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Agrophysical Properties of the Soil Depending on the Surface Treatment with Various Tillage Units

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Abstract. An important direction in the greening of tillage is to preserve and improve the physical properties of soils in the optimal range of values, which is a necessary condition for the effective use of other agronomic measures that affect the formation of crop yields. With the advent of new, modern energy-efficient tillage tools, there is a need to conduct research on their effectiveness on the first stubble cultivation on the southern chernozem. The purpose of the research was to establish the influence of surface (stubble) cultivation with tillage tools of the "Lozovsky mashiny" brand after harvesting winter barley on the agrophysical properties of Southern heavy loamy low-humus chernozem in the conditions of the Southern steppe of Ukraine. In the research process, methods were used: field, laboratory, comparative-calculation, statistical. It was found that DUCAT-2,5 (short Harrow-Husker) best structured the soil among the studied aggregates. The lowest soil hardness values (0.48-1.33 MPA) and the tendency to form a plow sole were obtained in the version with vertical processing – Verti-till (turbo disk). The obtained scientific results of the research will contribute to the wider introduction into the production of new units of the "Lozivski mashini" brand for surface soil cultivation, which will contribute to the reduction of mechanical stress and the preservation of moisture in the soil

Keywords: stubble tillage, structural and aggregate composition, field moisture capacity, soil hardness, plow sole

INTRODUCTION

In today's conditions of limited resources, the primary task is the efficient use of land, the introduction of resource-saving technologies for growing agricultural crops that prevent a decrease in soil fertility, contribute to the optimization of the agrophysical state with minimal energy and money costs [1; 2]. The main means of optimizing the agrophysical state of the soil is its cultivation. Under conditions of intensive cultivation, the structure and physical properties of soils deteriorate, the equilibrium density increases, which leads to adverse economic and environmental consequences [3; 4]. Therefore, one of the ways to overcome this problem is to reduce gradually the intensity of mechanical impact on the soil.

An important direction in the greening of tillage is the preservation and improvement of the physical properties of soils, which is a necessary condition for the effective use of other agrotechnical measures (tillage, fertilization, sowing rates) that affect the formation of crop yields [5]. Therefore, in modern conditions, the search for technologies, cultivation systems and tillage tools that would help preserve moisture and reduce soil density is becoming relevant.

A significant number of studies have been devoted to the influence of various tillage systems on its agrophysical properties.

Thus, many researchers point to the negative impact of long-term use of plowing on the water-physical and agrophysical properties of soils, due to the formation of a plow sole, which inhibits the growth of plant roots in the lower layers of the soil. The root system, which does not penetrate the lower layers of the soil, often does not provide plants with water and nutrients when the upper horizons dry out, especially during droughts. In addition, plowing contributes to excessive loosening of the upper soil layer, leads to increased mineralization of organic matter and significant losses of humus reserves [6-8].

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A. Balaiev and Yu. Borysenko [9] prove that minimizing tillage improves its water-physical properties and ensures the preservation of moisture throughout the growing season. However, the improvement of tillage methods should be based on knowledge of equilibrium and optimal soil density, which are the theoretical basis for minimizing tillage [10].

Determined [11] that plowing created more favorable conditions for reducing soil density, and the use of shallow and zero processing technology was accompanied by a slight compaction of 0-30 cm of the layer. Other researchers, on the contrary, prove that minimizing cultivation improves the parameters of the physical properties of soils [12-14].

Studies of N.D. Reznichenko [13] found that the lowest folding density of the upper (0-10 cm) soil layer at the beginning of the growing season was formed with the use of disk and chisel loosening, and with prolonged use of shallow disk cultivation (12-14 cm) during two rotations of crop rotation led to an increase in the folding density in the layer of 10-20 cm compared to deep chisel loosening.

O.I. Tsyliuryk [15] determined that the use of flat – cutting loosening in the technology of growing corn significantly increased the hardness of the arable layer-by 2.2 times compared to shelf plowing, where arable land was turned over and the soil was maximally loosened and decompressed.

Studies conducted in the Right-Bank forest-steppe of Ukraine on chernozems of typical medium loam have established that minimizing cultivation leads to an increase in the density of the treated layer and a decrease in the overall porosity of the soil [16].

A.A. Horbatenko et al. [17] found that the use of shallow disk and non-polar main treatment of pure Steam does not lead to a deterioration in the agrophysical properties of ordinary chernozem compared to deep plowing and chisel treatment. Against the background of minimal cultivation, there is a tendency to increase the volume mass and hardness of the sub-seed layer of soil by 10-30 cm, as well as an increase in the content of agronomically valuable fractions of 10-0.25 mm in the arable layer.

Studies of M.R. Nunes et al [18] based on a meta-analysis, the effects of chisel plowing, zero tillage (NT), and perennial cropping systems (PER) compared with plowing (MP) on soil structure parameters have been investigated and published. It was determined that reducing the intensity of tillage improves the soil structure.

Similar results were obtained for growing oats in the Left-Bank forest-steppe. The best structure and content of agronomically valuable soil aggregates in the germination phase of oat plants is formed in the variant with flat-cut processing [19].

O.V. Pikovska points out an increase in the content of agronomically valuable aggregates in the soil layers of 10-20 and 20-30 cm while minimizing cultivation compared to plowing [19].

Recently, in many farms of the steppe and forest-steppe zones of Ukraine, due to lack of moisture and some other factors, preference is given to minimal non-dump tillage stubble tillage with tillage units with simultaneous crumbling, pruning of the root system of weeds and crop residues of plants, partial sealing and mulching of the field surface. With this approach, plowing is not used at all. Especially widespread is the use of units for vertical tillage, which are able to carry out virtually universal tillage, which determines their wide versatility of application and allows the same unit to perform several tasks. As practice shows, after passing a properly configured vertical unit, you can immediately sow all types of crops [20].

So, the analysis of scientific publications has shown an improvement in the agrophysical indicators of the soil when using surface treatment, but with the advent of new, modern energy-efficient tillage tools, it becomes necessary to conduct research on their effectiveness at the first stubble treatment on Southern chernozem.

In the experiments of C. Chang and W. Lindwall, it is noted that more favorable conditions for the accumulation of productive moisture in the soil are created during surface or flat-cut mechanical soil cultivation, compared to plowing [21].

According to scientists, traditional methods of soil cultivation can be the reason for the reduction of macroaggregates, the occurrence of degradation phenomena in soils [22]. Soil cultivation with minimal mechanical impact on the arable layer leads to an increase in the content of water-resistant aggregates [23], which prompts the need to reduce the number of cultivations during crop cultivation.

The purpose of the research is to determine the agrophysical properties of the soil after harvesting spring barley under the influence of surface (stubble) tillage with tillage tools of the Lozivski mashini brand in the conditions of the Southern Steppe of Ukraine.

MATERIALS AND METHODS

The research was conducted during 2020-21 on the research field of the Educational-scientific-practical center of MNAU (Blagodarivka village, Mykolaiv district of Mykolaiv region). The soil of the research area is chernozem southern heavy loam low-humus.

The scheme of the experiment provided for variants of stubble tillage with tools of the "Lozovsky mashiny" brand:

1. Control (without processing);
2. DUCAT RST-6 chopping Rotary chopper (knife-rotor);
3. DUCATUVT-6 vertical Harrow Verti-till (turbo disc);
4. DUCAT-2.5 short disc harrow-Husker (variodisk);
5. LIRA XL-21 heavy spring tooth Harrow (strigel).

To simplify perception, these machines were named after the type of working body: knife-rotor; turbo-disk; variodisk; strigel.

The test conditions were generally characterized as typical for the Southern Steppe zone of Ukraine and contribute to high-quality surface treatment. The average daily air temperature for the study period was +25.4°C, the maximum one reached +33.5°C, and the minimum one was 17.5°C. The amount of precipitation for the reporting period was 14.2 mm.

Agro background was spring barley stubble, stubble height was 16.6 cm, soil condition in layers of 0-20 cm had humidity 22.1-23.9%, and hardness 0.54-0.94 MPa. Tillage was carried out immediately after harvesting spring barley.

Working speed: knife-rotor – 13.0 km/h turbo disc – 15.1 km/h, variodisk – 12.0 km/h, Strigel – 10.2 km/h.

Tools have a different structure of working bodies and modes of their operation, which ensures the quality and peculiarity of the technological process inherent in each machine.

The total area of the plot was 600 m^2, the accounting area was 100 m^2. The repetition in the experiment was threefold. The placement of land plots was consistent.

Field, statistical, and laboratory methods were used to conduct experimental work. The structural and aggregate composition of the soil was determined by the N.I. Savinov method (dry sieving) [24], the soil hardness was determined by the Kaczynski cutting ring method [24], and the volume water content (%) was measured using a portable device in layers every 5 cm of soil.

Soil samples were taken three times with an interval of 5 days – 12.07; 19.07; 23.07.

RESULTS AND DISCUSSION

Stubble treatment-surface treatment that includes loosening the soil to a depth of 5-8 cm without turning it over for the purpose of pruning crop residues, weeds, leveling the surface, mulching (mixing the soil with plant residues) in order to accumulate and preserve moisture and improve the agrophysical characteristics of the soil [25]. The structure of the soil determines the favorable structure of the arable layer, its water, and physical, mechanical and technological properties: such as soil density, hardness of the treated layer, in which the root system of plants develops, reserves of productive moisture. Optimal conditions of water and air regimes are formed in soils with a fine-grained and granular structure [24].

The soil structure according to the size of aggregates is divided as follows: lumpy (aggregates >10 mm); lumpy-granular, or macrostructure (aggregates 10-0.25 mm); powdery, or microstructure (aggregates 0.25 mm). In the resistance of soils to wind erosion, the main role is played by the clumsiness of the upper layer (0-50 mm) [26].

The vast majority of researchers note that flat-cut cultivation has a better effect on the structure than plowing, and minimizing soil cultivation is an effective means of improving the structure of ordinary chernozem by increasing the content of agronomically valuable aggregates [27; 28].

According to the results of A.A. Pavlichenko's research, it was established that the best structural condition was observed during long-term shallow tillage, where 60.2 and 64.2% of water-resistant aggregates were found in the plow layer, or 1.5 and 1.2% more than in control [29].

Shallow (10-12 cm) moldboard cultivation contributed to growth of the topsoil bulk density of chernozem by 0.3-0.5 g cm^{-3} and decrease in total porosity by 0.6-0.9% compared to plowing by depth of 20-22 cm in field experiment of the National University of Life and Environmental Sciences of Ukraine [30].

In studies, the structural and aggregate composition of the upper soil layer due to treatment with various tillage tools had significant differences between the variants (Fig. 1).

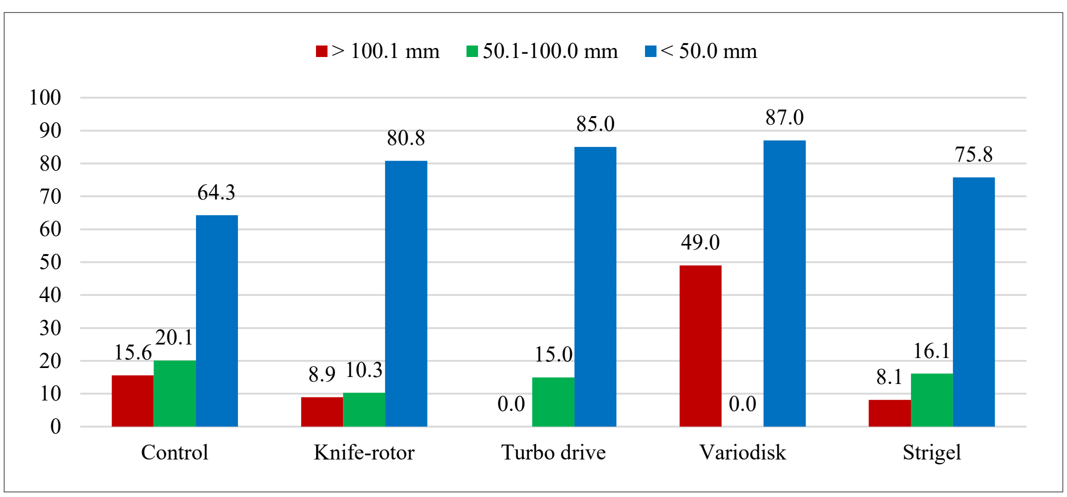

Figure 1. *Influence of stubble treatment with tillage tools on the content of soil aggregates in a layer of 0-8 cm, %*

A larger number of units up to 50 mm in size were formed as a result of crumbling the soil by working bodies with a short disc harrow-Husker (variodisk), a vertical processing harrow Verti-till (turbo disk) and a chopping Rotary chopper (knife-rotor). Lumpiness in these variants ranged from 80.8 to 87.0%, which exceeded the content of lumps up to 50.0 mm in the control variant by 16.5-22.7%.

Accordingly, the blockiness of the structure (aggregates >10 mm) was the lowest in the variant when processing with a short disc harrow-husker (variodisk) – 4.9%, and the maximum destruction of blocks occurred when processing with a vertical harrow treatment Verti-till (turbo disk). The increased content of block aggregates was observed in the control version – 15.6%.

To prevent the development of wind erosion in the post-harvest period, which is important in the conditions of the Southern Steppe, stubble treatment with a turbo disk and a knife-rotor can be a significant factor in the soil's anti-erosion resistance. The most agronomically valuable structure is the content of particles of 0.25-10 mm of at least 70%, less than 40% is unfavorable. In studies, the optimal amount of agronomically valuable aggregates in the upper layer of the soil was created by mulching treatment with a short disc harrow-husker (variodisk) and a chopping rotary chopper (knife-rotor) – 74.7-78.7% (Fig. 2).

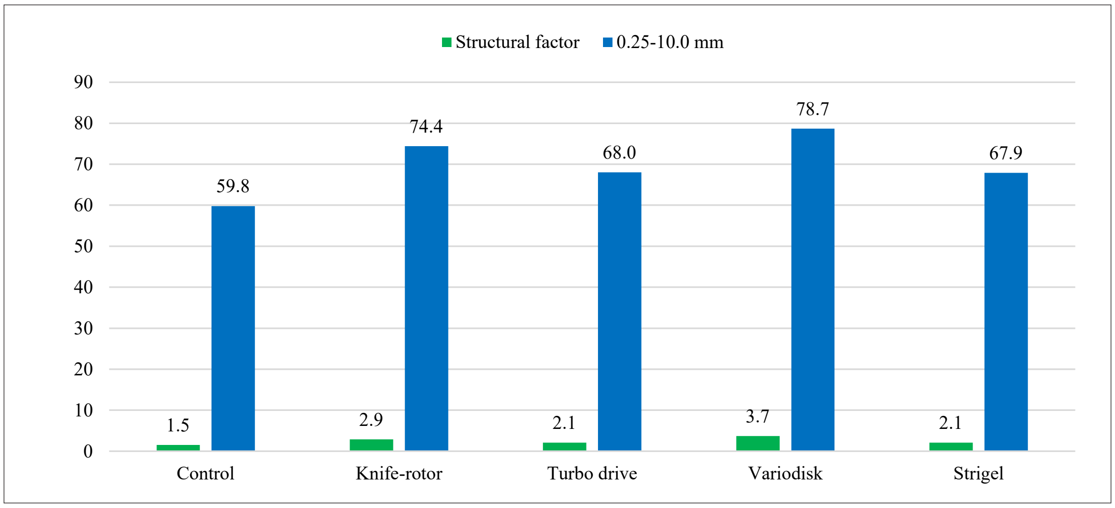

Figure 2. *Content of agronomically valuable aggregates (0.25-10 mm) in a layer of 0-8 cm, depending on the tillage of various aggregates %*

Soil hardness – the property of the soil in its natural composition to resist compression and prospection. This is one of the main indicators that characterizes its physical condition, determines the environment in which the root system of the plant is located, and, accordingly, it determines the efficiency of nutrition. Hardness often leads to a decrease in seed germination, affects the water, air and thermal conditions of the soil, the traction resistance of tillage machines and tools [30].

Stubble treatment with tillage tools significantly affected the hardness indicators in the soil layers and depended on the working bodies of the mechanisms. The lowest hardness was observed in the 0-5 cm layer and gradually increased down the profile in all variants of the experiment. The lowest hardness of the upper soil layer was observed with the Verti-till vertical harrow (turbo disk) – 0.48 MPA and in the control – 0.54 MPA (Table 1).

Table 1. *Soil hardness in different layers depending on stubble treatment with different tillage units, MPa*

Layers of soil, cm	Tillage units				
	Control	Knife-rotor	Turbo drive	Variodisk	Strigel
0-5	0.54	1.05	0.48	0.71	0.72
5-10	0.66	1.10	0.92	1.10	1.22
10-15	0.84	1.18	1.12	1.23	1.46
15-20	0.92	1.29	1.33	1.14	1.41

The highest hardness in the 0-5 cm layer was observed in the version when processing with a chopping rotary chopper (knife-rotor) – 1.05 MPa, which was 0.51 MPa higher than the soil hardness from the control version. In all soil layers, the lowest hardness values were in the control version (0.54-0.92 MPa).

When processing stubble with tillage tools, the best results were obtained in the version with the Verti-till vertical harrow (turbo disk) – 0.48-1.33 MPa. The greatest compaction and hardness in the soil layer of 5-20 cm was facilitated by processing with a heavy tooth spring harrow (strigel) – 1.22-1.46 MPa. Using this indicator, you can determine the depth, thickness, and density of the plow sole, the formation of which depends on the tillage technology. Increasing the hardness increases the energy intensity of tillage, reduces water permeability, it slows down the development of roots until they completely stop due to the inability to penetrate through the compacted layer. The results of assessing the propensity of the soil to form a plow sole using the falling cone method are shown in Figure 3.

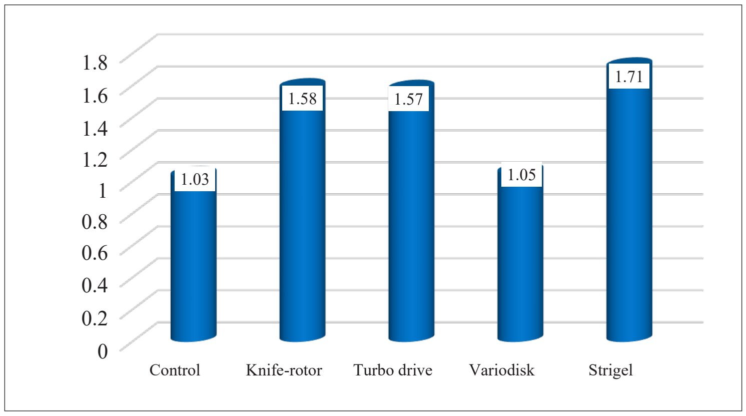

Figure 3. *Influence of tillage on the tendency to form a plow sole by the height of immersion of the falling cone, cm*

The least susceptible to the formation of a plow sole was the soil in the version when treated with working bodies with a short disc harrow-husker (variodisk) – 1.05 cm, which was at the level of the control Version (1.03 cm). The soil in the version of processing with a heavy tooth spring harrow (strigel) was most susceptible to the formation of a plow sole in terms of the height of immersion of the falling cone – 1.71 m. Processing with a verti-till vertical harrow (turbo disc) and a rotary chopper (knife-rotor) revealed the same tendency for forming a plow sole – 1.57-1.58 cm.

Soil hardness and humidity are related indicators. With a decrease in the moisture content in the soil, the hardness increases significantly and negatively affects the root system of plants. Therefore, before installing moisture supply, the soil hardness is determined to identify areas of over-compaction. In recent years (2020-2021), the risks of arid conditions have been increasing more and more, so modern technologies require significant improvement, in particular in the search for agricultural measures aimed at preserving natural moisture resources.

The most important physical property of the soil that determines its humidity is moisture capacity (capillarity) – a value that quantifies the water-retaining ability of the soil: the ability to absorb and retain a certain amount of moisture from draining under the influence of capillary and sorption forces. The degree of soil moisture retention was determined using the volume water content indicator, or field moisture capacity ("FMC"), which is a numerical indicator of soil moisture (Table 2).

Table 2. *Dynamics of moisture reserves in the surface layer (0-25 cm) depending on stubble treatment with various tillage units, %*

Tillage units	Layers of soil				
	0-5	5-10	10-15	15-20	20-25
First term					
Control	7.4	20.2	44.9	42.1	56.1
Knife-rotor	16.0	38.9	50.0	46.8	65.5
Turbo drive	11.5	25.4	46.0	45.6	66.1
Variodisk	0.0	41.6	64.1	60.5	62.8
Barbell	0.0	44.4	48.1	63.3	63.9
Second term					
Control	4.2	7.5	27.3	31.5	35.0
Knife-rotor	0.0	23.9	34.5	36.7	40.7
Turbo drive	6.7	8.2	38.3	44.4	55.4
Variodisk	0.0	28.0	46.3	56.1	59.3
Barbell	6.3	14.0	29.8	42.6	50.0
Third period					
Control	6.3	10.6	27.8	31.4	35.7
Knife-rotor	2.1	14.4	24.1	30.4	34.2
Turbo drive	1.9	5.8	36.0	42.0	50.0
Variodisk	9.9	24.1	47.3	52.2	28.1
Barbell	4.7	5.5	30.3	38.6	49.4

The control variant had the lowest values of field moisture capacity in all soil layers. Thus, the moisture reserves in the soil layer from 0-25 cm were higher in the variant with Ducat-2.5 variodisk and in dynamics they were: 45.8% (first term); 37.9% (second term) and 38.3% (third period) respectively (Fig. 4).

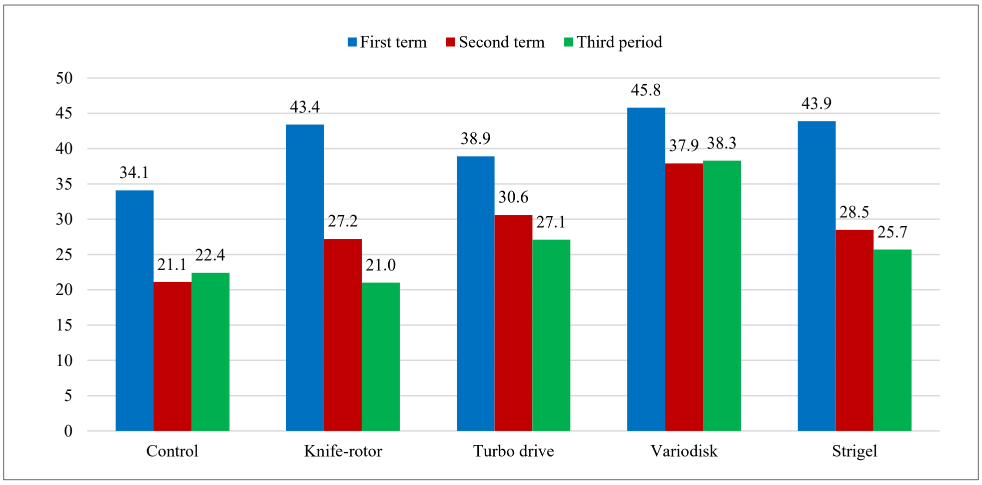

Figure 4. *Dynamics of moisture reserves (%) depending on stubble treatment with various tillage units, average at a depth of 0 to 25 cm*

Lower moisture reserves in the 25 cm soil layer were in the control version (without cultivation) – 34.1% (first term); 21.1% (second term) and 22.4% (third period).

Among the four tillage units studied, in the 25 cm layer the lowest moisture reserves were observed in the knife-rotor variant: such as 43.4, 27.2 and 21.0%, respectively. The water permeability of the soil depends on the mechanical composition and structure of the soil, the amount of swelling, the composition of absorbent bases, worm passages, etc. the optimal value is at least 30 mm/hour. Therefore, the regulation of soil water permeability should be reduced for improving the structure and structure of the soil by appropriate mechanical treatment, the introduction of organic (especially green manure) fertilizers.

The water permeability of the loosened soil was optimal after treatment with the studied aggregates in all variants (Table 3).

Table 3. Influence of tillage with tillage units on water permeability soil through a fixed area, mL/cm^2/min

Time interval, min	Tillage units							
	Knife-rotor		Turbo drive		Variodisk		Strigel	
	Subsided soil	Soles	Subsided soil	Soles	Subsided soil	Soles	Subsided soil	Soles
1	3.63	3.4	3.9	1.9	4.8	2.8	4.0	2.0
2	3.82	4.3	4.1	1.9	5.3	3.2	4.2	2.0
3	4.36	4.6	4.6	2.3	5.4	3.2	4.4	2.0
4	4.54	5.3	4.9	2.7	5.7	3.8	4.5	2.0
5	5.04	5.9	5.5	2.7	6.2	3.8	4.5	2.3
6	5.38	6.3	5.8	2.7	6.5	3.9	4.8	2.3
7	5.91	7.0	6.3	3.3	7.1	4.3	4.8	2.3
8	5.91	7.3	6.7	3.5	7.2	4.5	4.8	2.4
9	6.3	7.9	7.2	3.6	7.6	5.0	5.0	2.5

However, the soil was better able to pass the added water when treated with Ducat-2.5 variodisk both after 1 minute and after 9 minutes of research – 4.8-7.6 ML/cm^2/min. In addition, good results of water absorption along the loosened layer were obtained in the Verti-till vertical harrow treatment variant (turbo disk) – 3.9-7.2 mL/cm^2/min.

A valuable indicator of tillage is the water permeability of the sole, which affects the provision of moisture to the root system of plants. According to the table data, in all variants of studies on this indicator, the option for processing with a ducat RST rotary chopper (knife-rotor) was distinguished as 6 – 3.4-7.9 mL/cm^2/min. Lower rates of moisture absorption by the sole were shown by the option for stubble treatment with a heavy tooth spring harrow (strigel) LIRA XL-21 from 2.0 to 2.5 mL/cm^2/min.

CONCLUSIONS

Based on the results of a scientific study of the effectiveness of using surface tillage of tillage tools of the

"Lozovsky mashiny" brand, the following conclusions can be drawn:

– the best structured soil was a short harrow-husker DUCAT-2.5; the content of agronomically valuable aggregates of 0.25-10 mm was 78.7% (K page=3.7). The content of lumpy fractions of 0-50 mm in size of more than 70% in the treated layer was provided by all aggregates, which was an excellent indicator;

– the lowest indicators of soil hardness and the tendency to form a plow sole were obtained in the Verti-till vertical treatment variant (turbo disk) – 0.48-1.33 MPA. The greatest compaction and hardness in the soil layer of 5-20 cm was facilitated by processing with a heavy tooth spring harrow (Strigel) – 1.22-1.46 MPA;

– preservation of soil moisture in terms of moisture capacity (VWC) was best provided by a short disc harrow-husker (variodisk) DUCAT-2.5 (variodisk).

In connection with the significant mechanical load on soils and climate changes, especially in the Southern Steppe zone of Ukraine, the obtained scientific results are relevant and will be implemented in production. In addition, further tests of the "Lozivski mashini" brand tools on irrigation, which will contribute to the preservation of moisture in the soil, are promising.

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Агрофізичні властивості ґрунту залежно від поверхневого (стерньового) обробітку ґрунтообробними знаряддями

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Анотація. Важливим напрямком в екологізації обробітку ґрунту є збереження та покращення фізичних властивостей ґрунтів в оптимальному інтервалі значень, що є необхідною умовою ефективного використання інших агротехнічних заходів, які впливають на формування урожайності сільськогосподарських культур. З появою нових, сучасних енергоефективних ґрунтообробних знарядь виникає необхідність у проведенні досліджень з їх ефективності на першому стерньовому обробітку на чорноземі південному. Метою досліджень було встановити вплив поверхневого (стерньового) обробітку ґрунтообробними знаряддями бренду «Лозівські машини» після збирання ячменю озимого на агрофізичні властивості чорнозему південного важкосуглинкового малогумусного в умовах Південного Степу України. У процесі дослідження використовувалися методи: польовий, лабораторний, порівняльно-розрахунковий, статистичний. Встановлено, що серед досліджуваних агрегатів найкраще структурував ґрунт DUCAT-2,5 (коротка борона-лущильник). Найнижчі показники твердості ґрунту (0,48–1,33 МПа) та схильність до утворення плужної підошви було отримано у варіанті з вертикальним обробітком – Verti-till (турбо-диск). Отримані наукові результати досліджень сприятимуть широкому впровадженню у виробництво нових агрегатів бренду «Лозівські машини» для поверхневого обробітку ґрунту, що допоможе зменшувати механічне навантаження та зберігати вологу в ґрунті

Ключові слова: стерньовий обробіток ґрунту, структурно-агрегатний склад, польова вологоємність, твердість ґрунту, плужна підошва