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RESEARCH ARTICLE

Yield and energy efficiency of sunflower cultivation under different primary soil tillage methods

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Abstract

Under conditions of typical medium-loam black soil (Sumy region, Ukraine), it has been demonstrated that the productive moisture reserve either depends on the tillage method (plowing, deep loosening, disking) or may not depend, depending on the weather conditions during the research years. The highest soil moisture values were obtained with plowing and deep loosening. The highest sunflower yield was achieved with plowing in the research years of 2022 and 2023, reaching 2.86 t ha^{-1} and 2.51 t ha^{-1}, respectively. When assessing the energy efficiency of the studied tillage methods, it should be noted that plowing is the most energy-consuming and costly. The energy efficiency coefficient was highest with deep loosening.

Keywords: Soil fertility, Chernozem, Tillage, Disking, Soil moisture, Sunflower, Yield, Energy efficiency coefficient

Introduction

The selection of tillage tools occurs in both intensive and organic farming to reduce the presence of competitive plants and improve or stabilize the structural-aggregate composition of the soil, maintaining physical parameters at an appropriate level, without causing soil over compaction (Mischenko et al., 2024). The equipment should not compact the soil, as this could prevent seedlings from emerging or hinder their development. Often, at field turn-around areas, compacted and heavily trafficked zones can be observed, where water stagnates.

According to Antonets S., as cited in the book by (Pisarenko et al. 2016), soil tillage destroys the most valuable gift of nature given to human beings. Over the past hundred years, intensive degradation processes have occurred due to the intensification of soil tillage, leading to humus loss and an increase in mineralization processes.

Minimal tillage helps prevent the formation of a plow pan, as evidenced by research in the black soil zone, according to the results of Poltava scientists (Pisarenko, 2018). In this case, the plant root mass is merely cut, not removed or brought to the surface, preserving microchannels created by plant roots and earthworms. Scientists argue that this preserves vertical soil aeration.

Azuka 2024, through his experiments, demonstrated a significantly more positive impact of moldboard plowing compared to no-till on such parameters as infiltration capacity (63% higher), saturated hydraulic conductivity (+5.83 cm h^{-1}), and total porosity (by 10%).

Iancu et al. 2010, conducting research in Băilești-Dolj, Romania, in conditions of black soil with 3.1% organic matter content and clayey texture, determined that the best tillage option for sunflower cultivation was a combination of deep plowing, subsequent disking, and herbicide application. This method allowed for obtaining nearly 3.2 t ha^{-1} of sunflower seeds, positively influencing the mass of 1000 grains, oil content, head diameter, etc.

Dehtiarova et al. 2023 have in turn proven that the saturation of crop rotations with sunflower does not lead to a deterioration in fertility indicators of typical heavy loamy chernozem (Left-Bank Forest-Steppe of Ukraine). A correlation has been established between sunflower seed yield and agrophysical soil parameters.

Scientists conducting research in drier conditions in southern Ukraine on chernozem soils have shown that shallow tillage with the retention of mulch from crop residues is more appropriate compared to plowing and combined tillage systems. It positively affects the structural-aggregate state of the soil and the yield of crop rotations (Tsyliuryk et al., 2022).

Regarding moisture retention in the soil, it has been proven that in the conditions of the South Dobrudzha region (Bulgaria) on slightly alkaline chernozems, no difference in the percentage of field moisture capacity was observed under normal rainfall conditions between plowed and non-plowed tillage options (Yankov & Drumeva, 2021a). Plowing and chisel tillage contributed more to the accumulation of productive moisture during periods of excessive rainfall. In dry periods, non-plow tillage systems, such as shallow disk harrowing and no-till, proved to be the most effective, as they preserved more moisture under the crop residues.

Scientists conducting research in the Dnipropetrovsk region on ordinary chernozem also confirm that the use of plow-based tillage promotes root mass branching, microbiological activity, air availability, and productive moisture for plants, as well as the further mineralization of residues (Tsyliuryk et al., 2024). However, when selecting tillage without soil inversion, soils gain anti-erosion stability and more intensive humification. The advantage of no-till in crop rotation in Central Europe for moisture conservation in the soil has also been demonstrated by (Gelybó 2022) for cereal crops, but not for sunflower. Yankov & Drumeva 2021b indicate that in no till and disk harrowing systems, plant development at the early stages slowed down, affecting the biometric parameters, except for the sunflower head diameter. The scientists highlight chisel tillage to a depth of 24 cm-26 cm as the most optimal for uniform and optimal placement of sunflower seeds during sowing (compared to plowing to the same depth, disking, and no till systems).

As we can see from the reports of scientists, there are some discrepancies in results under different soil and climatic conditions, but there is a tendency towards choosing minimal non-inversion tillage under conditions of insufficient atmospheric precipitation.

Materials and Methods

The research was conducted in the fields of a stationary experiment of the Department of Agriculture of the Institute of Agriculture of the North-East (Sad village, Sumy district, Sumy region). The soil cover of the experimental field is typical low-humus slightly leached chernozem with a coarse-silty medium loamy texture, with the following agrochemical indicators of the arable layer (at the time of the experiment's establishment): humus content by Tyurin method 4.2%-4.8%; salt pH 6.0; water pH 7.9; content of easily hydrolyzable nitrogen by Kornfield – 107; mobile compounds of P_2O_5 and K_2O by Chirikov, respectively, 62.7 mg and 67.5 mg per 1 kg of soil. The granulometric composition of the soil by Kachynskyi is coarse-silty-medium-loamy: in the 0-20 cm layer, the physical clay (particles 0.05-0.01 mm) is 49.1%-52.1%, silt (particles less than 0.001 mm) is 23.4%-25.5%.

The experiment scheme includes 4 variants of primary tillage for sunflower in the rotation from 4 crops:

- Plowing to a depth of 20 cm-22 cm (Control);
- Deep soil loosening to a depth of 35 cm-40 cm;
- Husking disk cultivation to a depth of 12 cm-14 cm;
- Stubble cultivation (by light cultivator) to a depth of 12 cm-14 cm.

The research is conducted in four field crop rotations: the first rotation includes buckwheat, winter wheat, sunflower, barley. The placement of the variants and repetitions is systematic, with three repetitions. The cultivation techniques for growing crops, except for the primary tillage, are generally accepted for the northeastern Forest Steppe of Ukraine.

Soil moisture was determined using the gravimetric method according to GOST 70215-70273. The determination of sunflower seed yield was carried out in divided plots. The economic and energy assessment of tillage methods was calculated using the "Methodological recommendations and research program on soil tillage" (National Research Center "Institute of Agriculture of NAAS", Ukraine). Statistical processing of research results was performed using the dispersion method with the application of the Excel software package.

Results and Discussion

During the sunflower sowing period at 2022 year the highest content of available moisture in the 0-100 cm soil layer was observed in the control plot – 156.8 mm (Tab. 1),. According to experimental data, in the variants with stubble cultivation with a heavy cultivator (husking disk cultivation KLD-2) and with disc cultivator AG-2.4 conducted to a depth of 12 cm-14 cm, productive moisture in the meter-deep soil layer accumulated in spring period was 2.2% and 2.7% less than in plowing. It should also be noted that by the time of sowing, in the 0-20 cm soil layer, all variants had good reserves of productive moisture, ranging from 23,2 to 25.6 mm. Moisture reserves in the 0-20 cm layer in the disc cultivation variant (4) were 0.7 mm less than in plowing. In the variants with stubble cultivation using a heavy cultivator and discs, the moisture reserves were 1.3 mm and 7.7 mm higher than in plowing, respectively.

By harvest time, the reserves of available moisture in the meter-deep soil layer were highest with moldboard plowing conducted to a depth of 20 cm-22 cm. In this variant, the reserves of available moisture amounted to 103.3 mm. In the variant with deep loosening, the available moisture reserves were almost similar, at 102.7 mm, while in the heavy and light disc cultivators variants conducted to a depth of 12 cm-14 cm, the moisture reserves were 3.8 mm-4.3 mm lower than the control, respectively.

Table 1. Influence of primary tillage methods on available moisture reserves in the sunflower field, mm (2022).

Tillage Variant	Soil Sampling Time and Depth (cm)											
	Sowing						Harvesting					
	0-20 cm	± to control	0-50 cm	± to control	0-100 cm	± to control	0-20 cm	± to control	0-50 cm	± to control	0-100 cm	± to control
1*	27.6	cont.	80.5	cont.	168.8	cont.	52.8	cont.	113.9	cont.	180	cont.
2	26.3	-1.3	79.7	-0.8	155.8	-13	50.4	-2.4	111.7	-2.2	178.3	-1.5
3	24.3	-3.3	75.8	-4.7	149.4	-19.4	49.9	-2.9	110.4	-3.5	174.2	-5.8
4	23.9	-3.7	72.9	-7.6	147.1	-21.7	49.3	-3.5	110	-3.9	173.5	-6.5

*1. Plowing to a depth of 20 cm-22 cm (Control); 2. Deep soil loosening to a depth of 35 cm-40 cm; 3. Husking disk cultivation to a depth of 12 cm-14 cm; 4. Stubble cultivation (by light cultivator) to a depth of 12 cm-14 cm.

In 2023, during the sunflower sowing period, the highest content of available moisture in the 0-100 cm soil layer was observed in the control plot – 168.8 mm (Tab. 2). According to experimental data, in the variants with stubble cultivation (with husking disk and disc cultivators) conducted to a depth of 12 cm-14 cm, moisture in the meter-deep soil layer accumulated in spring period was 11.5% and 12.9% less than using plowing. It should also be noted that with moldboard plowing to a depth of 20 cm-22 cm, by the time of sowing, the reserves of available moisture in the 0-20 cm soil layer were good and amounted to 27.6 mm. Moisture reserves in the 0-20 cm layer in deep tillage option were 1.3 mm less

than using plowing. In the 3 variant and 4 variants, the reserves decreased by 3.3 mm and 3.7 mm relative to plowing, respectively.

Table 2. **Influence of primary tillage methods on available moisture reserves in the sunflower field, mm (2023).**

Tillage Variant	Soil Sampling Time and Depth (cm)											
	Sowing						Harvesting					
	0-20 cm	± to control	0-50 cm	± to control	0-100 cm	± to control	0-20 cm	± to control	0-50 cm	± to control	0-100 cm	± to control
1	23.9	K	77.3	K	156.8	K	13.9	K	54.1	K	103.3	K
2	23.2	-0.7	73	-4.3	154.7	-2.1	13.4	-0.5	52.7	-1,4	102.7	-0.6
3	25.2	1.3	74.7	-2.6	153.4	-3.4	13.7	-0.2	53.4	-0,7	99.5	-3.8
4	25.6	1.7	73.9	-3.4	152.6	-4.2	14	0.1	52	-2,1	99	-4.3

*1. Plowing to a depth of 20 cm-22 cm (Control); 2. Deep soil loosening to a depth of 35-40 cm; 3. Husking disk cultivation to a depth of 12 cm-14 cm; 4. Stubble cultivation (by light cultivator) to a depth of 12 cm-14 cm.

At the time of harvesting, the moisture reserves in the meter-deep soil layer were highest with moldboard plowing conducted to a depth of 20 cm-22 cm. In this variant, the available moisture reserves amounted to 180 mm. In the deep loosening variant, they were 1.5 mm less than the control, while in the husking disk tillage at a depth of 12 cm-14 cm and in the variant with disc cultivator at the same depth, there was no significant difference between them, but both were lower than the control by 5.8 mm–6.5 mm, respectively.

According to obtained results in 2022, sunflower seed yield across variants averaged from 1.79 t ha^{-1} to 2.86 t ha^{-1} (in the control). The highest yield – 2.86 t ha^{-1} was obtained in the control variant (plowing), which was 1.07 t ha^{-1} more than in the case of stubble cultivation at a depth of 12 cm-14 cm (Tab. 3). Other methods of non-plowing tillage also reduced sunflower seed yield by 0.28 t ha^{-1}-0.34 t ha^{-1}. According to research results in 2023, sunflower seed yield across variants ranged from 2.14 t ha^{-1} to 2.51 t ha^{-1}. The highest yield – 2.51 t ha^{-1} was obtained in the control variant (plowing). Yield reduction by 0.05 and 0.18 t ha^{-1} was noted on stubble cultivation 3 and 4 variants to a depth of 12 cm-14 cm, respectively. With deep loosening, a 14.7% reduction in seed yield compared to plowing was observed.

Table 3. **Energy assessment of sunflower cultivation efficiency depending on primary tillage methods, 2023.**

Tillage	Yield, t ha^{-1}		Energy Efficiency of Sunflower Yield, MJ/ha		Energy Intensity of Technologies, MJ/ha		Kee	
	2022	2023	2022	2023	2022	2023	2022	2023
Plowing to a depth of 20 cm-22 cm (Control)	2.86	2.51	5099	4475	37177	15384	7.3	3.4
Deep soil loosening to a depth of 35 cm-40 cm	2.52	2.14	4493	3816	37257	15302	8.3	4
Husking disk cultivation to a depth of 12 cm-14 cm	2.58	2.33	4600	4154	36745	15169	8	3.7
Disc harrow cultivation to a depth of 12 cm-14 cm	1.79	2.46	3191	4386	36654	15132	11.5	3.5

In 2022, the highest energy efficiency of sunflower yield was recorded in the plowing variant 5099 MJ/ha. With disc harrow cultivation to a depth of 12 cm-14 cm, the energy intensity of the yield decreased by 4600 MJ/ha, while on 4th variant 3191 MJ/ha.

Analysis of the data obtained in 2023 indicates the highest energy expenditures 15384 MJ/ha with moldboard plowing, as in 2022. The maximum energy output with the yield was also obtained in this variant 4475 MJ. The energy efficiency coefficient was the highest with deep loosening, amounting to an Kee of 4.0.

Conclusions

The primary tillage methods had no significant impact on soil moisture reserves. However, they were somewhat higher in the 0-100 cm horizon with plowing during sunflower cultivation in 2023. The August rainfall, totaling 122 mm (two monthly norms), evened out the moisture reserves in the soil, and the influence of primary autumn tillage methods was neutralized. By the time of harvest, moisture reserves in the meter-deep soil horizon were high 96 mm-103 mm. The

highest sunflower yield in 2023 was obtained with moldboard plowing at a depth of 20 cm-22 cm-2.5 t ha^{-1}. Deep loosening without inverting the soil layer and husking disk cultivation reduced sunflower yield by 0.18 t ha^{-1}-0.37 t ha^{-1}. Disc harrow cultivation at a depth of 12 cm-14 cm did not significantly reduce the yield.

In 2022, by the time of sunflower sowing, the highest moisture reserves were accumulated with plowing to a depth of 20 cm-22 cm, 167.2 mm-168.8 mm. With surface tillage to a depth of 12 cm-14 cm, they were lower by 2.1 percent -7.6 percent. The highest energy efficiency of sunflower yield was recorded in the plowing variant.

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