1}.

The highest profit from growing sunflower was obtained with plowing at 20–22 cm, amounting to €1161.0 per hectare. At the same time, the calculated profitability level was 193.0 percent. The energy efficiency coefficient was lower with plowing under sunflower – 2.6. As the energy intensity of the sunflower crop decreased with no-till soil treatments without turning the sod, it increased to 3.0–3.3.

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