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Changes in the hardness and moisture capacities of a typical black soil in the agrocenose of winter wheat and sunflower

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ABSTRACT

The investigations were done on the experimental field of the Bila Tserkva National Agrarian University with a typical deep low-humus chernozem. The aim of our research was to evaluate the influence of the main tillage and fertilization systems on the density, reserves of productive moisture and productivity of the agrocenosis of winter wheat and sunflower of the short crop rotation. With the use of soil tillage systems, the indicators of the treated layer of typical chernozem consistence did not exceed the optimal values. A small decrease in soil consistence was observed under differentiated and unplowed tillage compared to the variant of shallow loosening. At the beginning of the growing season of winter wheat in the soil's arable layer of 0–30 cm, the least amount of moisture was accumulated in the variants without fertilizers and the organic system of fertilization, the increase in the supply of available moisture under mineral and organic-mineral was 0.8-2.9% compared to organic. The plowing with unplowing and shallow unplowing tillage variants significantly exceeded the reserves of available moisture compared to the control by 1.2-5.5% during the wheat harvesting period. The highest yield of winter wheat and sunflower was reached under the mineral and organic-mineral fertilization system. Lower values were obtained under the organic system. The use of shallow tillage, which was carried out with disc tools to a depth of 10-12 cm, led to a significant decrease in the yield of crops compared to the control variant.

Keywords: soil processing, fertilizes system, harvesting, short-rotation crop rotation

INTRODUCTION

The productivity of agricultural crops is significantly influenced by the methods of soil processing that are carried out to optimize soil productivity and change their physical parameters (De Cárcer et al., 2019; Dekemati et al., 2019; Woźniak, 2020). Methods of soil processing can resist unfriendly environmental influences, as well as the strengthened soil. For the development of the agricultural state, it is necessary to increase the energy-saving soil's tillage and the possibilities for the development of tillage systems, for which they achieve the maximum yield and reduce the soil's degradation processes (Van Eerd, 2014).

Through the great variety of data, often super-efficient, it is important to plant the systems of the main soil processing and the fertilizer system for growing winter wheat and dormouse in the minds of an unstable plant.

The productivity of agricultural crops is significantly influenced by the methods of soil processing that are carried out to optimize soil productivity and change their physical parameters (De Cárcer, 2019; Dekemati, 2019; Woźniak, 2020). Methods of soisoilessing can resist unfriendly environmental influences, as well as the strengthened soil itself. Tillage and pre-sowing tillage in which implements and heavy machinery repeatedly move across the field, increases compaction (Schlüter, 2018; Voltr, 2021). Heavy equipment damages soil aggregates, increases soil consistence and moisture, and reduces water permeability and overall porosity (Somasundaram, 2018; Augustin, 2020). Excessive soil consistence impairs soil moisture capacity and aeration, and biological and chemical properties change (Ernst and Emmerling, 2009; Moinfar, 2021), this leads to a decrease in yield and soil degradation (Małecka, 2012; Shah, 2017). Today we can see attempts to replace energy-intensive plowing with less expensive surface or chisel tillage and to reduce the intensity of soil loosening (Orzech and Załuski, 2020). Such measures have a protective effect on the soil and help preserve agronomic systems.

MATERIALS AND METHODS

Description of the experimental plot

The experimental work was carried out on typical black soil, deep, low-humus, medium-loam during 2016-2020 in a five-field crop rotation, located on the experimental field of the Bila Tserkva National Agrarian University. The average annual rainfall is 500-550 mm, most of which falls from April to September. The average temperature in summer is 20.5 The monthly fall-out and average temperatures from 2016 to 2020 are given in Table 1.

Investigation's methods

Our investigations were conducted in 2016-2020 to study the influence of different tillage systems (A) and fertilization systems (B) in crop rotation on general porosity, and reserves of available moisture. The crop rotation had the following sequence: alfalfa - winter wheat + white mustard (siderite) - sugar beets and sunflower - buckwheat - barley with alfalfa sowing. The research was done in the agrocenosis of winter wheat and sunflower. The repetition in the experiment is three times and the placement of options is systematic. Plots for the study of tillage systems are placed in one tier, and fertilization systems are placed in four tiers. The sown area of elementary plots is 171 m^2, accounting - 112 m^2.

The content of the gradations of the first factor (A) of the main tillage systems was next. Differentiated (control) - shelf tillage in sugar beet and sunflower fields, under winter wheat, one shallow tillage under buckwheat and one chisel tillage under barley. Shelf-less plowing - 1 time of variable-depth plowing for row crops, 2 times of shallow tillage for winter wheat and buckwheat, and 1 time of chisel tillage for barley per crop rotation. Shallow tillage - soil cultivation with disc tools to a depth of 10-12 cm for all crop rotations. The main tillage measures were carried out with the following tools: 3-hull plow "Lemken Opal 110"; chisel deep loosener 4.2-wide; disk harrow "AG-2,1-20".

The content of gradations of the second factor (B) of fertilization systems was next. Zero level - without fertilizers; organic - application of 8 tons and 3.0 tons of non-marketable part of the crop per hectare, mass of harvest siderite per hectare of crop rotation area. The rate of organic fertilizers is determined by the need for a positive balance of humus. Organic-mineral - to restore soil fertility, the priority use of organic fertilizers, application of 8 tons of manure per 1 ha of crop rotation area and 3.5 tons of post-harvest siderites, non-marketable part of the crop, application of 110 kg (N_{27} P_{38} K_{45}) of mineral fertilizers. Mineral - to restore soil fertility, apply 8 tons of manure and 222 kg (N_{68} P_{72} K_{82}) of mineral fertilizers to 1 ha of crop rotation area. The following hybrids and varieties were grown in the experiment: alfalfa – "*Lidia*", winter wheat – "*Svitilo*", sunflower – "*Kondi NK*", sugar beet – "*Vapiti*", spring barley – "*Helios*", buckwheat – "*Dykul*". The main tillage measures were carried out with the following tools: such plow as "Lemken Opal 110"; chisel deep loosened 4.2 meters wide; "AG-2.1-20" disc harrow, "Europak combined unit" and 4.2-wider cultivator.

In all tillage variants, the remains of wheat straw after harvesting were crushed and plowed into the soil with a disc harrow. After harvesting the wheat, the soil was prepared for sowing white mustard on the seed mass. In late September and early October, post-harvest mustard crops were plowed into the soil in all variants. Herbicides were used on winter wheat and sunflower crops to control weeds during the spring-summer vegetation period.

Table 1. Meteorological parameters of the experimental plot (Bila Tserkva, Kyiv region)

Years	Temperature / fall-out	Month					
		April	May	June	July	August	September
2016	Temperature, °C	12.3	14.4	19.4	21.2	20.5	15.6
	Fall-out, mm	61.0	169.7	105.0	80.1	44.0	9.6
2017	Temperature, °C	10.3	14.9	19.7	20.4	22.4	16.1
	Fall-out, mm	58.1	40.5	42.4	56.1	44.0	53.2
2018	Temperature, °C	13.3	18.4	20.1	20.5	21.5	16.2
	Fall-out, mm	8.1	22.8	58.7	128.4	23.9	47.9
2019	Temperature, °C	10.0	16.6	22.0	19.3	20.1	15.3
	Fall-out, mm	45.5	54.0	79.2	41.2	17.1	19.2
2020	Temperature, °C	9.2	12.5	21.2	20.6	19.8	17.3
	Fall-out, mm	13.2	102.3	60.7	79.2	44.9	26.7

Soil measurements and sampling

Soil samples were taken every 10 cm from a depth of 0 to 100 cm. The raw weight of the soil samples was determined, after which the samples were dried in an oven at 105°C for 8 hours. Soil moisture content (X_0) was expressed as % of water to completely dry soil. Soil moisture reserves (W) were calculated as:

$$W = X_0 \times \text{soil layer} \times \text{soil volume.}$$

Volumetric mass (d) was determined by the ring method in a layer of 0-30 cm with an interval of 10 cm. The water profile in the soil represents changes in the water content in the soil layer of 0-1.5 meter in spatial and temporal scales and is created using the matrix function contour plot of "Origin 2018". Soil density was determined by the column method, metal cylinders with a volume of 160 cm^3 and a height of 10 cm were used. Three samples were randomly taken from each plot.

Crop yield

The yield of crops was determined in the state of technical ripeness by the method of continuous collection from the accounting plots with conversion to standard humidity and purity from each option separately. The yield of wheat grains was calculated based on the moisture content of 14%, and sunflower – 11%.

Statistical analysis

Means and standard errors were analyzed for each measured parameter, tillage and fertilization system. The Fisher's least significant difference (LSD) was performed to search for statistical differences between values at a 0.05 significance level. For the correction of multiple comparisons was used a one-way ANOVA analysis.

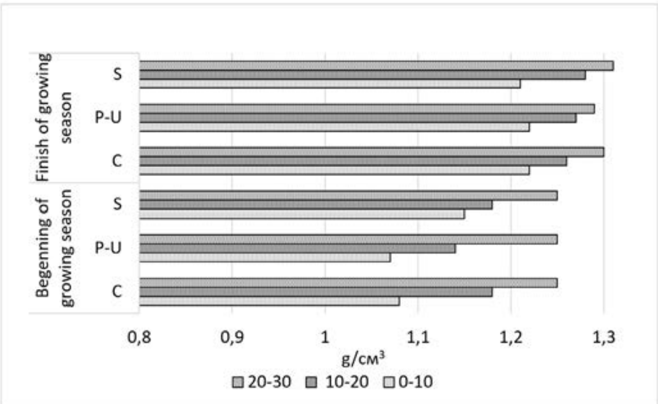
RESULTS AND DISCUSSION

Influence on soil density

According to the results of the research, the statistical analysis of the parameters does not allow us to reliably establish the difference between treatments in terms of their influence on the density of the soil for the cultivation of winter wheat and sunflower. The difference between the options in an average of 5 years during the cultivation of crops turned out to be much smaller than the error of the experiment, even taking into account the effect of the second factor - the physical impact of the upper layer on the lower one. At the same time, the value of the soil density, according to the generally accepted scale, was within the optimal values for growing these crops.

At the time of the spring vegetation of winter wheat (Figure 1), the density of the soil exceeded the plowed phones, the indicators differed little according to the profile of the plow layer and soil cultivation measures and were within the limits of the optimal values for the grain crop (1.18-1.32 g/cm^3).

During the summer period, the sowing layer of the soil (0-10 cm) in the winter wheat field was compacted, so the density for the period of winter wheat harvesting was 1.21-1.22 g/cm^3. In the lower part of the arable layer of the soil, an increase in the indicated parameters was observed. Thus, the density of the soil with differentiated soil's treatment in a layer of 20-30 cm was 1.30 g/cm^3, with plowing-non-plowing was 1.29 g/cm^3 and shallow non-plowing 1.31 g/cm^3.



(C – Complex (control variant); P-U – Plowing-Unplowing and S – Shallow unplowing system. Fisher's least significant difference: $LSD_{05}A$ = 0.01 and $LSD_{05}B$ = 0.03 - at the begin of vegetation, $LSD_{05}A$ = 0.02 and $LSD_{05}B$ = 0.08 – at the end of vegetation)

Figure 1. Soil bulk density depending on tillage systems in agrocenosis under winter wheat growing

In the spring, the consistence of the plow layer in all variants was within the optimal values. In a layer of 20-30 cm after shallow cultivation, it changed towards unfavorable conditions for plant development and deviation from optimal soil parameters. It exceeded 1.30 g/cm^3, which is an unfavorable soil condition even for winter wheat plants.

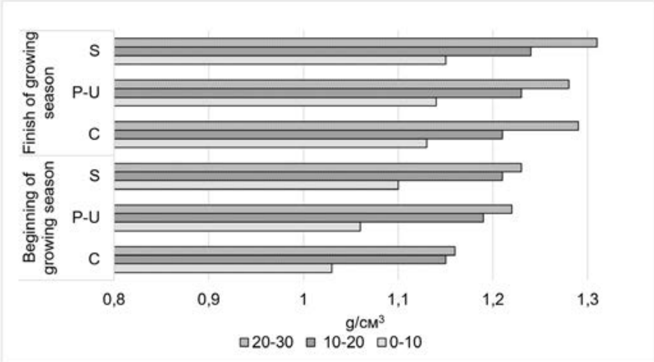
The use of soil tillage methods during sunflower cultivation had a slight effect on the change in the density of the layer at the beginning of the growing season (Figure 2). The research results show the level of this indicator is actually the same as the control level after using unplowing cultivation. A slight tendency to increase the consistence of the plowed layer was found after the use of shallow tillage with disc tools. The soil's consistence in the variant of unplowing cultivation in layers of 10-20 and 20-30 cm, its value was higher than optimal even for grain crops.

The upward dynamics of soil's consistence was also influenced by weather conditions. In years with sufficient moisture, it was mostly higher compared to dry years conditions and reached maximum values.

The dependence of soil's consistence on soil tillage before sunflower harvesting remained at the same level as at the beginning of the growing season. At the same time, it increased by an average of 0.03-0.08 g/cm^3 compared to the spring period. At the end of the sunflower growing season, the maximum values of soil consistence - higher than the level of 1.30 g/cm^3 were recorded in a 20-30 cm layer on the variant where cultivation was carried out with disc tools to a depth of 10-12 cm.

In the experiment, we hadn't observed any benefits for soil tillage systems in terms of its resistance to compaction during the growing season of crops. Compaction due to natural factors occurred almost equally – from 0.04 to 0.10 g/cm^3 in all variants.

Research has established that the optimal limits of indicators for most agricultural crops are within 1.1-1.3 g/cm^3. Optimum consistence contributes to the faster and friendly appearance of seedlings, so increase the vegetative mass of crops and a more productive development of the entire root system which helps to obtain high yields. This parameter is within the appropriate limits for almost all tillage options (with the exception of No-till in a layer of 20-30 cm) (Liashenko, 2021).



(C – Complex (control variant); P-U – Plowing-Unplowing and S – Shallow unplowing system. Fisher's least significant difference: $LSD_{05}A$ = 0.07 and $LSD_{05}B$ = 0.11 - at the begin of vegetation, $LSD_{05}A$ = 0.40 and $LSD_{05}B$ = 0.64 – at the end of vegetation)

Figure 2. Soil bulk density depending on tillage systems in agrocenosis under sunflower growing

Impact on soil moisture reserves

At the beginning of the growing season of winter wheat in the soil's arable layer 0–30 cm, the least amount of moisture accumulated without fertilizers and under the organic fertilization system (Table 2). Exceeding the supply of available moisture for mineral and organic-mineral by 0.8-2.9% compared to organic system.

There was no significant difference in the investigated treatment options. The amount of moisture on the tillage variants was in the range of 47.1-49.5 mm for $P > 0.05$, which indicates an insignificant difference between the variants.

Before harvesting winter wheat, significant differences in fertilization systems were noted. The highest reserves of available moisture were formed by the mineral and organic-mineral fertilization system. Complex plowing with unplowing variant and shallow unplowing tillage variant significantly exceeded the reserves of available moisture compared to the control by 1.2-5.5%.

No significant difference in available moisture reserves was observed in the 0–10 cm soil layer during the period of sunflower germination (Table 3). Soil moisture reserves ranged from 10.6 to 12.7 mm. The availability of such reserves of available moisture were within optimal parameters. This is a guarantee of obtaining timely and friendly seedlings and, in the future, normal growth and development sunflower's plants. Significantly higher reserves of available moisture in the upper 0-10 cm soil's layer were observed for shallow unplowing tillage compare with the control variant. The moisture reserve in other variants in 0-30 cm was at the level of 36.0 mm.

During the sunflower harvesting period, moisture reserves in the soil decreased significantly. As a result of the processes of physical evaporation, desiccation and capillary rise, moisture from the lower layers moved to the upper part of the soil layer. At the same time, the positive moment of shallow unplowing and complex processing over plowing was preserved. The presence of mulch, which prevented soil moisture from unproductive evaporation, contributed to higher residual moisture reserves with the use of tillage measures. At this time, fertilization systems did not significantly affect the reserves of available moisture in the 0–100 cm soil layer. Before harvesting, significantly higher reserves of available moisture were noted for the mineral fertilization system compared to the control. It is worth noting the decrease in available moisture reserves under the organic fertilization system by 2.0-5.0% due to the reduction of nutrients compared to the mineral and organic-mineral fertilization system.

The application of mineral fertilizers in combination with manure, straw, and cultivation of sideral crops, plants used soil moisture more economically - by 28-30% compared to the option without mineral fertilizers (Voronkova, 2009). In other investigations, it was found that with organic-mineral fertilization, the reserves of available moisture in soil's layer from 0-1 m were the highest (129.2 mm) with the plowing system, which is 6% more compared to the mineral system. A 7–17% decrease in available soil moisture reserves was noted under unplowing systems compared to the control (Kyryliuk et al., 2020).

A significant linear relationship was established between soil density and reserves of available moisture of winter wheat in the 0–10 cm layer at the beginning of the growing season (r = 0.85 ± 0.26) and at the end of the growing season (r = 0.98 ± 0.07).

Table 2. Reserves of available moisture in the agrocenosis of winter wheat (mm)

Variant of soil's cultivation, A	Fertilizer's system, B	Period of plant's growth					
		Vagetation's restore in spring			Harvest period		
		Soil's layer, cm					
		0-10	0-30	0-100	0-10	0-30	0-100
Complex (Control)	Without fertilizers	12.4	47.1	136.6	6.5	16.2	72.1
	Organic	13.0	47.7	139.2	6.9	18.7	73.3
	Organic-mineral	13.2	47.9	139.2	7.1	21.0	76.3
	Mineral	13.4	48.5	139.8	7.6	22.7	84.1
Plowing with unplowing	Without fertilizers	13.0	48.0	139.8	6.7	17.7	72.0
	Organic	13.3	48.3	140.0	7.6	18.8	74.5
	Organic-mineral	13.3	48.5	140.2	7.6	20.5	78.5
	Mineral	13.7	48.7	140.3	8.0	21.1	84.6
Shallow unplowing	Without fertilizers	13.1	48.1	138.6	6.8	17.9	75.0
	Organic	13.3	48.6	139.8	7.1	19.3	82.2
	Organic-mineral	13.6	49.1	140.0	7.6	20.1	83.4
	Mineral	14.0	49.5	141.2	8.3	22.3	85.3
$LSD_{05}A$		0.5	0.64	4.2	0.2	0.7	3.5
$LSD_{05}B$		0.6	3.0	6.1	0.3	0.8	3.6

Crop harvest

The final harvest of winter wheat under the organic-mineral fertilization system was not significantly different from the control (Figure 3). A significant decrease in the yield of winter wheat was observed under the organic fertilization system compared to the mineral one by 31.0%, and the organic-mineral one by 28.0%. The highest productivity indicators were against the background of unplowing system. The use of shallow tillage led to a significant decrease in the yield of winter wheat compared to the control.

The highest yield of sunflower was recorded under the mineral fertilization system, lower values were obtained under the organic system. The use of shallow tillage, which was carried out with disc tools to a depth of 10–12 cm, led to a significant decrease in sunflower yield compared to the control.

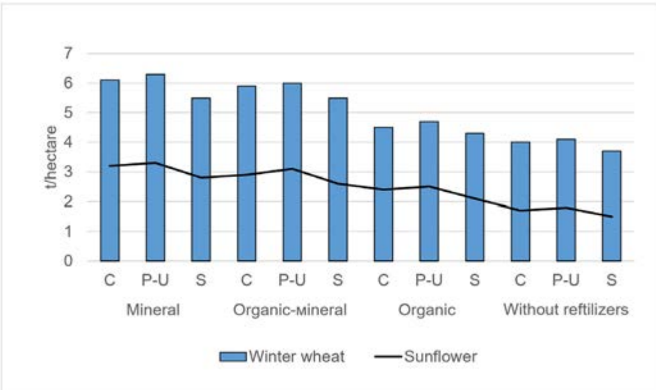
In the experiment, the productivity of wheat and sunflower differs significantly according to the tillage systems. Therefore, the results of the research are consistent with other studies in which no significant difference in yield was observed for tillage systems. In one study with wheat, no significant differences in grain yield were found under traditional and minimal tillage (Glab and Kulib, 2008).

In another experiment, it was established that the optimal method of soil cultivation under winter wheat there is plowing for 18-20 cm. The use of other researched treatments leads to a decrease in the yield of winter wheat grain in the range of 0.08-0.56 t/ha (Sayuk et al., 2018).

Table 3. Reserves of available moisture in sunflower agrocenosis (mm)

Variant of soil's cultivation, A	Fertilizer's system, B	Period of plant's growth					
		Vagetation's restore in spring			Harvest period		
		Soil's layer, cm					
		0-10	0-30	0-100	0-10	0-30	0-100
Complex (Control)	Without fertilizers	10.6	35.7	120.1	7.5	17.1	79.0
	Organic	11.9	36.4	125.4	8.1	19.0	80.4
	Organic-mineral	11.7	36.7	130.7	8.0	20.2	82.2
	Mineral	12.3	36.8	132.6	8.6	22.0	83.1
Plowing with unplowing	Without fertilizers	10.7	35.9	121.3	7.6	18.0	80.0
	Organic	11.9	36.3	125.4	8.0	19.0	81.1
	Organic-mineral	12.1	36.4	131.4	8.6	19.6	82.3
	Mineral	12.4	36.8	132.3	9.0	20.0	84.5
Shallow unplowing	Without fertilizers	11.3	35.7	122.4	8.1	18.0	80.6
	Organic	12.1	36.4	126.1	8.3	19.1	81.5
	Organic-mineral	12.5	36.8	131.2	8.4	19.4	83.0
	Mineral	12.7	36.7	133.2	8.6	20.4	83.6
$LSD_{05}A$		0.2	1.7	4.2	0.1	0.4	3.5
$LSD_{05}B$		0.3	1.8	4.5	0.2	0.5	3.7

The cultivation of winter wheat on fertilized fields (harvest residues + $N_{60}P_{30}K_{30}$) using the technology of shallow tillage did not lead to decrease in crop yield compared to deep tillage (Tsylyurik, 2019). The highest productivity of crop rotation was ensured by plowing with unplowing tillage – 3.5% more compared to differentiated tillage. Surface soil's treatment with disc tools reduced productivity by 9-15% compared to traditional (Tsyuk, 2022). The research results indicate a significant increase in the yield of sunflower for different fertilization systems. On average, the maximum increase in sunflower's harvest seeds (0.45 t/ha or 18.4%) compared to the variant without fertilization was obtained with the organic-mineral system (Hanhur, 2022).



(For winter wheat $LSD_{05}A$ = 0/17; $LSD_{05}A$ = 0/19; Sunflower $LSD_{05}A$ = 0/13; $LSD_{05}A$ = 0/16; C – Complex (Control); P-U – Plowing-unplowing; S – Shallow unplowing)

Figure 3. Crop harvest depending on fertilizer's system and soil's tillage (t/hectare), 2016-2020

In other experiments, the author believes it's need to apply a system of differentiated by methods and depth, the main cultivation with plowing at 28–30 cm for sunflower, shallow (12-14 cm) disk loosening for winter wheat, ensures a yield increase compared to the control by 7.2%, and compared to shallow disc loosening at 12-14 cm in the system of single-depth shallow tillage by 42.3% (Malarchuk, 2021).

CONCLUSIONS

With the use of soil tillage systems, the indicators of the soil's layer of typical chernozem that was cultivated the soil's consistence did not exceed for the optimal parameters. A small decrease in soil consistence was observed under differentiated and plowing-unplowing tillage compared to the variant of shallow loosening. At the beginning of the growing season of winter wheat in the soil's arable layer of 0-30 cm, the least amount of moisture was accumulated in the variants without fertilizers and the organic system of fertilization, the increase in the supply of available moisture under mineral and organic-mineral was 0.8-2.9% compared to organic.

The plowing-unplowing and shallow unplowing tillage variants significantly exceeded the reserves of available moisture compared to the control by 1.2-5.5% during the wheat harvesting period.

The highest yield of winter wheat and sunflower was recorded for the mineral and organic-mineral fertilization system; lower values were obtained in the variant with organic system. The use of shallow unplowing tillage, which was carried out with disc tools to a depth of 10-12 cm, led to a significant decrease in the yield of crops compared to the control variant.

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