# Peculiarities of tillage in the conditions of dry farming in the cultivation of soybeans

*Yulia* Semenikhina[1*], *Sergey* Kambulov[1,2], and *Victor* Pakhomov[1,2]

[1]Federal State Budgetary Scientific Institution, Agrarian Research Center "Donskoy", Nauchny Gorodok st, 3, 347740 Zernograd, Russia
[2]Don State Technical University, Gagarina Square, 1, 344010 Rostov-on-Don, Russia

**Abstract.** Soy is a multipurpose oilseed crop. It is highly nutritious and improves soil fertility. Rainfed agriculture needs to improve crop cultivation technologies and focuses on various methods of soil cultivation that contribute to the formation of an optimal agrophysical structure that contributes to a consistently high soybean yield. Therefore, it is expedient and relevant to study the influence of various methods of tillage on the density and hardness of the soil in two phases of soybean development (beginning of soybean vegetation and before harvesting) with the identification of its yield. The following methods of tillage have been studied: flat-cutting, layer-by-layer, mouldboard and without tillage (direct sowing). The highest soil density in both phases of soybean development on the agrobackground without tillage was 1.34 g/cm$^3$ and 1.27 g/cm$^3$. The decrease in soil density was revealed by 13.43-16.53% with flat-cut tillage; by 6.71-16.53% with layer-by-layer tillage; by 5.22-5.51% during moldboard tillage. The highest soil hardness in both phases of soybean development, 1.15 MPa and 2.65 MPa, was established on the agrobackground without tillage. A decrease in soil hardness by 1.53-1.92 times was revealed during flat-cut processing; 1.77-2.77 times with layer-by-layer processing; in 1.64-2.07 at dump. The highest soybean yield was obtained on the agrobackground with flat-cut tillage – 1.90 t/ha. A decrease in yield was established by 15.82% with the layer-by-layer method, by 3.44% with the moldboard method of tillage, by 7.11% on the agrobackground without tillage.

## 1 Introduction

Soy is a protein-oil crop. Protein content varies from 35 to 40%, oil content from 18 to 22%. With a high percentage of carbohydrates (up to 20%), soybean seeds are also rich in amino acids (tryptophan, lysine, methionine), vitamins and microelements [1]. In addition to high nutritional qualities, soybean is able to increase soil fertility and yields of subsequent crops, since due to symbiotic activity it is able to satisfy up to 70% of its own needs for nitrogen [2], as well as accumulate it in the soil (up to 120 kg/ha), acquiring the most important agrotechnical value, which allows to intensify agriculture with the help of a

* Corresponding author: semenixina1982@mail.ru

biological factor. The tap root system of soybean is able to have a decompacting effect on the soil, therefore, the introduction of this crop into crop rotation with prolonged use of small and no-tillage treatments has a beneficial effect on the physical properties of the soil and its structure.

In modern crop production, the cultivation of soybeans in rainfed farming is of great interest. As a rule, rainfed agriculture is widespread in climatic zones with insufficient and unstable moisture. The productivity of agricultural crops in rainfed agriculture is ensured by the moisture charging of the soil exclusively by precipitation in the autumn, winter and spring periods. High summer air temperatures provoke strong evaporation, and variable rainfall leads to a lack of moisture in the soil.

In rainfed agriculture, the cultivation of soybeans in an arid climate with insufficient moisture [3] requires a competent approach and is based on a rational combination of agricultural practices, among which a special place is given to the main tillage [4]. The task of tillage is to form a loose soil structure. Soil aggregates interconnected in layers form a soil skeleton with a chaotic distribution in the interaggregate space of macro- and micropores [5, 6]. In such spaces, the process of thermal diffusion takes place, which is interconnected with atmospheric phenomena, contributes to the long-term preservation of soil moisture and favorably affects the development of plants during the growing season [7]. To form a favorable soil structure, various methods of its cultivation are used: moldboard, layer-by-layer, flat-cut or without basic tillage at all, immediately using direct sowing for a long time, thereby completely switching to zero technology of crop cultivation [8]. The choice of method depends on climatic and soil conditions, crop rotation, soil texture, erosion and other factors (Gaevaya and Vasilchenko, 2016).

Important agrophysical indicators of the soil are its density and hardness, which largely determine the soil structure of the arable layer [9]. At the same time, the regulation of these indicators (in addition to natural factors) is possible due to the influence of various working bodies on them, which makes the study of soil cultivation methods in rainfed agriculture of particular importance [10, 11]. In this regard, it is very important to study the dynamics of density and hardness of soils with various methods of tillage. The significance of these studies increases due to the trend of mass transition to resource-saving technologies, the basis of which is the minimization of tillage in order to preserve soil moisture and optimal soil structure [12].

The density of the soil was determined by the ratio of the absolutely dry mass of the soil and the volume occupied by it, taken with an undisturbed structure. It is known that the density affects its water, air, thermal regimes, and, consequently, the conditions of biological activity. Therefore, soil density is regulated by tillage [13].

Under natural conditions, under the influence of the forces of compaction and decompaction, the soil acquires an equilibrium (natural) density, the value of which depends on the particle size distribution, humus content, and water resistance of soil aggregates.

For the normal growth and development of plants of the legume family, appropriate conditions must be created for the formation and work of nitrogen-fixing bacteria on the roots.

According to previous studies, for the active functioning of the soybean root system, the optimal value of soil density in rainfed agriculture common in the South of Russia should not exceed 1.10–1.35 g/cm$^3$.

The study of another important agrophysical indicator of soil, soil hardness, is relevant, since it is soil hardness that determines the ability of the structure of the soil skeleton and the structural composition of the soil to provide mechanical resistance to the developing root system of plants, which determines their germination and germination [14, 15, 16, 17].

The purpose of our research was to study the effect of various tillage methods on the density and hardness of the soil with the identification of soybean yields.

## 2 Materials and methods

When cultivating soybeans in rainfed conditions, the influence of various methods of basic tillage on [13,14,15] the density and hardness of the soil, and its productivity was studied. To conduct research, a long-term stationary experiment was set up on the experimental field of the Federal State Budgetary Scientific Institution, Agrarian Research Center "Donskoy" (ARC "Donskoy"). The size of the experimental plot: length - 90 m, width - 20 m. The studies were carried out in 2020-2022. The cultivated crop is soybeans. The predecessor is spring barley. The soil of the experimental plot is ordinary calcareous heavy loamy chernozem. The content of humus in the arable layer of the soil – 3,3 %, $P_2O_5$ – 19,0-24,5 mg/kg and $K_2O$ – 327-337 mg/kg, pH – 7,1.

We studied 4 options for tillage: flat-cut method of tillage; layer-by-layer processing; mouldboard tillage and no tillage variant with direct sowing. The repetition of the experiment is three times.

In the variant of the experiment with flat-cut tillage, a UNS-3 combined tillage unit was used. Depth of processing is 20-25 cm. Structurally, the working bodies going ahead on the frame of the unit are narrow-grip flat-cutting paws, on which trihedral wedges are installed in the center and edges of the paws. Following the paws on spring-loaded leashes, a drum is installed, equipped with teeth in the geometric shape of trihedral pyramids. The technological process of tillage with this unit consists in the fact that the paw, when moving, cuts the soil layer, which, advancing on the edges and edges of the wedges, breaks and stretches, as a result of which longitudinal cavities are formed inside the soil layer – molehills, which contribute to moisture accumulation. The rear drum breaks clods, compacts the soil in layers, and also levels and mulches the soil surface.

In the variant of the experiment with layer-by-layer tillage, a combined soil-cultivating unit KAO-2 was used. Depth of processing is 20-25 cm. Working bodies of a moldboard type and a press roller are fixed on the frame of the unit. The working bodies are made in the form of two-tier rippers, which are equipped with flat-cutting paws with wings of different sizes, a ripper and a chisel. The technological process of tillage with this unit consists in the fact that flat-cutting paws cut the top layer of soil, loosen it and lay it on the sole without turning. The soil monolith located deeper cuts the cultivator and this layer of soil moves along the surface of the chisel, is loosened and placed on the bottom of the furrow. The roller running along the track of the rippers crushes the clods, levels the surface layer of the soil, and at the same time compacts it.

In the variant with the moldboard method, tillage was carried out to a depth of 20-25 cm with a serial plow PN5-35. A skimmer is installed on the plow frame in front of the main body. The technological process of the plow is that the skimmer cuts the top layer of soil to a depth of 12 cm, then turns it over and lays it on the bottom of the furrow. Then the laid layer of soil is covered with a layer raised and wrapped by the main body, as a result of which a complete and deep incorporation of weeds and crop residues is achieved.

In the variant without soil tillage with direct sowing (principle of zero cultivation technology), a multi-purpose grain-fertilizer stubble seeder SZU-4U was used, which is designed for row sowing of seeds of grain and leguminous crops. It was used when sowing both on the prepared background and on the stubble background and minimally processed with the use of coulters in front of the coulters.

The study of soil density under soybean crops was carried out by drilling in layers (0-10 cm, 10-20 cm, 20-30 cm), taking into account the phase of plant development - at the beginning of the soybean vegetation in the phase of the real leaf at the third node and before harvesting in the phase of full ripeness.

Studies of soil hardness with a step of 2.5 cm were carried out to a depth of 30 cm using an electronic hardness tester SC-900 for the same phases of soybean development.

During the research, the biological yield of soybeans was determined by the method of selecting sheaves.

The received data were processed in Microsoft Excel. The data are presented as arithmetic averages.

## 3 Research results

The study of soil density on soybean crops in the phase at the beginning of the growing season and in the phase before harvesting (full ripening) was carried out in three soil layers of 0-10 cm, 10-20 cm and 20-30 cm. density over the three years of the study are shown in Figure 1.

At the beginning of the soybean vegetation in the soil layer of 0-10 cm, it was found that on the agrobackground with flat-cut tillage, the soil was the least compacted 0.69 g/cm$^3$ and increased by 0.12 g/cm$^3$ before soybean harvesting, on the agrobackground with layer-by-layer and moldboard tillage soil density was respectively 0.78 g/cm$^3$ and 0.91 g/cm$^3$ and before soybean harvest increased by 0.14 g/cm$^3$ and 0.12 g/cm$^3$ respectively, the highest soil density of 1.08 g/cm$^3$ was agrobackground without treatment and before harvesting increased by 0.31 g/cm$^3$.

In the soil layer of 10-20 cm on agrobackgrounds with flat-cut, layer-by-layer, moldboard and without cultivation, the density of the soil at the beginning of the growing season was 1.25 g/cm$^3$, 1.36 g/cm$^3$, 1.24 g/cm$^3$ and 1.40 g/cm$^3$ respectively. Before soybean harvesting, soil density decreased by 0.26, 0.39, 0.16 and 0.32 g/cm$^3$, respectively.

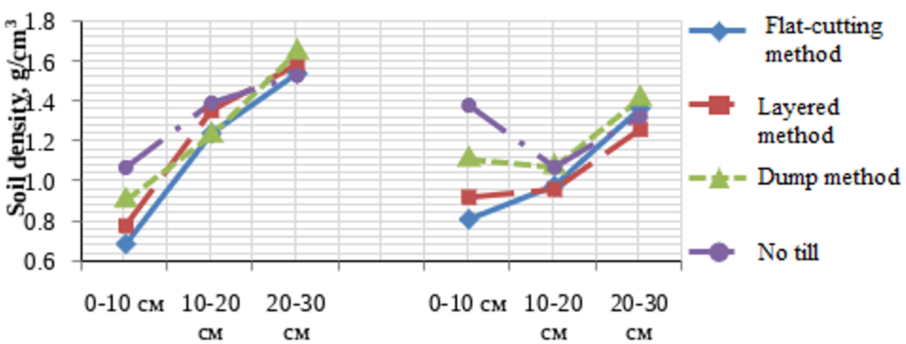


**Fig. 1.** Dynamics of soil density on soybean crops depending on the methods of tillage in soil layers of 0-10 cm, 10-20 cm and 20-30 cm

In the soil layer of 20-30 cm on agrobackgrounds with flat-cut, layer-by-layer, moldboard and without tillage, the soil density was 1.55 g/cm$^3$, 1.59 g/cm$^3$, 1.65 g/cm$^3$ and 1.54 g/cm$^3$, respectively and before soybean harvesting, the soil density decreased by 0.18, 0.33, 0.23 and 0.20 g/cm$^3$, respectively.

Thus, as a result of the study of soil cultivation methods, an increase in soil density was established on all agricultural backgrounds in the 0-10 cm layer by the time of soybean harvesting compared to the beginning of its vegetation. In the soil layers of 10-20 cm, 20-30 cm, a similar comparison revealed decompaction of the soil.

The hardness of the soil on soybean crops at the beginning of its vegetation and before harvesting was studied depending on the method of tillage used. The results of soil hardness studies are shown in Figure 2.

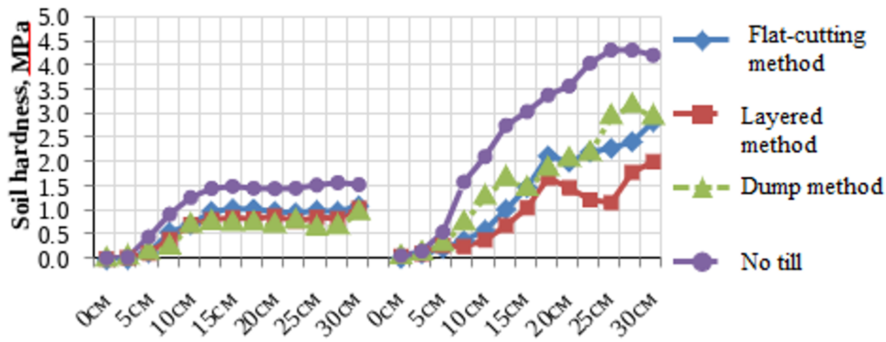


**Fig. 2.** Dynamics of soil hardness on soybean crops depending on the methods of tillage at different depths of research 30cm

As a result of data analysis, when comparing different methods of tillage at the beginning of the soybean growing season, it was found that the increase in soil hardness on the agrobackground without tillage occurred to a depth of 15 cm and amounted to 1.52 MPa; the increase in soil hardness on agricultural backgrounds with flat-cutting, layer-by-layer and moldboard tillage occurred up to a depth of 10 cm and amounted to 0.73 MPa. According to the average indicators of soil hardness, it was revealed that the soil on the agrobackground without tillage is the hardest (1.15 MPa) and exceeds the soil hardness by 1.53 times with flat-cut tillage, 1.77 times with layered tillage and 2. 07 times at dump.

Soil hardness before soybean harvest increased significantly in all agrobackgrounds. When comparing different tillage methods, it was found that the increase in soil hardness on the agricultural background without tillage occurred with an average growth rate of 0.56 MPa to a depth of 25 cm and amounted to 4.34 MPa. An intensive increase in soil hardness with flat-cut and layer-by-layer methods occurred up to a depth of 17.5 cm and amounted to 2.15 and 1.70 MPa, respectively, after a slight decline, the growth of soil hardness continued and at a depth of 30 cm reached its maximum value of 2.86 and 2, 03 MPa. On the agrobackground with moldboard cultivation, a curvilinear increase in soil hardness was established, first to a depth of 12.5 cm and amounted to 1.68 MPa, then to a depth of 27.5 cm and amounted to 3.19 MPa.

According to the average indicators of soil hardness, it was revealed that the soil before harvesting soybeans on the agrobackground without tillage is the hardest (2.65 MPa) and exceeds 1.92 times the hardness of the soil with flat-cut tillage, 2.77 times with layered tillage and 1.64 times at dump.

Nevertheless, the revealed soil hardness on all agricultural backgrounds meets the agrotechnical requirements (no more than 4 MPa) for the soils of the southern zone of the Rostov region, where rainfed agriculture is developed.

Correlation analysis of the relationship between the density and hardness of the soil at the beginning of the soybean growing season revealed a high relationship for all methods of processing r = 0.90 ... 0.99. Before harvesting soybeans, a high correlation was revealed with flat-cutting, layer-by-layer and moldboard methods, respectively, r = 0.93, r = 0.82, r = 0.83, and a weak negative relationship was revealed on the agrobackground without tillage r = -0.38 .

Soybean yield studies for three years are presented in the table. From her analysis, it follows that 2021 was distinguished by high soybean yields in general, and in 2020, low yields were noted for all tillage methods.

**Table 1.** The influence of the main method of tillage on the yield of soybeans

| **Soil cultivation method** | **Productivity by years, t/ha** | | | | **Deviation from control** | |
|---|---|---|---|---|---|---|
| | 2020 | 2021 | 2022 | Average | t/ha | % |
| Flat cut | 1.02 | 2.61 | 2.06 | 1.90 | - | - |
| Layered | 0.91 | 2.17 | 1.72 | 1.60 | -0.30 | 15.82 |
| Dump | 1.06 | 2.89 | 1.55 | 1.83 | -0.07 | 3.44 |
| No processing | 1.23 | 2.13 | 1.94 | 1.77 | -0.14 | 7.11 |

The average yields over three years of observations indicate that the yield (1.90 t/ha) obtained on the agrobackground with a flat-cut tillage method is the highest among other tillage methods. On the other agricultural backgrounds, a decrease in yield was found by 15.82% (by 0.3 t/ha) with the layered method, by 3.44% (by 0.07 t/ha) with the moldboard method of tillage, by 7.11% (by 0.14 t/ha) on the agricultural background without tillage.

A correlation analysis of the relationship between soybean yield and soil density and hardness was carried out. As a result of the analysis, the following relationship was revealed between soybean yield and soil density on agrobackgrounds with flat-cut and layered tillage methods r=0.99 and r=0.98, on an agrobackground without tillage r=0.86, while on an agrobackground with there was no relationship between moldboard tillage r=0.17. The relationship between productivity and soil hardness was established on the agrobackground with layered tillage r=0.98, on the agrobackground with flat-cut and no tillage r=0.83 and r=0.79, on the agrobackground with moldboard tillage r=0.41 .

According to the analysis, it was found that the regulation of soybean yield is possible due to a change in the method of tillage through the influence on the agrophysical properties of the soil, however, a large spread in correlation coefficients indicates that it is necessary to continue research to study the share of influence of other factors.

## 4 Conclusion

As a result of many years of research in the cultivation of soybeans in conditions of dry farming, the influence of various methods of tillage on the density and hardness of the soil was established, and the yield of soybeans was determined.

An assessment of the influence of the method of tillage on its agrophysical indicators revealed that at the beginning of the soybean growing season, the soil was the most compacted than before harvesting. The highest soil density in both observed phases (beginning of soybean vegetation and before harvesting) 1.34 g/cm$^3$ and 1.27 g/cm$^3$ was established on the agrobackground without tillage (No-Till). Comparison of soil density for the same phases with respect to other methods of tillage made it possible to establish a decrease in density by 13.43-16.53% with flat-cut tillage; by 6.71-16.53% with layer-by-layer tillage; by 5.22-5.51% during moldboard tillage. As a result of the study of soil hardness with various methods of tillage, it was found that the soil on the agrobackground without tillage had the highest hardness at the beginning of the soybean vegetation (1.15 MPa) and before harvesting (2.65 MPa). A decrease in soil hardness by 1.53-1.92 times was revealed during flat-cut processing; 1.77-2.77 times with layer-by-layer processing; in 1.64-2.07 at dump. The highest soybean yield for three years of soybean cultivation on dry land was obtained on the agrobackground with flat-cut tillage - 1.90 t/ha. As a result of the correlation analysis, it was found that the density and hardness of the soil had the greatest positive effect on soybean yield on the agrobackground with flat-cut tillage.

## References

1. Y. Assefa, N. Bajjalieh, Archontoulis, S. et al. Sci Rep, **8**, 14653 (2018) https://doi.org/10.1038/s41598-018-32895-0
2. M. J. de Luca, M. Hungría, Plant densities and modulation of symbiotic nitrogen fixation in soybean (2014)
3. S. Torabian, S. Farhangi-Tabriz, M. D. Denton, Soil and Tillage Research, **185**, 113-121 (2019) https://doi.org/10.1016/j.still.2018.09.006
4. A. Monsefi, A. R. Sharma, N. Rang Zan, U. K. Behera, T. K. Das, International Journal of Plant Production, **8(3)**, 429-440 (2014) https://doi.org/10.22069/ijpp.2014.1618
5. P. Chandrasekhar, J. Kreiselmeier, A. Schwen, T. Weninger, S. Julich, K.-H. Feger, K. Schwärzel, Geoderma, **353**, 401-414 (2019) https://doi.org/10.1016/j.geoderma.2019.07.017
6. A. A. Tagar, J. Adamowski, M. S. Memon, D. M. Cuong, A. S. Mashori, A. S. Soomro, W. A. Bhayo, Soil and Tillage Research, **197**, 104494 (2020) https://doi.org/10.1016/j.still.2019.104494
7. G. Mokryakov, T. Minnikov, K. Kazeev, S. Kolesnikov, Agronomy Research, **17(6)**, . 2350-2358 (2019) https://doi.org/10.15159/ar.19.202
8. S. Zikeli, S. Gruber, Agriculture, **7(4)**, 35 (2017) https://doi.org/10.3390/agriculture7040035
9. T. Drobnik, L. Greiner, A. Keller, A. Grêt-Regamey, Ecol. Indic., **94**, 151-169 (2018) https://doi.org/10.1016/j.ecolind.2018.06.052
10. J. P. Laborde, C. S. Wortmann, H. Blanco-Canqui, J. L. Lindquist, Soil Till, **213**, 105113 (2021) https://doi.org/10.1016/j.still.2021.105113
11. S. G. Mudarisov, I. I. Gabitov, Y. P. Lobachevsky, N. K. Mazitov, R. S. Rakhimov and et. al., Soil and Tillage Research, **190**, 70-77 (2019) https://doi.org/10.1016/j.still.2018.12.004
12. M. Sutri, M. Shanskiy, M. Ivask, E. Reintam, Agriculture, **12(12)**, 2149 (2022) https://doi.org/10.3390/agriculture12122149
13. Y. Seifu, S. S. Hiremath, S. Tola, A. Wako, African Journal of Agricultural Research, **19(2)**, 170-177 (2022) https://doi.org/10.5897/AJAR2022.16270
14. H. Blanco-Canqui, Ruis, S.J., Geoderma, **326**, 164-200 (2018) https://doi.org/10.1016/j.geoderma.2018.03.011
15. A. M. Gajda, E. A. Czyż, A. R. Dexter, K. M. Furtak, J. Grządziel, J. Stanek-Tarkowska, Int. Agrophys, **32(1)**, 81–91 (2018) https://doi.org/10.1515/intag-2016-0089
16. K. Skaalsveen, J. Ingram, L. E. Clarke, Soil Till. Res., **189**, 98-109 (2019) https://doi.org/10.1016/j.still.2019.01.004
17. A. Almajmaie, M. Hardie, T. Acuna, C. Birch, Soil Till. Res., **167**, 39-45 (2017) https://doi.org/10.1016/j.still.2016.11.003