Influence of direct seeding technology on typical chernozem structure

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Abstract. The paper discusses the impact of direct seeding technology on volumetric weight of arable layer, content (%) of air-dry and water-resistant aggregates (mm), as well as agronomically valuable aggregates during dry sifting. The fact of using the direct seeding technology for four years in grain crop rotation did not lead to an increase in volumetric weight of an arable horizon. This increases the content of dry agronomically valuable aggregates and the coefficient of structure increases. The direct sowing positively affects the water-resistant structure of typical chernozem, increasing the content of water-resistant aggregates in dry fraction > 10 mm from 68.7% (plowing option) to 80.7%.

1. Introduction

Traditional “arable” farming is usually based on mechanical tillage. The retrospective of agricultural farming in the world and Russia shows that the mechanical tillage with a plow and other equipment (flat cutter, chisel, cultivator, etc.) is accompanied by significant degradation of black soil [1]. In the initial stage of application of “arable” farming, as a result of the process of mineralization of the organic matter of soil, there is an increase in the nutritional elements providing an increase in potential fertility. However, over time the intensive farming techniques lead to a decrease in the organic matter in soil, as a result of which they degrade. The soil organic matter (OM) not only provides nutrients for cultivated plants, but also is a key element in stabilizing soil structure. The destruction of soil aggregates as a result of mineralization of organic matter leads to the formation of upper compacted horizons, reduction, deterioration of gas exchange, and finally the loss of soil resistance to adverse environmental factors. The most important integral characteristics of physical fertility of chernozem are the indicators of their structural state - the distribution of structural individual sizes, their mechanical strength and water resistance, which ultimately affect the chemical, physical and biological processes in the soil [2–4]. These indicators are informative not only in relation to the complex physical parameters of fertility, but they are interesting in solving the issues of soil treatment technology.

The degradation of black soil with the current intensive agricultural use makes it necessary to look for technologies and methods of cultivating crops that would restore the original fertility of soil. The technology change for biologization of farming in the form of refusing to plow with a reservoir turnover,
the use of surface treatment (disc harrows) or deep loosening (chisel) helps reduce the degradation of black soil as shown by numerous experiments and practical examples [3, 5, 6]. For several decades in the countries of South and North America, Australia, Europe and New Zealand they have been using environmentally-friendly technology of direct seeding (DS) or no-till, which is associated with high yields and minimal damage to the environment. The use of DS technology, which preserves plant residues on the soil and reduces the mechanical load, entails an increase in the share of macroaggregates and generally improves the soil structure [5, 6]. Due to the fact that this new approach to agriculture is only gaining the experience in Russia there was set a goal to assess the impact of DS on the structural state of typical chernozem.

2. Materials and methods

The object of the study was a typical heavy loamy chernozem [7, 8] located on the divide of the Kursk Region near the village of Cheremushki (51°37'46" N; 36°15'40" E). Since 2013 four fields were founded on a plot of 9.2 ha each of which is of 2.4 ha. The fields are separated from each other by a 3 meter protective strip. Each field is divided into 4 plots of 0.6 ha (100x60 m). The effect of 4 treatment options (plowing, combined treatment, minimum - surface treatment, no treatment - DS) on the properties and productivity of typical chernozem in a four-field grain crop rotation is studied. To assess the heterogeneity of soil morphological, agrochemical, and physical properties, a statistical analysis was carried out, which showed that all the studied parameters refer to the same general population with a probability of 95%.

Upon the completion of rotation, the second soil survey was carried out at the control points. The samples were taken from the depth of 2−7 and 10−15 cm to determine the equilibrium density of chernozem along two different options, i.e. plowing and DS [9, 10]. For comparison and as a control measure on density, the samples were taken from the same depths in a forest belt located 200 m from the site. The forest belt was founded in 1964 and is characterized by high fertility and structural characteristics of chernozem [1].

In addition, to analyze the capacity of macroaggregates on plowing and DS options, samples of chernozem were taken from the depth of 0−15 cm, approximately 15×15×25 cm in size and weighing about 5 kg each from five points within the area of 5 m in radius using an envelope method. Such an approach made it possible to avoid losses and artificial redistribution of size fractions of aggregates [11]. The samples were dried to an air dry state.

The obtained five air-dry samples were analyzed separately for both options and then the weighted average value for the desired index was calculated. Dry sieving was carried out according to the method of Savvinov [11, 12]. A set of 0.25, 0.5, 1.0, 2.0, 3.0, 4.0, 5.0, 7.0 and 10.0 mm sieves was used, through which each individual sample was passed. To estimate the water resistance, the Hahn approach was used [12] according to which the aggregates of the target size fraction (usually 1−2 or 1−3 mm) were sieved in water.

3. Results and discussion

In 2013, the equilibrium density of the arable horizon of chernozem was characterized by optimal values and was at a depth of 2-7 cm - 1.08±0.10 g/cm³; 10-15 cm - 1.18±0.07 g/cm³. Upon the completion of the first rotation of grain crop rotation, the state of the arable horizon in the plowing option almost remained the same. 4-year-application of DS technology did not have a significant impact on density of the arable horizon. The mean values over the depths of 2−7 cm and 10−15 cm, in the options of plowing and DS are close to each other and stay within the confidence limit (Table 1).

The agricultural use of typical chernozem affects the distribution of dry aggregates into fractions. In the forest belt option the content of the blocky fraction (> 10 mm) is minimal and amounts to 19.1%, while in the plowing option the maximum is 30.9%. The direct seeding option occupies an intermediate value, i.e. 26% (Figure 1).
Table 1. Influence of direct seeding technology on the volume weight of arable horizon of typical chernozem

| Options          | Depth, cm | Volume weight, g/cm³ | Confidence limit 0.05 |
|------------------|-----------|----------------------|------------------------|
| Plowing, 2013    | 2-7 cm    | 1.08                 | 0.10                   |
|                  | 10-15 cm  | 1.18                 | 0.07                   |
| Direct seeding, 2017 | 2-7 cm    | 1.11                 | 0.06                   |
|                  | 10-15 cm  | 1.17                 | 0.09                   |
| Plowing, 2017    | 2-7 cm    | 1.11                 | 0.06                   |
|                  | 10-15 cm  | 1.09                 | 0.09                   |

Figure 1. Influence of tillage on the content (%) of air-dry aggregates, mm

Considering the fractions of aggregates with dry sifting, it can be noted that the refusal from plowing leads to a gradual restoration of the soil structure, as it can be seen from the content of any of the fractions in the DS option, tending to the options of the forest belt option (Figure 1). Similar situation is observed with the coefficient of the structure and the content of agronomically valuable aggregates in terms of the sum of fractions in the forest belt option and direct seeding, which can be attributed to the optimal indicators according to the standards (Table 2).

Table 2. Influence of direct seeding technology on the content of agronomically valuable aggregates during dry sifting

| Option          | 0.25 - 10 mm | <0.25 -10 mm | Structural coefficient |
|-----------------|--------------|--------------|------------------------|
| Plowing         | 66.9         | 33.1         | 2.0                    |
| Direct seeding  | 71.5         | 28.5         | 2.5                    |
| Forest belt     | 77.8         | 22.2         | 3.5                    |
Long-term intensive plowing of chernozem led to a decrease in the structural coefficient (down to 2) and a decrease in agronomically valuable aggregates (down to 66.9%), which corresponds to an acceptable level of aggregate structure according to standards [10].

The tillage has had a significant impact on the maintenance of water-intensive aggregates. There was a significant transformation of waterproof units in the barable soil. First of all, the attention is drawn by a sharp decrease in the number of water-intensive aggregates of large fractions and an increase in fine fractions (Figure 2). In the forest belt option, the content of fractions > 10, 10-7 and 7-5 is several times higher than the indicator compared to the plowing option. An inverse pattern is observed in the following fractions: 3–2, 2–1, 1–0.25, and <0.25. The agricultural use of chernozem typical in the technology (DS) has a beneficial effect on the restoration of the water-resistant structure of the arable horizon. The content of the fraction > 10 mm increased up to 28.9%, and the fractions 10-7 and 7-5 increased up to 7.1% and 5.5%, respectively with DS compared to the plowing option.

Table 3. Content of water-resistant units, fractions > 0.25 mm depending on the tillage

| Option          | Fraction | >10 mm | 7-10 mm | 5-7 mm | 3-5 mm |
|-----------------|----------|--------|---------|--------|--------|
| Plowing         |          | 7.3    | 2.6     | 1.3    | 1.7    |
| Direct seeding  |          | 28.9   | 7.1     | 5.5    | 2.7    |
| Forest belt     |          | 61.3   | 18.1    | 6.4    | 1.4    |

As it has been already noted, the bulk of the water-resistant aggregates of typical chernozem is concentrated in fractions of more than 3 mm, moreover, this figure exceeds 90% in the forest belt option. 4-year-application of DS technology in grain crop rotation leads to an increase in the water-resistant structure of the fraction > 10 mm relative to plowing up to 80.7%.

4. Conclusion

4-year-application of DS technology in grain crop rotation did not lead to an increase in the volumetric weight of the arable layer. Its values at the depth of 2-7 cm and 10-15 cm are characterized as optimal ones and are 1.1±0.06 g/cm³; 1.17±0.09 g/cm³, respectively.
Under the influence of direct seeding technology, the content of dry agronomically valuable aggregates increases. In this case, the coefficient of structure increases up to 2.5.

The technology of direct seeding has a positive effect on the water-resistant structure of typical chernozem. The content of water-resistant aggregates in the dry fraction > 10 mm increases from 68.7% (plowing option) to 80.7%.

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