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# Agrophysical Properties of Ordinary Chernozem as the Basis of Stability of Modern Agriculture

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## Abstract

The optimal parameters of agrophysical soil properties are important for ensuring favorable conditions for plant development. This study found a significant impact of various tillage technologies on the agrophysical state of ordinary chernozem. The long-term use of the no-till technology decreased soil density in the arable and root-inhabited (0-60 cm) layers. Before sowing winter crops using the no-till method, the soil had the best porosity level - more than 57%. Due to the reduction of agricultural machinery passes through the field, the structural aggregates increased to 52.6%, which was 12.7% more than during the dump treatment. Improving the agrophysical state of the soil with the no-till technology had a significant impact on the water permeability of the soil and its water regime. When using the no-till technology, the best agrophysical soil properties in the arable layer had a decisive influence on the yield of the field crops. In 2006-2018, the no-till technology provided a steady yield gain of 3.1-5.2 kg / ha or 6.5-38.2%. The long-term use of the no-till technology ensured the conservation of the soil, demonstrating the environmental benefits of this technology. The optimal agrophysical properties of ordinary chernozem when using the no-till technology ensured the effective use of moisture, improved the field crop productivity, and enabled more effective conservation of arable land in the arid conditions of the Rostov region.

**Keywords:** agrophysical soil properties, porosity, water permeability, productivity, no-till technology

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## 1. Introduction

The leading role in creating optimal conditions for the crop productivity belongs to the main tillage [1]. The traditional farming system destroys the soil structure; it becomes less fertile due to the removal of straw or its burning and embedding of plant debris deep into the soil, as well as the death of agronomically useful macro- and mesofauna of the soil, microorganisms. Intensive tillage has a negative impact on the quality of soil, water, air, climate and landscapes [2].

An alternative to the traditional technologies was found by Russian agronomist I. E. Ovsinsky. The resource-saving technology that allows you to achieve good results under various weather conditions and at minimal cost is the no-till method [1–3].

The minimum tillage includes one or a number of small tillages by cultivators or harrows, with straw and stubble in the form of mulch in the upper soil layer (a mulching layer). Seeds are sown on finely cultivated soils in the mulching layer. The mulching layer reduces the evaporation of moisture, eliminates the risk of water and wind erosion. Fuel consumption is reduced by 60%. The soil fertility and structure improve, and favorable conditions for the soil fauna develop [4–6].

The change in density of the arable layer of the soil is related to the soil tillage system. Soil density is the main agrophysical indicator affecting the root system of crops, development and productivity of plants. Under the existing system of agriculture with intensive tillage, soil fertility, moisture capacity, crop productivity and crop production profitability are reduced. The introduction of energy-saving tillage techniques and methods is one of the ways to reduce the cost and increase profitability of crops, including sunflower and corn [7–9].

The scientific basis of the no-till technology is accumulation of organic matter in the upper soil layer, creation and regulation of the optimal amount of mulch in the form of rotted and semi-matured crop residues, performing multifaceted functions of energy, moisture and resource conservation [10, 11].

This is an improvement in the physical, agrochemical, and agrobiological soil conditions, a decrease in soil erosion, and the number of weeds, and an improvement in the phytosanitary state.

With the No-till technology, plant roots cut through the soil in different directions and the soil becomes loose, without losing its capillarity [12]

An organic layer of crop residues formed on the surface attracts earthworms, restores soil microflora, which enriches the soil with nitrogen and stops the loss of humus [8].

Using the no-till technology, the mulching layer is created once for all years; moreover, it works continuously both in winter and summer, and is regulated by the system due to crop residues of the main crops and biological mass of sideral and intermediate crops. The no-till technology has the most unique mechanisms for realizing the potential of biologizing agriculture and adaptive crop production [1].

The most important role in ensuring the living conditions of plants belongs to the optimal parameters of agrophysical properties of the soil. According to V.R. Williams [13], N.A. Kachinsky [14] and many other researchers, agrophysical properties are one of the most important factors of soil fertility management. For agronomic assessment of the agrophysical properties, the decisive indicators are a duty cycle and soil density. For most field crops, the addition density in the range from 1.10 to 1.30 g / cm3 is optimal [15].

Along with optimal density, one can also distinguish between equilibrium density or natural density, which often coincide, especially for chernozems. The granulometric composition, structural state, the presence of organic matter and the tillage technology affect density.

When using the traditional intensive technologies in agriculture, a rapid mineralization of organic matter in the soil occurs and degradation processes develop.

## 2. Methods and Equipment

The research purpose is to determine the effect of the long-term use of no-till and till technologies on the agrophysical properties of ordinary chernozem and the crop yield.

The studies were conducted in 2006-2018 at LLC NPP Agrosfera (Oktyabrsky district of Rostov region) in the field crop rotation "winter wheat-peas-winter wheat-sunflower-winter barley-winter rape".

The climate is temperate continental, with a SCC of 0.7-0.8, the frost-free period lasts 180-190 days (April-November), the average annual rainfall is 470 mm, and the average annual air temperature is 9 ° C. The soil is ordinary chernozem, the humus content is 3.5-3.8%, the content of mobile nitrogen and phosphorus is low, and the content of potassium is high.

## 3. Results

The long-term studies established that using various tillage technologies, it is possible to change density of soil compilation and regulate its water and air regimes.

As can be seen from Table 1, density of the arable soil layer in 2006 (initial state) increased from 1.16 to 1.20 g / cm3. The highest soil compaction density was observed in the layer of 20-30 cm. This is explained by numerous technological operations (plowing, disking, cultivating, rolling, etc.).

In the steppe reserve (virgin soil), the soil density in the 0-30 cm layer did not change significantly during the year and was 1.09-1.11 g / cm3. An analysis of the initial state of soil density shows that in the winter-spring period, a decrease in density is observed

Table 1: The dynamics of soil density with various tillage technologies, g / cm3

| Option | Soil layer, cm | before the main tillage (October) | at the beginning of field works (April | before sowing winter crops (September) |
|---|---|---|---|---|
| 2006 (initial state) | | | | |
| Long-term tillage (control) | 0-10 | 1,09 | 1,05 | 1,07 |
| | 10-20 | 1,12 | 1,11 | 1,23 |
| | 20-30 | 1,26 | 1,25 | 1,29 |
| | 0-30 | 1,16 | 1,14 | 1,20 |
| Virgin land | 0-10 | 1,02 | 1,00 | 1,02 |
| | 10-20 | 1,08 | 1,06 | 1,09 |
| | 20-30 | 1,22 | 1,20 | 1,22 |
| | 0-30 | 1,11 | 1,09 | 1,11 |
| 2017 (after two crop rotations) | | | | |
| Long-term tillage (control) | 0-10 | 1,13 | 1,06 | 1,10 |
| | 10-20 | 1,18 | 1,12 | 1,22 |
| | 20-30 | 1,29 | 1,28 | 1,31 |
| | 0-30 | 1,20 | 1,15 | 1,21 |
| No-till | 0-10 | 1,06 | 1,03 | 1,05 |
| | 10-20 | 1,11 | 1,09 | 1,10 |
| | 20-30 | 1,19 | 1,20 | 1,22 |
| | 0-30 | 1,12 | 1,11 | 1,12 |
| Virgin land | 0-10 | 1,04 | 1,02 | 1,03 |
| | 10-20 | 1,09 | 1,11 | 1,12 |
| | 20-30 | 1,19 | 1,21 | 1,20 |
| | 0-30 | 1,11 | 1,11 | 1,12 |

both on the cultivated arable land and steppe reserve. This can be explained by the fact that in winter, ordinary chernozem is prone to self-loosening under the influence of temperature fluctuations

E.V. Poluektov [16] came to the similar conclusions when studying the influence of various tillage methods on the agrophysical properties of ordinary chernozem, depending on the degree of erosion. In his studies, he noted that addition density of the arable layer of ordinary chernozem after winter wetting comes to a certain equilibrium state by spring.

If we compare the cultivated arable land and the steppe reserve (virgin land), density of soil compaction in the arable layer is subject to significant fluctuations from 1.16 g / cm3 before tillage to 1.20 g / cm3 through the year before sowing winter crops. At the same time, we did not observe changes in the density of soil compaction in the steppe reserve.

Soil compaction density in 2017, i.e. after two rotations, showed significant differences in the options. In the control option, the soil density in the arable layer (0-30 cm) before the main cultivation was 1.20 g / cm3, i.e. it increased by 0.04 g / cm3 compared with the original value (1.16 g / cm3). By sowing winter crops, the soil density increased to 1.21 g / cm3. It should be noted that the greatest soil compaction was observed in a layer of 20-30 cm, which amounted to 1.28-1.31 g / cm3. With the long-term use of the no-till technology, the soil density was significantly lower - 1.11-1.12 g / cm3.

Consequently, in the control option, the soil gradually acquires a composition close to natural, i.e. soil density approaches an equilibrium.

The soil compaction in the arable layer is due to the compression action of the running systems of agricultural machines. During the dump tillage, the number of technological operations was 8–9. Numerous treatments contributed to soil compaction in the arable layer and formation of the “plow sole”.

Many researchers [16, 17], who observed the soil density, dealt with the arable horizon, although the vegetation conditions largely depend on the root layer composition density.

Due to the insufficient study of soil compaction density in the root-inhabited layer (0-60 cm), we conducted observations of soil compaction density in this layer. Our research determined that while in the arable layer it is possible to vary the density with various treatments, in the subsoil layer the soil remains quite compacted (Table 2).

Table 2: Dynamics of soil density depending on the tillage technology (average for 2012-2017)

| Option | Soil layer, cm | before the main tillage (October) | at the beginning of field works (April) | before sowing winter crops (September) |
|---|---|---|---|---|
| Long-term tillage (control) | 0-30 | 1,21 | 1,18 | 1,20 |
| | 0-60 | 1,36 | 1,32 | 1,34 |
| (No-till | 0-30 | 1,13 | 1,10 | 1,12 |
| | 0-60 | 1,26 | 1,27 | 1,26 |
| Virgin land | 0-30 | 1,11 | 1,09 | 1,10 |
| | 0-60 | 1,27 | 1,25 | 1,25 |

In the control option, the soil density in the 0-60 cm layer was below the optimal value - 1.32-1.36 g / cm3, and this requires additional energy-intensive and high-cost agricultural practices such as deep loosening or chizing in these soil layers.

Numerous passes of agricultural machines lead to the soil compaction and destruction of the soil structure and decrease its porosity (Table 3).

Table 3: Characterization of the agrophysical soil properties with the long-term use of various treatments in the autumn period (average for 2012-2017)

| Option | Soil layer, cm | | | | | |
|---|---|---|---|---|---|---|
| | 0-10 | | 10-20 | | 20-30 | |
| | total porosity, % | density, g / cm3 | total porosity, % | density, g / cm3 | total porosity, % | density, g / cm3 |
| Long-term tillage (control) | 49,7 | 1,14 | 51,4 | 1,17 | 50,3 | 1,30 |
| No-till | 58,6 | 1,05 | 57,9 | 1,10 | 57,2 | 1,19 |
| Virgin land | 61,8 | 1,04 | 59,3 | 1,09 | 59,7 | 1,17 |

Before sowing winter crops using the no-till method, porosity in the control option was better.

## 4. Discussion

Thus, in the experimental option, the soil in the root-inhabited layer had a higher density level than in thecontrol option. One of the important agrophysical soil indicators is its structurally-aggregate state.

Our findings were confirmed by the results of studies on the steppe reserve, where the total soil porosity had maximum values (59.3-61.8%), which is 1.4-3.2% more than in the control option. If we compare the control option with the steppe reserve, differences in porosity are 7.9-12.1%.

Structural soils retain lower density. This determines the favorable water, air, thermal and food regimes. According to N.A. Kachinsky [14], it can be considered generally accepted that fertility of soils that are heavy in grain size distribution, depends on their structure.

The studies conducted in 2012-2017 showed that the soil treatment technology had a significant effect on the soil structure (Table 4).

The long-term use of the no-till technology contributes to the formation of a coarse-grained structure both in the upper (0-10 cm) and arable layers (0-30 cm). Before the main tillage in the control option, the value of the structural aggregates of the upper soil layer (0-10 cm) was 39.9%, and for the no-till technology, it was 52.6%, i.e. 12.7% more than in the control option. In the arable layer, these differences were the same - with the no-till technology it was 11.4% more.

In the steppe reserve, the structural state of the soil was maximum - 61.3-67.9%, which is 21.4% more in the 0-10 cm layer and 16.4% more in the 0-30 cm layer. In spring,

Table 4: The dynamics of structural aggregates with various tillage technologies (average for 2012-2017)

| Option | Soil layer, cm | Structural aggregates> 1 mm | | |
|---|---|---|---|---|
| | | before the main tillage (October) | at the beginning of field works (April) | before sowing winter crops (September) |
| Long-term tillage (control) | 0-10 | 39,9 | 41,2 | 40,1 |
| | 0-30 | 51,5 | 52,8 | 53,6 |
| No-till | 0-10 | 52,6 | 52,9 | 53,4 |
| | 0-30 | 62,9 | 64,6 | 65,0 |
| Virgin land | 0-10 | 61,3 | 62,8 | 63,5 |
| | 0-30 | 67,9 | 68,1 | 68,7 |

determination of the soil structural aggregates revealed their increase in all the options. On arable land, this indicator increased by 1.3-1.7%, and on the steppe reserve - by 0.2%. In the autumn period, in the control option, we identified a decrease in structural aggregates in the upper layer (0-10 cm) by 1.4%, and an increase in the steppe reserve.

Table 5: Dynamics of water-resistant aggregates with various tillage technologies (average for 2012-2017)

| Option | Soil layer, cm | Water resistant aggregates> 0.25 mm | | |
|---|---|---|---|---|
| | | before the main tillage (October) | at the beginning of field works (April) | before sowing winter crops (September) |
| Long-term tillage (control) | 0-10 | 43,1 | 42,6 | 40,4 |
| | 0-30 | 50,3 | 49,4 | 49,9 |
| No-till | 0-10 | 49,7 | 50,5 | 51,0 |
| | 0-30 | 58,9 | 59,6 | 60,2 |
| Virgin land | 0-10 | 69,2 | 68,6 | 70,1 |
| | 0-30 | 71,3 | 71,8 | 72,2 |

The agrophysical properties of ordinary chernozem have changed – the soil structure has deteriorated, dispersion has increased, and chernozem has become more erosion-hazardous.

As our studies have shown, with the long-term use of the no-till technology on ordinary chernozem, a good lumpy-granular structure consisting of more than 50% of lumpy aggregates (> 1 mm in diameter) was formed. They create a basis that determines optimal folding and helps to maintain optimal folding.

We found that the coarse-grained structure is formed on a natural phytocenosis (steppe reserve), which is maintained in optimal conditions. On cultivated arable land, the negative effect of anthropogenic factors is evident. Therefore, we need to develop and apply highly effective agricultural measures that ensure conservation and increase soil fertility. In modern agriculture, the most effective method is the No-till technology.

One of the qualitative indicators of the soil structure is its water resistance, which determines stability of the soil structure (Table 5).

When determining water resistance of the soil structure, we found that in the control option involving winter crops, the number of water-resistant aggregates (> 0.25 mm) decreased from 43.1 to 40.4%. In the arable layer, the number of water-resistant aggregates remained about 50%.

When using the no-till method and in the steppe reserve, water resistance of the structure was constant throughout the entire agricultural year, with the only difference that it was within 50% on the arable land in the upper layer and about 60% in the arable layer. In the steppe reserve, these indicators were 69 and 72%, respectively.

Describing the arable layer by the content of water-resistant aggregates, it should be noted that using the no-till method, this indicator was within 60% throughout the year, which is 8.6-10.3% higher compared with the control option.

Thus, an analysis of the structural composition of the arable layer after 12 years of application of various tillage technologies showed that the long-term use of the No-till technology increases the number of lumpy and water-resistant aggregates in the arable soil layer. It should be noted that the share of water-resistant aggregates larger than 0.25 mm was more than 50%, which indicates the high structural condition of the soil.

Compared to the steppe reserve, the arable land contained less structural aggregates: more than 20% in the control option and more than 12% when using the no-till method. The maintenance of water-resistant aggregates is one of the main criteria for predicting a stable time for optimal soil compaction. If the share of water-resistant aggregates more than 0.25 mm in diameter is less than 45%, the soil is quickly compacted under the influence of the running systems of agricultural machines which deteriorate its agrophysical properties.

We obtained interesting data when analyzing the dynamics of content of water-resistant soil aggregates in the steppe reserve lands. The water-resistant soil structure of the virgin land is less susceptible to seasonal changes. It has a stable value of about 70%, and it is possible to restore water-resistant aggregates on the arable land under cultivation.

Among the most important water-physical properties of the soil, water permeability determines the value and intensity of the surface runoff of melt and storm water; this is crucial in shaping the water regime and protecting the soil from water erosion. The

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value and speed of water permeability depend on the presence of crop cover or crop residues on the surface, as well as human activities, which transforms the density of addition, the structural-aggregate composition.

For a more complete understanding of the relationship between various factors affecting the amount of water absorption, we conducted a comparative study of water permeability of the soil with various cultivation methods (Table 6).

TABLE 6: Water permeability of the soil with various tillage methods, (average for 2012-2017)

| Option | Soil density in the layer of 0-30 cm, g / cm3 | Content of water-resistant aggregates in the layer of 0-30 cm,% | Water permeability of the soil during the first hour, mm | Moisture filtration during the 2nd and 3rd hours, mm |
|---|---|---|---|---|
| Long-term tillage (control) | 1,18 | 49,8 | 312 | 390 |
| No-till | 1,11 | 50,7 | 468 | 621 |
| Virgin land | 1,09 | 69,0 | 659 | 976 |

Studies have established that the most intensive absorption of water was for the steppe reserve and arable lands with the prolonged use of the no-till method. During the first hour of observation, water permeability in the steppe reserve was 659 mm, which is 347 mm more compared to the control option, and 191 mm more compared with the no-till method.

The lowest water permeability can be explained by the fact that the soil had a higher density and a low percentage of water-resistant aggregates in the arable layer. The most intensive absorption of water was observed in the steppe reserve, since there was a sufficiently powerful cover from steppe forbs and the maximum content of water-resistant aggregates was more than 71%.

Water permeability is characterized by high dynamics. Initially, when filling free pores and voids with moisture, water is absorbed at a significant rate. Subsequently, the rate of water absorption decreases and the filtering process begins. Under the influence of pressure, water seeps through the water-conducting pores with a constant value of the steady flow.

We found that the intensive absorption of water decreases after 35-40 minutes. There is a sharp decline due to a strong siltation of pores. Despite the fact that the highest absorption rate was observed in the first quarter of an hour (186 mm), later water permeability decreased, and amounted to only 126 mm. Subsequently, the moisture filtration rate decreased faster than in the case of the no-till method. In total, during three hours of observations, water absorption was 1089 mm, which is 687 mm more than in the control option.

In the virgin area, water permeability of the soil was maximum - 659 mm, which is 347 mm, or 2.1 times more than in the control option. Compared with the no-till option, these differences were significantly smaller - 191 mm, or 29% than in the steppe reserve. On the virgin plot, the moisture filtration amounted to 1989 mm; during the second and third hours of observations, it increased by 976 mm. Consequently, soil treated with the tillage method better absorbs short rains; however, with the no-till method, rains of low intensity and intense long-lasting rain are absorbed better. This protects the soil from water erosion on sloping lands.

Thus, the results have established that the most intensive absorption of water is observed on the steppe reserve lands and using the no-till method, i.e. in the options with the best agrophysical properties in the arable soil layer, which is one of the determining factors affecting the yield of field crops.

Stable yield is the main indicator of effectiveness of the applied agricultural methods regardless of the prevailing weather conditions.

The yield was different for different crops (Table 7).

Table 7: Productivity of field crops with various tillage technologies (average for 2006-2018)

| Crop | Yield, t / ha | | Gain | |
|---|---|---|---|---|
| | Tillage | No-till | c/ha | % |
| Winter wheat [1] | 47,6 | 51,4 | 3,8 | 7,9 |
| peas | 13,6 | 18,8 | 5,2 | 38,2 |
| Winter wheat2 | 42,1 | 45,5 | 3,4 | 8,1 |
| Sunflower | 17,7 | 22,8 | 5,1 | 28,8 |
| Winter barley | 47,8 | 50,9 | 3,1 | 6,5 |
| Winter rape | 29,0 | 29,6 | 0,6 | 2,1 |

In 2006-2018, the no-till technology increased the crop yield. The yield of winter wheat sown after winter rape averaged 51.4 kg / ha, which is 3.8 kg / ha, or 7.9% higher than in case of the till technology. We observed a similar increase in the yield of winter wheat sown after peas and winter barley. It should be noted that for peas and sunflowers, the advantage of the no-till technology was 5.2 and 5.1 c / ha, respectively. Only for winter rape, the yield did not change and was 29.0-29.6 c/ha.ъ

## 5. Conclusion

Thus, the long-term studies allowed us to draw conclusions about the optimal agrophysical properties of ordinary chernozem when using the no-till technology. This ensures the rational use of moisture, creates favorable conditions for realizing the productivity potential of field crops and indicates a more intensive conservation use of arable land in the arid conditions of Rostov region.

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## Conflict of Interest

The authors have no conflict of interest to declare.

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