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Investigation of the influence of crop cultivation technologies on soil compaction in the steppe zone of Ukraine

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Abstract: The article presents the results of the action of agricultural machinery on soil compaction - chernozems. The dependence of changes in soil compaction on crop cultivation technologies is shown. A comparison is made for such technologies as No-Tillage and traditional. The technique used in these technologies is analyzed. Conclusions were made and recommendations were given to reduce the negative impact of technology on the soil.

KEYWORDS: GROWING TECHNOLOGY, SOIL COMPACTION, SOIL DEFORMATION ENERGY.

1. Introduction

Despite the war, Ukraine remains a powerful exporter of food grains to Europe and the world. Weather conditions in 2023 were favorable for growing most crops. However, the increase in prices for fuel and mineral fertilizers, as well as a significant reduction in cultivated areas (up to 25%), forces farmers to increase production culture and use available resources more efficiently. The Steppe Zone of Ukraine, which also passes through the Dnipropetrovska oblast, is in the zone of risky agriculture. The main risk is insufficient rainfall. As a result, farmers get less harvest precisely because of the insufficient amount of moisture reserves in the soil. This is a natural risk. A technological risk is over-compaction of the soil. Today, the Ukrainian farmer mainly uses modern and highly productive equipment. To increase the productivity of the unit, the working width and (or) working speed of movement are usually increased. To increase the working width of the unit, it is necessary to increase the power of the engine and of the weight of the tractor. The large weight of the tractor is the reason for the large compaction of the soil. The disadvantages of soil compaction are known to everyone, and we will not list them here. Soil compaction can be reduced by changing the technology of growing agricultural crops and using techniques with low pressure on the soil. It can be tracked machinery or wheeled, equipped with special low-pressure tires (for example, Ultraflex tires).

The purpose of the work is to reveal the influence of crop cultivation technologies and using modern technique on the amount of soil compaction.

The investigations was carried out in the Steppe Zone of Ukraine, on ordinary chernozems, humus content 4 % on the territory of the private enterprise "Myr" of the Dnipropetrovska oblast. These soils are among the most fertile in Ukraine and the world.

2. Research materials and methods.

This enterprise uses traditional farming methods: intensive mechanical cultivation (deep plowing, cultivation), extensive use of chemical plant protection. As research shows, compaction from the wheels of a grain harvester weighing 130 kN can reach up to 80 cm deep into the soil [1]. Other heavy equipment also has a large negative impact. It is advisable to control compaction with modern digital penetrometers [2]. This allows you to quickly establish the state of the field and make a decision regarding the further use of the agricultural machines, if necessary. Three fields were chosen for investigations: two on which traditional farming technology is used and one field on which No-till technology has been implemented for the last two years.

Geometric parameters of fields:

Field No. 1: 1139 m × 709 m. Area 72.7 hectares (Fig. 1).

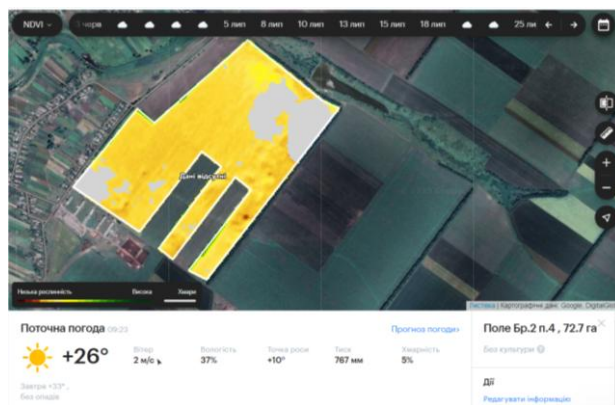


Fig. 1. General view of field No. 1. Parameters obtained using OneSoil Software.

Field № 2: 755 m × 345 m. Area 25.4 ha (Fig. 2).

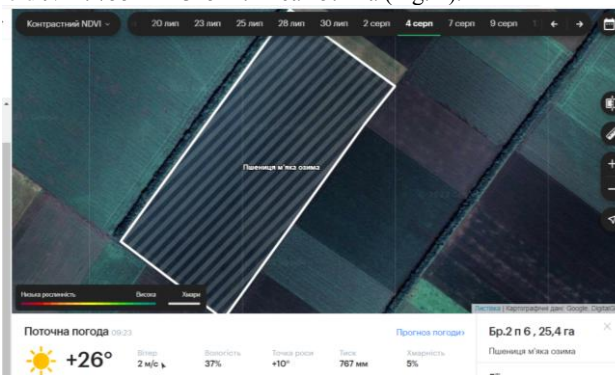


Fig. 2. General view of field No. 2. Parameters obtained using OneSoil Software.

Field No. 3: 1107 m × 442 m. Area 46.7 hectares.

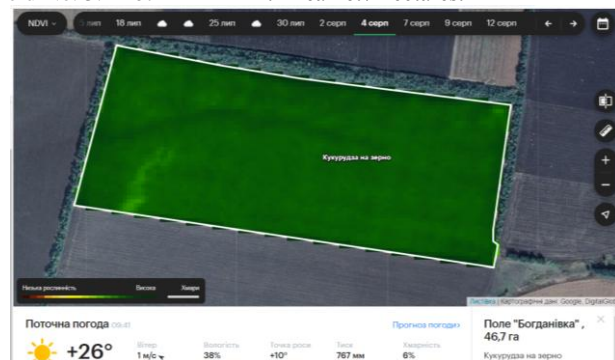


Fig. 3. General view of field No. 3. Parameters obtained using OneSoil Software

Crops and their yields are shown in Table 1.

Table 1. History of crop rotation and yield, t/ha

Year	Field 1	Field 2	Field 2
2020	Sunflower 3,3	Sunflower 3,5	Sunflower 3,5
2021	Winter wheat 3,6	Winter wheat 4,8	Corn 7,0
2022	Winter canola 4,3	Winter canola 4,3	Sunflower (No-till) 2,7
2023	Winter wheat 5,6	Winter wheat 5,9	Corn (No-till) -

Detailed technological operations, tractors and machines that performed these operations are given in the table. 2.

Table 2. Farming technologies crops on experimental fields

№	Operation	Tractor	Agricultural machinery
Sunflower – Traditional technology			
1	Plowing	JD 6930	Kuhn MM 122
2	Cultivation	JD 6150M	KPIC-8ПМ
3	Pre-sowing cultivation	JD 6150M	KPIC-8ПМ
4	Seeding	JD 6150M	JD 1785
5	Chemical protection	JD 6125M	JD M740
6	Chemical protection	JD 6125M	JD M740
7	Harvesting	CLAAS MEGA 350	
Winter wheat - Traditional technology			
1	Deep tillage of the soil	JD 6930	ATH-4,2
2	Cultivation	JD 6150M	KPIC-8ПМ
3	Pre-sowing cultivation	JD 6150M	KPIC-8ПМ
4	Seeding	JD 6125M	AMAZONE D9 4000 SUPER
5	Chemical protection	JD 6125M	JD M740
6	Chemical protection	JD 6125M	JD M740
	Chemical protection	JD 6125M	JD M740
7	Harvesting	CLAAS MEGA 350	
Winter canola - Traditional technology			
1	Deep tillage of the soil	JD 6930	ATH-4,2
2	Plowing	JD 6930	Kuhn MM 122
3	Cultivation	JD 6150M	KPIC-8ПМ
4	Pre-sowing cultivation	JD 6150M	KPIC-8ПМ
5	Seeding	JD 6125M	AMAZONE D9 4000 SUPER
6	Chemical protection	JD 6125M	JD M740
7	Chemical protection	JD 6125M	JD M740
8	Chemical protection	JD 6125M	JD M740
9	Chemical protection	JD 6125M	JD M740
10	Chemical protection	JD 6125M	JD M740
11	Chemical protection	JD 6125M	JD M740
12	Harvesting	CLAAS MEGA 350	
Sunflower and Corn – No-Till			
1	Application of herbicides	JD 6125M	JD M740
2	Seeding	JD 6125M	JD 1785
3	Chemical protection	JD 6125M	JD M740
4	Harvesting	CLAAS MEGA 350 / CLAAS Lexion 570	

3. Results

According to the method [2], the hardness was controlled with a digital penetrometer S600. Recall that the hardness meter measures the hardness parameter, which is estimated in kPa. The accepted conventional scale of soil condition:

Hardness up to 1000 kPa – loose soil;

1000 ... 2000 kPa - relatively loose;

2000 ... 3000 kPa - medium hardness, suitable for cultivation;

3000 ... 4000 kPa - hard, not suitable for cultivation,

cultivation is risky and unprofitable;

>4000 kPa – very hard soils, agricultural cultivation cultures is impossible or unprofitable.

Field No. 1. The results of the measurements showed (Fig. 4) that the hardness of the arable layer of the soil - up to 30 cm - does not exceed 3000 kPa. There are individual points that showed an increase in hardness up to 4000...4500 kPa at a depth of more than 45 cm, but this is more the exception than the rule. Plowing to a depth of 30 cm is carried out by a John Deere 6930 + Kuhn MM 122 unit once every two years. However, the hardness curves clearly show the effect of mechanical tillage on soil hardness. The increase in hardness from a depth of 27 cm indicates the possible beginning of the formation of a plow sole. However, there is no direct threat to its formation next year. Conclusion: the soil hardness of the arable and subsoil layers is within acceptable limits.



Fig. 4. Characteristic dependence of soil hardness on depth on experimental field No. 1.

Field No. 2. The surface of the field is stubble after harvesting winter wheat. At the time of measurement, part of the field was plowed (Fig. 5). The characteristic hardness curve shows that up to the depth of plowing (30 cm), the hardness of the soil is within 2000 kPa, which is a good result of annual tillage and soil care. However, at a depth of more than 35 cm, the hardness increases significantly.

The reason for this increase may be the use of agricultural machines with a small width of grip (see table 1). As a result, correct and timely mechanical tillage of the soil provided the necessary aggregate state of the soil, but compaction is formed in the deeper layers, where there is no tillage.

At the same time, the hardness of the soil was investigated in the area of the field where plowing was carried out (Fig. 6). A clearly recorded increase in hardness, which begins at a depth of 30 cm. It was established that at a depth of 37 cm, the hardness of the soil reaches 3000 kPa, and at a depth of 60 cm - 4400 kPa. Such a picture is characteristic of the entire area of the field on which plowing was carried out.

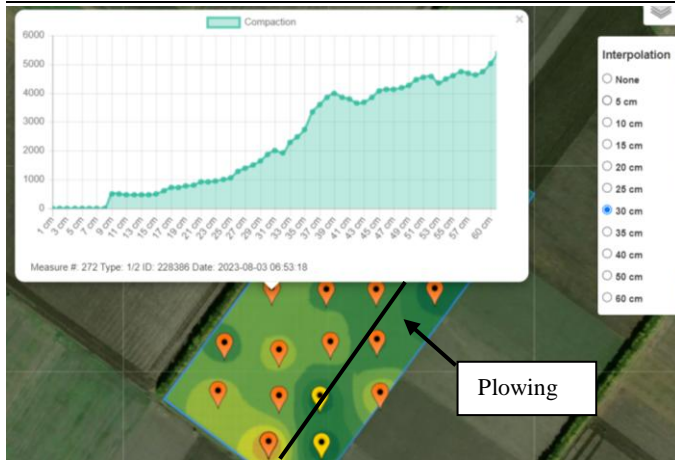


Fig. 5. Characteristic dependence of soil hardness on depth at experimental field No. 2.

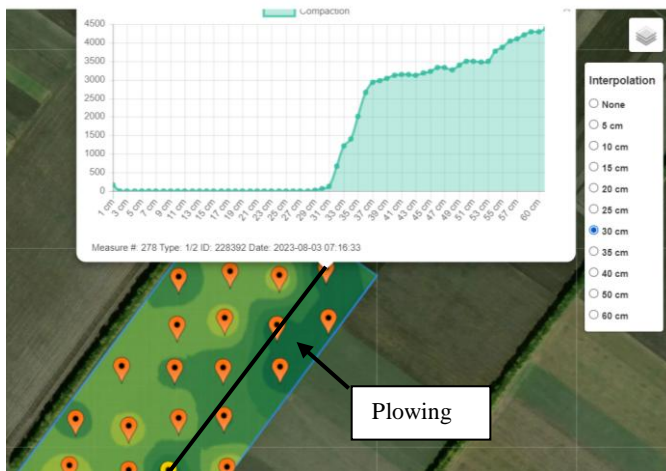


Fig. 6. Characteristic dependence of soil hardness on depth on experimental field No. 2. The plot on which plowing was carried out

Field No. 3. No-Till technology has been implemented for two years on Field No. 3, as was indicated earlier. At the same time, the technical composition of the units remained the same as in other fields. This is a technological error. The characteristic curve of soil hardness (Fig. 7) shows that the arable layer of the soil is in a solid state. A clear formation of a plow sole was detected at a depth of 9 ... 17 cm. The reason for this condition is the intensive action of tractors (wheels) on the soil.

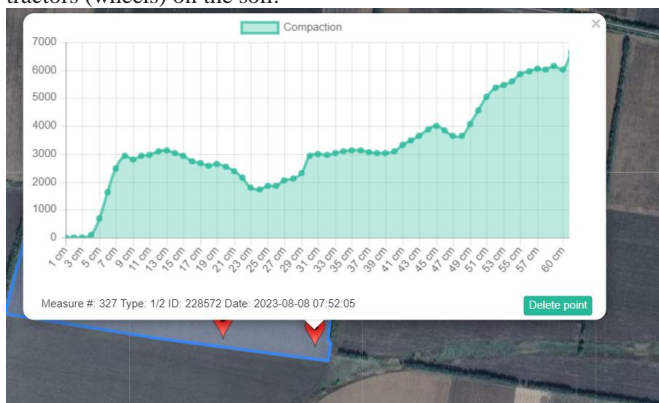


Fig. 7. Characteristic dependence of soil hardness on depth at experimental field No. 3.

One of the indicators of the state of the soil is the environmental friendliness of the technological operation according to the criterion of soil deformation. This is the amount of work spent by the wheels of the machine-tractor unit to deform the soil. The greater this work, the greater the deformation of the soil. This indicator correlates with the hardness and density of the soil.

Determined by the formula:

$$A_f = \frac{10 \cdot (\eta \cdot f_m \cdot G_m + \sum f_{Mj} \cdot G_{Mj})}{B_p}$$

where - A_f soil deformation work, MJ/ha;

η - coefficient of internal losses in the running system of tractors, which can be accepted for wheeled tractors = 0.98, and for tracked tractors = 0.9...0.93;

f_m, f_{Mj} - rolling resistance coefficients of the tractor and the jth machine in the unit;

G_m, G_{Mj} - operational weight of the tractor and j-th agricultural machine, kN;

B_p - the unit's grip width, m.

Using raw data from open sources [1, 3 – 5], the following dependencies were calculated and obtained (Fig. 8). As we see...

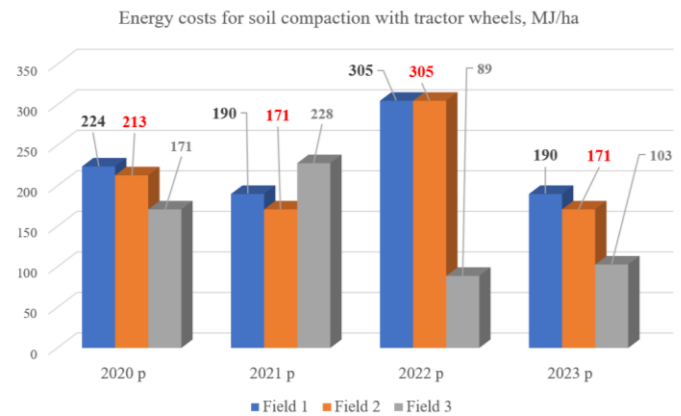


Fig. 8. Energy consumption on the amount of soil deformation A_f , MJ/ha

In the process of implementing the technology of growing plants, tractors and self-propelled vehicles drive over the field repeatedly. Often this happens on the same areas of the field. Thus, gradual compaction of the soil occurs. Therefore, an important practical indicator is the multiplicity of the track area from the tractor wheels to the field area formed in the process of growing agricultural crops. So, the higher this coefficient, the larger the area of field compaction by tractor wheels. And vice versa. To some extent, the results shown in fig. 8 and 9 are correlated. Sometimes this correlation is broken, such as the results of fields 1 and 2 in 2020 and 2022 (Figs. 8 and 9). The reason for this is the configuration of the fields, and therefore the different trajectory of the aggregates.

Multiplicity of the area of tracks of running systems by the area of the field

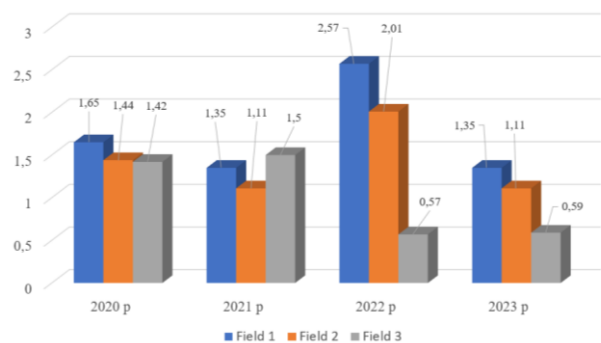


Fig. 9. Multiplicity of the area of tracks of running systems by the area of the field.

Despite the fact that when implementing the No-Till technology, both the soil deformation energy and the field compaction area are significantly lower (Figs. 8 and 9, 2022-2023),

this did not ensure the natural loosening of the soil. On the contrary, the hardness has increased.

One of the most important reasons for this is the use of equipment with a small grip width of aggregates (Table 1). Thus, the use of a seeding unit with a working width of 4.0 m for No-Till technology is inefficient in terms of the frequency of adjacent passes. The same applies to the use of the Mega 350 combine harvester with a working width of the harvester of 6.0 m and Lexion-570 for harvesting corn with a harvester - 5.6 m.

For example, the Case Magnum MX 380 + Horsch Maestro 36.50 seeding aggregate is effective in No-Till technology. Its working width is 18 m. For example, if the No-Till technology would be implemented on field No. 3 with the aggregates listed in the table. 3, then the indicator Multiplicity of the area of tracks of running systems by the area of the field would decrease from 0.59 to 0.23. That is, only 23% of the field area would be exposed to the negative impact of the wheels of tractors and self-propelled machines.

Table 3. Design proposal for the implementation of No-Till technology

№	Technological operation	Tractor	Machine	Grip width, m
1	Application of herbicides	JD 4930		36
2	Seeding	JD 8335R	Maestro 36.50	18
3	Chemical protection	JD 4930		36
4	Harvesting	Case 9240	MacDon FD75	13,75

Comparing the results of the value of hardness P (kPa) and the multiplication of the compaction area of the Scomp field on three fields in 2023 (Fig. 10), it can be concluded that the reduction of the direct impact of wheels on the soil under No-Till technology in 2023 did not contribute to the reduction of its hardness.

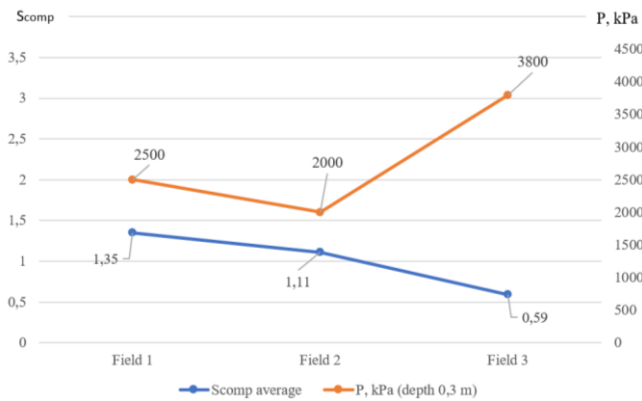


Fig. 10. Results of measurements of soil hardness P and calculated data of the compacted area of Scomp fields

It should be noted that we are observing a transition period at Field No. 3. It is characterized by temporary compaction of the soil, increased germination of weeds, and a decrease in agricultural productivity. It is also worth noting that in 2022, the sunflower yield using No-Till technology was 2.7 tons/ha. This is a good indicator.

4. Conclusions.

The following conclusions can be drawn from the given results.

1. The high culture of agriculture allows maintaining soil hardness no higher than 3,000 kPa with intensive mechanical tillage of the soil, i.e. under the traditional system of agriculture.

2. It was established that soil compaction increases starting from a depth of 31 ... 37 cm. Therefore, it is recommended to carry out processing with deep looseners to a depth of 45 ... 50 cm every 3 ... 4 years.

3. In the No-Till technology, it is necessary to use seeding aggregates with a larger working width. The same applies to combine harvesters.

4. The increase in soil hardness with the reduction of the negative effect of tractor wheels in the No-Till technology (field No. 3) is explained by the transition period and the natural compaction of the soil and the continuation of the action of the wheel systems.

5. The authors understand that many more indicators and parameters are used to determine the effectiveness of technologies. However, our goal was to investigate precisely the change in soil hardness from the technology used in the field.

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