Organic carbon and particle size distribution of aggregates from chernozem under arable land and shelterbelt

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Abstract. The particle size distribution (PSD) and the content of organic carbon ($C_{org}$) in dry and water-stable aggregates were determined in the upper layer of chernozem under arable land and shelterbelt. In water-stable aggregates, the $C_{org}$ content is 1.2–1.5 times higher than in dry sieving aggregates. Dry sieving and water-stable aggregates of arable chernozem consist of particles identical in terms of the PSD. And in the chernozem under the shelterbelt the content of physical clay increases with a decrease in the size of the aggregate in water-stable aggregates isolated from the fraction of dry sieving < 1 mm.

1. Introduction

The aggregate structure of the soil plays an important role in the functioning of the soil. It ensures the ecology of the habitat of plant roots and microorganisms, the preservation of organic carbon, regulates the reserves and availability of moisture, and protects the soil from wind and water erosion [1]. To characterize the aggregate structure, the dry and wet sieving methods are used. The fraction analysis of dry and water-stable aggregates is mainly aimed at investigating the mechanisms and factors of carbon sequestration. This is due to the fact that organic matter and aggregates are interrelated and interdependent solid phase products of soil formation. Organic matter (OM) promotes the aggregation of mineral particles, and the environmental conditions in the aggregates protect OM from rapid mineralization under quasi-anaerobic conditions [2]. Despite a large amount of data on the content of organic carbon in aggregates, studies on the interaction of OM with the mineral phase inside aggregates and how these interactions affect the physical properties are very limited [3]. The anthropogenic evolution of arable chernozems is accompanied by a decrease in the humus content, the formation of a plow sole, and a significant compaction of the upper layer. The downfall filtration capacity of the upper horizons of virgin chernozems on arable land decreases. The aggregates lose the property of water resistance; there is an increase in the content of fractions of physical clay and silt with a significant decrease in medium and coarse sand fractions in the composition of microaggregates. All this points to significant fundamental changes in the structure of chernozems during plowing, which are manifested, first of all, in relation to its resistance to water.

Soils under shelterbelt and adjacent arable land are of great interest for the studies of all aspects of the aggregate formation mechanisms. Shelterbelts are widespread in the European part of Russia. They were mainly planted on old arable soils of different genesis and landscapes in the second half of the last century. At present, in comparison with the soils of the adjacent arable land, the processes of accumulation of organic matter and the restoration of the (previously lost) aggregate structure are taking
place in the soil under the shelterbelt [4].

The goal of the study is to determine the particle size distribution and distribution of organic matter in dry and water-stable aggregates of chernozem under arable land and shelterbelt.

2. Materials and methods
The research objects are located in the territory of the Kursk Federal Agrarian Scientific Center (Kursk region, Russia). Soil samples were taken in 2009 and stored in an air dry state. The soil is typical chernozem (according to WRB – Haplic Chernozems), layer 0–10 cm, arable land with grain-fallow crop rotation (51°37′17.0″N 36°15′41.8″E). Typical chernozem, layer 0–10 cm, under a shelterbelt litter adjacent to arable land (51°37′19.1″N 36°15′42.4″E). Vegetation: pedunculate oak (Quercus robur), common ash (Fraxinus excelsio), and field maple (Acer campestre). The herbaceous layer is absent. Water-soluble organic matter from the litter horizon plays a significant role in the modern accumulation of organic matter in the mineral horizons of the profile.

Dry sieving (3, 4 replications) was carried out through sieves of 7, 5, 3, 2, 1, 0.5, 0.25, and 0.1 mm on an AS 200 control (Retsch, Germany). The amplitude was 2.5 mm, the time was 2 min. Water-stable aggregates (2, 3 replications) were isolated by wet sieving of dry sieving aggregate fractions of 5–3, 3–2, 2–1, 1–0.5, 0.5–0.25 and 0.25–0.1 mm on an AS 200 control. The amplitude was 2.5 mm, the time was 3-5 min (until the suspension stops flowing out of the 0.1 mm sieve).

The particle size distribution was determined on the particle size analyzer “Analysette 22 comfort” (FRITSCH, Germany) using the laser diffraction method. The dispersion of the sample suspension (80–120 mg) in water (40 ml) before the analysis was carried out on a S-250 Ultrasonic Disperser (Branson, USA) with the energy of 450 J/ml. The total carbon content (Total) was determined by dry combustion in a stream of oxygen at 950 °C, 3 replications for dry sieving aggregates, and 1 replication – for water-stable aggregates. Carbonates in these soils are present deeper than 40–60 cm and Total is represented by organic carbon (Corg). The figures show the average values of the analytical data with standard deviation bars.

3. Results and discussions
Prior to planting of the shelterbelt (in the 1960s), chernozem was under arable land for more than 100 years. The dry sieving data (Figure 1) demonstrate the restoration of the aggregate structure of chernozem under the shelterbelt. Due to long-term presence of chernozem under arable land, the content of >7 mm and <1 mm fractions is increased in the aggregate composition. In the composition of the chernozem aggregates under the shelterbelt, agronomically valuable fractions of aggregates of 5–3, 3–2 and 2–1 mm prevail.

![Figure 1. Distribution of aggregates of dry sieving fractions](image-url)
C$_{org}$ content in the dry sieving aggregates is shown in Figure 2. The average carbon content in fractions from 7–5 to 0.25–0.1 mm is 4.8 % (shelterbelt) and 3.3 % (arable land). In total, regardless of the size of the aggregates, the carbon content in the chernozem aggregates under the forest belt is 1.4 times higher than in the arable land chernozem aggregates. For both land use variants, there is a weak tendency to increase the carbon content with a decrease of aggregate size from 3–2 to 0.25–0.1 mm. The high (6.7 %) carbonization of aggregates 10–7 cm in size in chernozem under shelterbelts is most likely associated with the inclusion of plant residues in them. In the fraction of dry sieving <0.1 mm, the carbon content sharply decreases (2.7 % for arable land, 3.7 % for shelterbelt).

Figure 2. Distribution of C$_{org}$ by aggregates of dry sieving fractions.

Wet sieving on a vibrating screen provides a significantly stronger physical effect on the aggregates compared to a sieve analysis in stagnant water. In arable chernozem, there are no water-stable aggregates larger than 3 mm (Figure 3a), and the content of fractions 2–1 and 1–0.5 mm in size is less than 1 %. The increased water resistance of the aggregate structure of chernozem under the shelterbelt is manifested in the presence of fractions of water-resistant aggregates. There should be a space >0.5 mm (Figure 3b). The fraction of water-stable aggregates <0.1 mm, regardless of the size of dry aggregates and the type of land use, is the predominant and most stable form of aggregated fine earth. The absolute predominance of water-stable microaggregates during wet sieving on an analytic sieving machine was noted in [5, 6].

Figure 3. Content of water-stable aggregates in dry sieving aggregates; a – arable land, b – shelterbelt.

The distribution of carbon content by fractions of water-resistant aggregates of arable chernozem (Figure 4a) obeys the following basic laws. The general trend is a decrease in the carbon content with a decrease in the size of fractions of dry and water-stable aggregates. The absolute carbon content in the
composition of water-stable aggregates is significantly higher (4.3–5.5 %) than its average content (3.3 %) in dry sieving aggregates. With the minimum absolute carbon content of the fraction <0.1 mm, the bulk of the organic matter is concentrated in this fraction.

Except for the <0.1 mm fraction, the carbon content in the water-resistant aggregates of chernozem under the shelterbelt (Figure 4b) is 1.2–1.5 times higher than in the aggregates of dry sieving (4.8 %). Regardless of the size of the dry screening fractions, the carbon content in water-stable aggregates >0.25 mm is ~6 %. The carbon content in fractions less than 0.25 mm decreases with a decreasing size of dry aggregates. As in the chernozem of arable land, the minimum carbon content (4.3–3.7 %) was found in the fraction of wet sifting less than 0.1 mm.

Figure 4. Distribution of C$_{org}$ by fractions of water-stable aggregates; a – arable land, b – shelterbelt.

The granulometric composition of dry sieving aggregates of chernozem on arable land and shelterbelt has similar fraction content (Figure 5). Apart from the fraction of dry sieving <0.1 mm, the granulometric composition does not depend on the size of the fractions. Regarding the content of physical clay, the aggregates of arable chernozem are represented by light clay (particles <10 μm ≈ 60 %), and forest belts – by heavy loam (particles <10 μm ≈ 56 %). Compared to others, the fraction of aggregates <0.1 mm in both cases is enriched with particles of coarse dust (52–55 %).

Figure 5. Granulometric composition of the dry sieving aggregates; a – arable land, b – shelterbelt.
The granulometric composition of the fractions of the water-stable aggregates has revealed an unexpected pattern (Figures 6a–b). A significant weighting of the granulometric composition of the water-resistant aggregates was detected, in comparison with the dry sieving aggregates, from which the water-stable aggregates were isolated. The water-resistant aggregates of arable chernozem, as well as aggregates of dry sieving, are represented by light clay in terms of the particle size distribution. However, the content of physical clay in them increased by 6–17% (Figure 6a).

The granulometric composition of the water-resistant aggregates of chernozem under the shelterbelt changes with a decrease in the size of the fraction of dry sieving aggregates (Figure 6b). The water-stable aggregates in dry sieving fractions 5–3, 3–2 and 2–1 mm have the heavy loamy granulometric composition.

The general consistent pattern for the water-resistant aggregates from the dry sieving fractions of 1–0.5, 0.5–0.25 and 0.25–0.1 mm is an increase in the content of physical clay with a decrease in the size of the water-stable aggregate. At the same time, the heavy loamy granulometric composition of the dry sieving aggregates has changed by three classification categories to a heavy clay one.

![Granulometric composition of the water-stable aggregates; a – arable land, b – shelterbelt.](image)

Differential curves of the particle size distribution allow the determination of the preferred diameter of particles (Figure 7). The water-resistant microaggregates from the fraction of dry sieving 1–0.5 mm of arable chernozem are formed by elementary soil particles (ESP) with diameters of 1.6 and 15.7 µm, and the soil as a whole by ESPs of 1.6 and 18.1 µm (Figure 7a). Large particles (15.7 µm) predominate in the composition of microaggregates and soil. The water-stable microaggregates from the fraction of dry sieving 1–0.5 mm of chernozem under the shelterbelt (Figure 7b) consist of elementary soil particles...
with a diameter of 1.6 μm (all microaggregates and soil), 5.9 μm (fraction <0.1 μm), 6.7 μm (fraction 0.25–0.1 mm), 7.8 μm (fraction 0.5–0.25 mm), and 18.1 μm (soil as a whole).

**Figure 7.** Differential curves of the granulometric composition of the soil as a whole and of the water-stable aggregates from the fraction of dry sieving 1–0.5 mm; a – arable land, b – shelterbelt; predominant particle diameter in μm is noted.

There is an opinion that with a decrease in the size of the aggregates, the forces of interparticle interactions increase and, accordingly, the stability of the microaggregate increases [7]. The formation of heavily clayey water-resistant microaggregates <1 mm in size under the shelterbelt can occur as a result of several processes. Water-soluble organic substances migrating from the litter horizon, as well as exudates of higher plants and microbial metabolites, are sorbed on mineral particles of silt and fine dust. As a result of the sorption of organic substances, the surface of the mineral particles is hydrophobic. In spring and autumn, when the soil is saturated with moisture, it is energetically advantageous for hydrophobic particles to minimize their contact with water, and they combine with each other. The absence of external physical impact is the necessary condition for hydrophobic interactions between particles. Regular alternation of the drying – moistening, freezing– thawing and swelling–compression processes contributes to an increase in adhesion between the particles of such a microaggregate. The formation of very stable microaggregates after the sorption of *Bacillus circulans* metabolites on montmorillonite was shown in [8]. Deficiency of organic matter, regular mixing and destruction of the aggregate structure in the chernozem of arable land prevent the formation of similar microaggregates.

At present, the nature of particles in the composition of fractions of water-stable aggregates with predominant diameters of 5.9–7.8 μm remains in question (Figure 7b), namely, whether these are individual particles or micro-aggregates that are resistant to ultrasonic dispersion. To answer this question, it is necessary to determine the rheological parameters of water-stable aggregates of different sizes, their wettability with water, as well as the particle size distribution after the oxidation of organic matter in our future studies.

4. Conclusion
The carbon content in the chernozem aggregates under the shelterbelt is 1.4 (dry sieving) and 1.2–1.5 (water-resistant aggregates) times higher than in the chernozem aggregates under arable land. The granulometric composition of the dry sieving aggregates (arable land – light clay; forest belt – heavy loam) and the water-resistant aggregates of arable chernozem (light clay) does not depend on the size of the aggregate fractions. The water-stable aggregates of chernozem under the shelterbelt made of dry sieving fractions. There should be a space >1 mm have the heavy loamy granulometric composition. The granulometric composition of the water-resistant aggregates of chernozem under the shelterbelt made of dry screening fractions <1 mm is heavy clay.
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