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Influence of the No-till Technology on the Bulk Density of the Calcic Chernnozem of the Volgograd Region

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ABSTRACT

Background: Technologies for the cultivation of agricultural plants have positive and negative sides. The indisputable positive features of No-till technology include the elimination of the cost of fuel needed for tillage. The negative aspects potentially include an increase in soil density, leading to a deterioration in plant nutrition. This article presents research materials on the impact of crop cultivation technologies on the physical properties of soils. The authors study in detail the issue of changes in the soil bulk density index depending on the applied agricultural technology in comparison with the treated soil as a control. It is important to note that the study of the features of the use of agricultural technologies has a pronounced zonal aspect. The object of study is represented by the soil cover of an agricultural landscape located in the steppe zone of the Volgograd region. The soil cover of the study area is represented by Calcic Cherrnozem. No-till technology has been used in this agricultural landscape for 9 years.

Methods: The changes in the soil bulk density index depending on the applied agricultural technique was studied in detail in comparison with the treated soil as a control variant. The study considered three options: a) no-till tillage, b) traditional tillage technology, c) soil covered with natural vegetation. Determination of the density of soil composition was carried out by the cutting ring method. Under field conditions, soil samples were taken from pits and analysis was carried out in laboratory.

Result: The results revealed that soil compaction was occurred in no-till technologe. The bulk density of 10-20 cm soil layer was 1.33 g cm^3 under no-till? 0.81 g cm^3 under traditional technology and 1.14 g cm^3 under natural vegetation.

Key words: Bulk density, Classical technology, Duration of cultivation according to technology, No-till technology, Soil cultivation technologies, Soil properties.

INTRODUCTION

The direct seeding technology is becoming popular due to its beneficial effect on ecology, reduction in soil erosion and defoliation and decomposition of soil organic matter. Secondly, this technology reduces the anthropogenic load on arable agricultural land and production costs. However, these statements are controversial (Pittelkow *et al*., 2015; Kiryushin, 2013; Ovchinnikov, 2011; Solonkin *et al*., 2019; Vlasenko *et al*., 2021; Kazeev *et al*., 2020; Esaulko *et al*., 2021).

The problem of studying the influence of modern agricultural technologies on agricultural landscapes is multifaceted and often interdisciplinary in nature. The aim of the research was to study the changes in the bulk density of soil in the fields tilled using the new technology No-Till and those tilled according to the traditional technology and to compare the data obtained with soil in the areas with natural vegetation.

The study of changes in the physical properties of soils under the influence of the applied agricultural technologies form the basis of many future areas of scientific research, in particular, concerning the influence of the No-till technology on the development of erosion processes, the availability of nutrients to cultivated plants, *etc*. (Dridiger *et al*., 2018; Montgomery, 2007; Menkina, 2019; Volkov *et al*., 2021; Skaalsveen *et al*., 2019).

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MATERIALS AND METHODS

The research object is represented with the soil cover in the territory of the Agro-3 farm, located in the Bocharovsky farmstead of the Novoanninsky district of the Volgograd region, which is part of the agricultural holding Gelio-Paks.

In 2012, an experimental field was laid in the Agro-3 farm, which has been used to compare various aspects of the application of the No-Till technology with the traditional technology.

The traditional agricultural technology was used for growing crops in the steppe zone. Its main distinguishing features are the use of a plow as a tool in the main tillage and the fallowing of land as a method of moisture accumulation.

The studied area refers to the northwestern steppe agroclimatic region. The main indicators of heat and moisture availability are as follows: the sum of active temperatures is 2700-2800°C; hydrothermal coefficient (HTC) is 0.8-0.7; the average temperature in July is -21.2 -21.5°C; the average temperature in January is -9.8 -11.3°C; precipitation of the warm period -250 -330 mm; the frost-free period lasts 148-165 days; the average height of the snow cover is 17-18 cm (Atlas of the Volgograd region, 1993; Degtyareva and Zhulidova, 1970).

The modern relief is characterized by weak manifestation of erosion processes: the length of gully erosion is 0.2-0.5 km km^{2-1} (Selezneva, 2019). The natural vegetation cover is diverse and formed mainly by forb-fescue-feather grass associations.

The soil cover is represented with southern chernozems according to the USSR Soil Classification (Classification and diagnostics of soils of the USSR, 1977). According to the Russian Soil Classification, it corresponds to texture-carbonate chernozem (Classification and diagnostics of Russian soils, 2004) and according to the international soil classification-Calcic Chernozem (World Reference Base for Soil Resources, 2014).

Soil and climatic conditions of this region are very favorable for agriculture. Over 70% of the territory is plowed up.

The research methodology consists of four main stages: 1) preliminary field surveys; 2) field studies of soil profiles; 3) analytical study of soil samples in laboratory and 4) analysis and synthesis of the data obtained.

During the first stage, the fields were surveyed using a field mechanical density meter. Preliminary field research resulted in the selection of key sites for basic field studies of soil cover in soil profiles. The field studies included morphological description of soil profiles and soil sampling for analysis in laboratory.

Determination of the bulk density of soils was carried out by the cutting ring method (Kachinsky, 1965; Pansu *et al*., 2014; Mineev, 2004). Soil samples were taken from soil profiles every 10 cm to a depth of 1 m. To prevent errors associated with sampling, samples were taken in four replicates (Dospekhov, 1985, 2011).

Soil profiles were laid in the experimental field which consisted of 3 land plots: an area cultivated using the No-till technology; an area cultivated using the traditional technology, as well as a steppe area with natural vegetation (Fig 1).

During the research period, the experimental field was occupied by sunflower crops. Field studies were carried out in the summer months of 2021 and 2022.

Soil samples taken during the field phase of research were analyzed in laboratory. A drying oven and an analytical balance were the main equipment used in the course of the laboratory research. This work was carried out at the Federal Scientific Center of Agroecology, Complex Melioration and Protective Afforestation, Russian Academy of Sciences.

RESULTS AND DISCUSSION

The preliminary surveys conducted with the use of a field density meter allowed for the identification of a compacted soil layer in the fields tilled with the use of the No-till technology. The depth of this layer varies across fields within the range of 8-23 cm with the average value of about 15 cm.

Fig 2 shows photographs of soil profiles laid out for morphological studies of the soil cover and soil sampling to determine the bulk density of soils in laboratory conditions. The morphological studies of the soil cover allowed us to make up morphological descriptions of soil profiles.

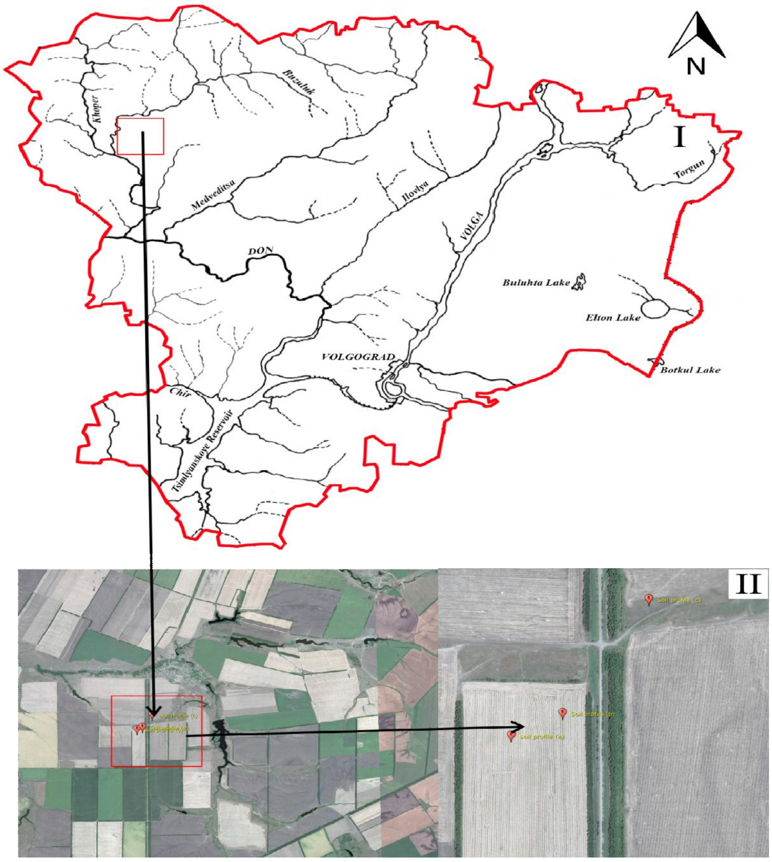
a) Soil profile (a) is laid in sunflower crops on the experimental field with the use of direct seeding technology. The thickness of horizon A_{plough} is 22 cm. The color is black, homogeneous. The soil is moist, loose, granular, heavy loamy. Horizon AB with a thickness of 17 cm stands out. The color is black, homogeneous. The horizon is moist, dense, merged, heavy loamy. The transition to horizon B is gradual. The depth of horizon B is 27 cm. The color of the horizon varies from dark chestnut to light chestnut. The color heterogeneity is due to numerous inclusions of loess with lime nodules and humus streaks. The horizon is damp, dense, the structure is coarse-cloddy, heavy loamy. The transition to horizon C is gradual. Horizon C extends to a depth of 66 cm. The color of the horizon is homogeneous. Single inclusions of loess with lime nodules are observed. The horizon is dense, moist, structureless, heavy loamy.

b) Soil profile (b) is laid in sunflower crops on the experimental field with the use of the traditional technology. The thickness of horizon A_{plough} is 28 cm. The color is black, homogeneous. The soil is moist, dense, granular, heavy loamy. The 16 cm thick AB horizon is weakly manifested. The transition is gradual. Transitional 25 cm thick horizon B is distinguished. The color of the horizon changes from dark chestnut to light chestnut. The color heterogeneity is due to numerous inclusions of loess with lime nodules and humus streaks. The soil is moist, dense, the structure is coarse-cloddy, heavy loamy. The transition is gradual. Horizon C extends to a depth of 69 cm. The color of the horizon is chestnut. The horizon is evenly colored. Inclusions of loess with lime nodules are observed. The horizon is dense, moist, structureless, heavy loamy.

c) Soil profile (c) is laid in the land plot with natural vegetation. Horizon A_0 represents grassy litter of grass-forb vegetation mold 4 cm thick. The thickness of horizon A is 23 cm. The color is black, homogeneous. The soil is fresh, loose, fine-grained, medium loamy with abundant inclusions of small roots. The transition is sharp. Horizon B is 47 cm thick. The color is light chestnut, heterogeneous due to numerous inclusions of loess with lime nodules and humus streaks. The soil is moist, dense, the structure is coarse-cloddy, medium loamy. There are molehills. Horizon C extends to a depth of 60 cm. The horizon is chestnut, evenly colored. There are no inclusions of loess with lime nodules. The soil is compacted, moist, structureless, medium loamy.

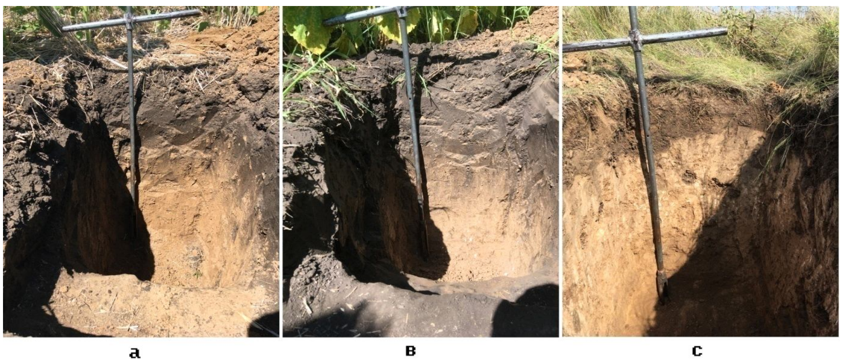
The conducted morphological studies of the structure of the studied profiles made it possible to establish the upper boundary of the compacted layer of soils tilled with the use of the No-till technology as well as the thickness of this layer. For the soil of the experimental field, this indicator is 20 cm-horizon AB of the soil profile (a).

Table 1 shows the data of laboratory studies of the bulk density of the surveyed soils. Analysis of the data presented in Table 1 allowed us obtain the following information.



I - Volgograd region; II - fragment of space image of soil sampling points: a- Area of the experimental field tilled using the No-till technology; b- Area tilled with the use of the traditional technology; c- Area with natural vegetation.

Fig 1: Location of the study area.



a- Area of the experimental field tilled with the use the No-till technology; b- Area tilled with the use the traditional technology; c- Area with natural vegetation.

Fig 2: Soil profiles.

1. In general, if we evaluate the arithmetic mean values of the index of soil bulk density, then all the studied variants correspond to an equal value of 1.1 g cm^{3-1}.

2. The maximum values of the soil bulk density index are as follows: 1.4 g cm^{3-1} - for a 80-90 cm layer of the soil profile (a); 1.31 g cm^{3-1} - for a 60-70 cm layer and a 70-80 cm layer of the soil profile (b); 1.43 g cm^{3-1} - for a 50-60 cm layer of the soil profile (c). These values correlate with the morphological description of the soil cover and refer to the soil horizons with the maximum content of loess with lime nodules. The carbonate soil layer is an important distinguishing feature of steppe soils.

3. The minimum values of the index of soil bulk density are as follows: 0.86 g cm^{3-1} - for a 0-10 cm layer of the profile (a); 0.81 g cm^{3-1} - for a 10-20 cm layer of the profile (b); 0.94 g cm^{3-1} - for a 0-10 cm layer of the profile (c). These values refer to the surface layers of the soil. The lowest soil density refers to the variant of the soil tilled according to the traditional technology.

The data of laboratory analyses confirm the data of preliminary studies conducted with the use of a field density meter that let reveal the compaction of the root layer of soil in the fields tilled according to the new technology. The bulk density of the soil cultivated with the use of the No-till technology is equal to 1.33 g cm^{3-1} for a layer of 10-20 cm.

In recent decades, No-till technology has been widely introduced into farming practice (Pittelkow *et al*., 2015; Kiryushin, 2013; Ovchinnikov *et al*., 2011; Duboc *et al*., 2011). The development of ideas on minimizing tillage has also been promoted by the current climate agenda to achieve carbon neutrality (Chen, 2021; Liu *et al*., 2022; Huovila *et al*., 2022; Reijnders, 2023) in all spheres of human activity, including agriculture.

According to FAO, No-till technology refers to conservation agriculture, which is based on three principles (Mandal and Mani, 2020; Choudhary *et al*., 2016): 1 - minimal mechanical impact on soil; 2 - permanent soil organic cover; 3 - plant species diversification. The practice of conservation agriculture is aimed at preserving and increasing soil fertility, improving soil moisture availability and increasing soil biological resources, which are the most urgent issues under anthropogenic pressures and climate change (Gupta, 2019; Kust *et al*., 2020; Derpsch *et al*., 2010; Belyakov and Koshelev, 2023; Zhang *et al*., 2022; Tufa *et al*., 2023; Francaviglia *et al*., 2023).

A number of authors (Kiryushin, 2013; Konischev, 2020; Tupitsin and Valiaiki, 2001; Cherkasov *et al*., 2011) argue that the "primitive" minimization of tillage established in Russia leads to increased erosion processes, weediness of crops and, in the eastern steppe regions of the country, to the growth of dust storms, which has been happening recently (Belyakov and Koshelev, 2023; Belyakov, 2021; Kulik and Dubenok, 2016; Shinkarenko *et al*., 2020).

As a result of our research it was established that on the studied fields of the farm with No-till technology the problem of erosion processes development differs significantly. Thus, the territory of Agro-1 (Novokievka farm) belongs to Medveditsky Yars territory with an average manifestation of gully erosion 1-2 km km^{2-1}; the territory of Agro-3 (Bocharovsky farm) belongs to Khopersko-Buzulukskaya plain, territory with a weak manifestation of gully erosion at 0.2-0.5 km km^{2-1}.

These specific indicators are eloquent evidence of the fact that the problem of erosion processes development is more relevant for the farm Agro-1. Closely related to the development of gully erosion is the problem of soil cover condition of hollows located on arable land. To assess the state of the processes in Agro-1 (Novokievka village), ground reconnaissance reconnaissance traversals of some hollows were made (Fig 3). Traversals of the hollow valleys showed active, progressive state of erosion processes. As one moves from the top to the mouth of the hollows, one can observe traces of water erosion everywhere-transit outflow and accumulation of fine-grained soil. Soil washout processes are very strongly developed in the hollows-one can observe outcrops of bedrock (clay) in the hollows' thalweg. Water channels are concentrated and form a single channel. The mouths of scour holes are interlocked with the existing hydrographic network (gullies) - the stage of transition of scour holes into gullies or the "hanging gully" stage.

The results of our research indicate a higher soil density of fields cultivated with No-till technology in comparison with conventional tillage. They are consistent with the research data obtained for chernozems of the Voronezh region (Struchkova *et al*., 2019; Artemyeva *et al*., 2019).

According to Selezneva, Dedova (2019) the density of erosion network for different territories of Volgograd region varies 40 times from 0.1 to 4 km km^{2-1}. An increase in soil density in the 20-30 cm layer especially in rugged terrain can contribute to the development of erosion processes, because during spring snowmelt due to over-compacted soil layer, surface runoff may not pass into in-soil runoff (Barabanov, 2020; Barabanov *et al*., 2018; Yasinsky and Kashutina, 2007; Dagesse, 2010; Cerda *et al*., 2021; Kumar

Table 1: Bulk density of soil depending on the variant of the applied technology, g cm^{3-1}.

Sampling depth, cm	No-till	Traditional technology	Untilled soil
0-10	0.86	0.95	0.94
10-20	1.33	0.81	1.14
20-30	1.08	0.95	1.22
30-40	0.89	1.20	0.96
40-50	0.97	1.25	1.17
50-60	1.02	1.08	1.43
60-70	1.03	1.31	1.10
70-80	1.16	1.30	1.03
80-90	1.40	1.18	1.20
90-100	1.26	1.08	0.92
Average value 0-20 cm	1.09	0.88	1.04
Average value 0-100 cm	1.1	1.1	1.1

Fig 3: Photo of soil erosion location on no-till fields.

et al., 2022; Hieke and Schmidt, 2013), this is also true for storm precipitation in the rest of the seasons of the year.

Thus, in conjunction with other aspects of the impact of the application of the technology under consideration (Struchkova *et al*., 2019; Nikitin *et al*., 2020; Voloshenkova *et al*., 2021; Singh *et al*., 2010; *etc*.), it is important to note the need to develop a set of measures aimed at compensating for the impact of factors that reduce crop yields, weediness of crops, development of erosion processes and further improvement of this technology in the zonal aspect for the territory of Russia.

CONCLUSION

The conducted research allowed for the identification of soil compaction in the fields tilled with the use of the No-Till technology. Examination of the fields with a mechanical density meter made it possible to establish the range of depths of the compacted soil layer - from 8 to 23 cm with the average value of about 15 cm. Morphometric studies of the soil cover made it possible to establish the thickness of this layer. Thus, for the experimental field, this indicator makes 20 cm. Laboratory analysis of soil samples allowed us to determine the value of the bulk density index. The value of this index for the soil corresponding to the use of the No-till technology on the experimental field for a layer of 10-20 cm is equal to 1.33 g cm^{3-1}. This value exceeds the value of the bulk density index for the soil corresponding to the variant of tillage according to the traditional technology, as well as the value corresponding to untilled soils.

Thus, the obtained research results show that on the southern chernozems in the conditions of the Volgograd region, the thickness of the humus horizon on the cultivated arable land reaches 22-28 cm and together with the AB horizon -39-44 cm, which indicates positive processes in relation to virgin soil indicators. The No-till technology promotes the appearance of a compacted soil layer at a depth of 10-20 cm, with a thickness of 20 cm, as compared to the traditional tillage system. The average values of soil density are within the biological requirements of agrophytocenoses - 1.15-1.23 g cm^{3-1} for Southern chernozems.

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Conflict of interest

All authors declare that they have no conflicts of interest.

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