The tillage effect on the change of soil structure

Galina Parkhomenko¹, Sergei Kambulov¹, Anastasiya Olshesvskaya², Arkadiy Babadzhanyan², Natalia Gucheva², Irina Mekhantseva²

¹State Scientific Establishment “Agricultural research center “Donskoy”, Russian Federation, Zernograd, Lenina st., 14
²Don State Technical University, Russian Federation, Rostov-on-Don, Gagarina sq., 1

E-mail: parkhomenko.galya@yandex.ru

Abstract. In the arid conditions of the southern regions of Russia, cultivated crops lack moisture. At the same time, agronomically feasible tillage becomes important. Ecological safety of the environment presumes protecting the land resources from possible negative anthropogenic impact. Humus accumulation decreases due to increasing soil compaction. Soil compaction is a type of physical degradation. Soil degradation occurs as a result of excessive loads. Soil compaction is the cause of increasing erosion processes. In the fractured porous massif of the treated soil, moisture loss from the depth of the formation during physical evaporation is detected. Physical evaporation of moisture in arid conditions leads to desiccant soil degradation. Pseudo-compaction of the lower part of the treated layer can occur when loosening only the surface layers, which leads to hydrolysis degradation of chernozem soil. The factors for the development of man-made soil degradation as a result of its processing by tillage tools of various types are studied, and the results of the studies are presented. Recommendations for reducing their impact on cultivated soil horizons have been developed, and working bodies for reducing the negative impact on the soil have been proposed. The feasibility of flat-cutting processing of the surface soil layer and the deepening of the subsoil layer by chisel working bodies is proved.

1. Introduction

V.V. Dokuchaev, P.A. Kostychev, A.A. Izmailskii, N.M. Tulaykov in their researches noted that soil cultivation is of great importance in the arid conditions of the southern regions of the country, where cultivated crops lack moisture and groundwater lies deep. The fractured porous [1] mass of soil is formed after mechanical treatment, inside of which preferential moisture flows [2] are formed. They are directed both deep into the formation (during precipitation) and to the field surface, leading to moisture loss during physical evaporation. Only surface treatment, such as diskimg, is carried out in order to prevent physical evaporation of moisture from the arable layer, which leads to dry soil degradation when combined with atmospheric drought. However, the so-called (according to the classification of Landscape Geochemistry and Soil Geography Department of Moscow State University) pseudo-compaction of the lower part of the arable layer may occur after constant surface treatments without deep loosening of the formation. It can lead to hydrolytic soil degradation due to its dehumification, especially chernozem soil. Frequent use of dump plowing leads to dehumification. Thus, the 13-year dumping of the southern carbonate chernozem reduced the humus content in the 20-cm soil layer by 10%, and the 30-year by 20%. The stabilization of the humus balance is noticeable with a reduction in the number of dump plowing. Soil over-consolidation can also lead to physical
degradation, which is a negative transformation process of the formation structure from the micromorphometric point of view, resulting in a decrease in the number of agronomically valuable aggregates. Without tillage, the formation structure at long-term maintenance in the reservoir mode can no longer be decompressed to the compaction value in its natural state, but it can also decompress from 1.40-1.50 to 1.20-1.28 g/cm$^3$ [3, 4].

Degradation is characterized by a change in soil properties as a result of anthropogenic impact that worsens the physical condition and agronomic structure. At the same time, the deterioration of the water-air regime, the vital processes of microorganisms can be observed. It is also the cause of increased erosion processes. In addition, the energy efficiency of tillage units [5] and operational reliability [6] decrease when operating on over-consolidated soils, the process indicators [7] get worse, and an increased deterioration rate of the working bodies can be observed.

One of the ways to prevent soil degradation is the periodic alternation of moldboard plowing with deep subsurface loosening with chisel and flat-cutting working bodies. The soil with a good structure and agronomically valuable moisture-containing aggregates is introduced into the crop culture during subsoiling, which will lead to boosting the vital processes of microorganisms. There is a decrease in soil compaction when using deep subsurface cultivation. The goal of research is to determine the effect of subsurface loosening on soil structure change.

2. Materials and Methods

The studies were carried out on untreated stubble background immediately after harvesting winter wheat. Sampling for determining the structure, soil grading and preparatory measures for laboratory and field studies were carried out in accordance with Russian State Standard GOST 17.4.4.02 “Protection of Nature. The soil. Methods of sampling and sample preparation for chemical, bacteriological, helminthological analysis”. The total number of aggregates was determined using dry and wet sieving according to the methodology of N.I. Savvinova and I.V. Kuznetsova. During dry sieving, soil samples brought to an air-dry state by drying with a thin layer under natural conditions, were divided into the following fractions using a set of sieves: more than 10 mm; 10-5 mm; 5-3 mm; 3-2 mm; 2-1 mm; 1-0.5 mm; 0.5-0.25 mm and less than 0.25 mm. Then, the percentage of crumbs of each fraction was determined by weighing. Wet sieving was carried out directly in water using a set of sieves with hole diameters of 5 mm; 3 mm; 2 mm; 1 mm and 0.25 mm. Analysis of the physical properties of the soil was carried out in accordance with Russian State Standard GOST 5180 “Soils. Laboratory methods for determining physical characteristics”. The density of the solid phase of the soil was determined by the pycnometric method. The soil samples in an air-dry state with a predetermined hygroscopic humidity were used. Density was determined using the weight method, the ratio of the soil sample mass to the volume, taking humidity into account. The soil was prepared for analysis by grinding samples, followed by sieving through sieves of 1 and 0.25 mm. Porosity was determined by the ratio of the solid phase density and the density of the soil itself. The obtained research results are presented in the form of arithmetic mean values, their adequacy was checked according to the Student test at a 5% significance level.

3. Research results

The considered soil is represented by ordinary chernozem, slightly humic, powerful light argillic on loessal clays (table 1).
Table 1. Physical properties of the studied soil.

| Repetition | Sampling depth, cm | Hygroscopic humidity, % | Soil density, g/cm³ | Soil phase density, g/cm³ | Porosity, % |
|------------|-------------------|-------------------------|---------------------|--------------------------|-------------|
| 1          | 5-15              | 4.7                     | 1.21                | 2.67                     | 54.7        |
| 2          | 5-15              | 4.6                     | 1.20                | 2.68                     | 55.2        |
| 3          | 15-25             | 4.7                     | 1.16                | 2.69                     | 56.9        |
| 1          | 5-15              | 4.3                     | 1.32                | 2.70                     | 55.1        |
| 2          | 15-25             | 4.4                     | 1.33                | 2.69                     | 50.6        |
| 3          | 15-25             | 4.4                     | 1.38                | 2.68                     | 48.5        |
| 1          | 25-35             | 4.5                     | 1.30                | 2.69                     | 51.7        |
| 2          | 25-35             | 4.7                     | 1.35                | 2.69                     | 49.8        |
| 3          | 25-35             | 4.6                     | 1.32                | 2.67                     | 50.6        |

The studied soil is light argillic (3.0-5.0% and 60-75% according to the classification of N.A. Kachinsky) dusty, of steppe type soil formation by hygroscopic humidity (4.3-4.7%) and by the content of fractions (table 2) finer than 0.01 mm (63.3-66.7%). The soil density (1.16-1.38 g/cm³) is high, especially for the layer below the surface treatment (15 cm and deeper – 1.30-1.38 g/cm³), it exceeds the optimal value and is often critical. According to the standards for changing the physical properties of chernozems depending on the nature of the anthropogenic impact, the optimal density range of the tilth soil in the Rostov Region is 1.10-1.25 g/cm³, critical – more than 1.35 g/cm³ with a humus content of 3.5-4.5% [3]. Therefore, it is necessary to soften the soil by mechanical treatment.

Table 2. Granulometric composition of the studied soil.

| Sampling depth, cm | 0.06-0.250 mm | 0.025-0.050 mm | 0.005-0.010 mm | 0.001-0.005 mm | less than 0.010 mm | less than 0.001 mm (clay) | less than 0.001 mm (dust) | 0.00-0.0001 mm (sand) | Sum of fractions, % |
|--------------------|---------------|----------------|----------------|----------------|-------------------|--------------------------|--------------------------|----------------------|---------------------|
| 5-15               | 0.7           | 5.8            | 30.2           | 14.5           | 17.9              | 30.9                     | 63.3                     | 62.6                 | 6.3                 |
| 15-25              | 0.2           | 5.8            | 27.3           | 14.5           | 15.6              | 36.6                     | 66.7                     | 57.4                 | 6.0                 |
| 25-35              | 0.1           | 4.5            | 28.7           | 12.3           | 16.9              | 37.5                     | 66.7                     | 57.9                 | 4.6                 |

The use of plane cutter contributes to an increase in the content of agronomically valuable aggregates in the surface soil layer (5-15 cm) by 8.6%, in the layer of 15-25 cm by 8.2%. And in the lower soil layer (25-35 cm) after plane cutting, on the contrary, there is a decrease of 11.1% in the content of agronomically valuable aggregates (0.25-10.0 mm), which can be seen from the analysis of the data obtained (table 3, table 4).
After chisel processing, on the contrary, the content of agronomically valuable aggregates in the surface layer (5-15 cm) decreases by 31%, although it increases in layers of 5-15 cm by 5.0% and 25-35 cm by 8.4%.

A good (more than 60%) soil condition is observed (table 4) according to the method of N.I. Savvinov without treatment, after flat-cutting and chisel tillage at all depths, except for satisfactory (40-60%) with surface chiseling (5-15 cm).

Thus, the use of flat-cutting processing is agronomically appropriate at a depth of up to 25 cm, and soil deepening must be performed with chisel working bodies.

The water resistance of the soil structure is analyzed (table 5).

### Table 3. The structural composition of the studied soil (dry sieving).

| Sampling depth, cm | More than 10.0 mm | 10.0-5.0 mm | 5.0-3.0 mm | 3.0-2.0 mm | 2.0-1.0 mm | 1.0-0.5 mm | 0.5-0.25 mm | Less than 0.25 mm |
|-------------------|------------------|-------------|------------|------------|------------|------------|-------------|------------------|
| Before tillage    |                  |             |            |            |            |            |             |                  |
| 5-15              | 17.7             | 16.7        | 11.5       | 8.4        | 14.6       | 10.4       | 10.4        | 10.3             |
| 15-25             | 32.9             | 28.1        | 16.8       | 7.5        | 6.7        | 3.4        | 2.4         | 2.2              |
| 25-35             | 21.6             | 27.9        | 18.8       | 9.5        | 10.0       | 5.2        | 3.6         | 3.4              |
| After flat tillage|                  |             |            |            |            |            |             |                  |
| 5-15              | 11.5             | 17.4        | 16.7       | 12.1       | 16.1       | 9.5        | 8.8         | 7.9              |
| 15-25             | 21.0             | 24.0        | 14.5       | 8.6        | 11.2       | 8.2        | 6.6         | 5.9              |
| 25-35             | 31.3             | 23.0        | 12.4       | 7.5        | 9.4        | 6.2        | 5.4         | 4.8              |
| After chisel tillage|                |             |            |            |            |            |             |                  |
| 5-15              | 53.1             | 9.5         | 5.6        | 4.9        | 8.4        | 6.7        | 5.9         | 5.9              |
| 15-25             | 28.5             | 20.6        | 11.4       | 7.6        | 11.1       | 8.4        | 7.8         | 7.3              |
| 25-35             | 11.8             | 29.6        | 19.0       | 11.0       | 11.8       | 6.9        | 5.1         | 4.8              |

### Table 4. The content of agronomically valuable air-dry units (0.25-10.0 mm) in the studied soil.

| Sampling depth, cm | The content of fractions with a size of 0.25-10.0 mm, % |
|-------------------|--------------------------------------------------------|
|                   | Before tillage | After flat tillage | After chisel tillage |
| 5-15              | 72.0          | 80.6              | 41.0                  |
| 15-25             | 64.9          | 73.1              | 66.9                  |
| 25-35             | 75.0          | 63.9              | 83.4                  |

### Table 5. Composition of water-resistant aggregates (0.25-5.0 mm) in the studied soil (wet screening).

| Sampling depth, cm | Fraction composition, % | Sum of fractions with a size of 0.25-5.0 mm, % |
|-------------------|--------------------------|----------------------------------------------|
|                   | 5.0-3.0 mm               | 3.0-2.0 mm                                   | 2.0-1.0 mm                                   | 1.0-0.5 mm                                   | 0.5-0.25 mm                                   |
|                   |                           |                                              |                                              |                                              |                                              |
| Before tillage    |                           |                                              |                                              |                                              |                                              |
| 5-15              | 0.4                      | 1.6                                          | 3.2                                          | 16.6                                         | 17.8                                         | 40.6                                         |
| 15-25             | 1.4                      | 6.6                                          | 17.8                                         | 16.6                                         | 15.6                                         | 58.0                                         |
| 25-35             | 1.0                      | 20.8                                         | 22.8                                         | 12.4                                         | 34.8                                         | 65.2                                         |
| After flat tillage|                           |                                              |                                              |                                              |                                              |                                              |
| 5-15              | 0.8                      | 2.6                                          | 6.6                                          | 21.0                                         | 17.6                                         | 48.6                                         |
| 15-25             | 2.4                      | 3.6                                          | 7.2                                          | 17.4                                         | 16.2                                         | 46.8                                         |
| 25-35             | 3.4                      | 3.8                                          | 7.4                                          | 19.4                                         | 15.6                                         | 49.6                                         |
After chisel tillage

| Layer | Before | After |
|-------|--------|-------|
| 5-15  | 1.0    | 3.6   |
| 15-25 | 1.0    | 3.2   |
| 25-35 | 1.8    | 7.6   |

The positive feature of flat cutting processing of the surface soil layer (5-15 cm) should be noted by the change in the content of water-resistant aggregates (table 5). The flat cutting contributed to the increase of aggregates by 8%.

In other cases, the content of water-resistant aggregates (0.25-5.0 mm) decreased.

According to the method of I.V. Kuznetsova (table 5), the water resistance before tillage is excellent at a depth of 25-35 cm (60-75%), and good in layers of 5-15 cm and 15-25 cm - (40-60%).

After flat tillage, water resistance of the soil according to the method of I.V. Kuznetsova is good (40-60%) in all considered layers (5-35 cm).

After chisel soil cultivation, water resistance of the soil according to the method of I.V. Kuznetsova is good (40-60%), even close to excellent (58.6% with the required 60%) in the lower layer (25-35 cm), and satisfactory in the layers of 5-15 cm and 15-25 cm (30-40%).

Thus, deepening the treated layer with chisel working bodies is agronomically appropriate, since it is used with a water-resistant stable structure.

4. Conclusions

As a result of studies, it was found that the studied soil has high density, especially the layer below the surface treatment (15 cm and deeper – 1.30-1.38 g/cm³), exceeds the optimal value (1.10-1.25 g/cm³) and often critical one (more than 1.35 g/cm³). Therefore, it is necessary to soften the soil using mechanical treatment.

It has been established that the use of flat-tillage increases the content of agronomically valuable aggregates in the surface soil layer by 8.6%, by 8.2% in the 15-25 cm layer, a decrease of 11.1% is observed in the lower soil layer. After chisel processing, on the contrary, the content of agronomically valuable aggregates in the surface layer decreases by 31%, but then increases in 15-25 cm layers by 5.0%, and by 8.4% in 25-35 cm layer. The change in the content of water-resistant aggregates proved the expediency of flat-carved processing of the surface soil layer, which contributed to their increase by 8%. It is recommended to deepen the treated layer by chisel working bodies, since soil with a water-resistant stable structure is used.

References
[1] Burton G, Shend D, Cambell C 2014 Géotechnique Letters 4 2 pp 88-93 http://doi.org/10.1680/geolett.14.00003
[2] Konrad J, Lebeau M 2015 Canadian Geotechnical Journal 52 12 pp 2067-2076 https://doi.org/10.1139/cgj-2014-0300
[3] Medvedev V, Slovinska-Yurkevich A, Brik M 2012 Gruntoznovstvo 13 1-2 pp 5-22
[4] Gao Y, Sun D, Zhu Z, Xu Y 2018 Acta Geotechnica pp 1-12 http://doi.org/10.1007/s11440-018-00662-5
[5] Parkhomenko S, Parkhomenko G 2016 Innovatsii v sel'skom khozyaystve 3 18 pp 40-47
[6] Parkhomenko G, Parkhomenko S 2016 Trudy GOSNITI 122 pp 87-91
[7] Parkhomenko G, Parkhomenko S 2017 Khraneniye i pererabotka zerna 1 209 pp 55-60