Wettability of soil surface as a property of solid phase studied for Chernozems of Kursk region

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Abstract. Soil surface wettability is the main physical property that defines organization of elementary soil particles into soil structure. Human impact affects the changing in properties of soils under arable land use. The objective of this research is to study this impact by the example of two profiles of Chernozems (Kursk region), located under the forest and at the arable field. For both profiles some soil solid phase properties (contact angle, aggregate composition, aggregate waterstability) were measured. There was a positive correlation between the content of organic matter and soil’s wettability in studied soils – a growth of contact angle with the increasing the content of organic matter. Under the forest the content of soil organic matter was changed from 6.41\% on the surface to 1.9\% at the depth of 100 cm. In the Chernozem under the arable land use the organic carbon content in arable horizon is almost two times less. The maximum of hydrophobicity (78.1°) was observed at the depth of 5 cm under the forest. In the profile at the arable field the contact angle value at the same depth was 50°. The results of the structure analysis showed a decrease in the content of agronomically valuable and water stable aggregates in the profile under arable land.

1. Introduction
Soil surface properties play the major role in the soils and are of great practical significance. Voronin [1] noted that all soil properties and all processes, occurring in soils, are related to the soil surface properties in the direct way or indirectly. He wrote, that a joint study of geometry, energetics and properties of interphase surfaces, composition and energetics of the soil solutions, as well as artificially added to these solutions chemical substances, as well as micromorphological researches of the organization of the elementary soil particle, provided an opportunity to build a real model of soils’ aggregates. In this case we can find the relationships between the surface properties and the main macroscopic properties of the soils, to find ways for their directional changes, improvements and optimization [1].

It is well known, that most interaction processes of soil particles with external environment occur through the water, always surrounding these particles in natural conditions. That is why Voronin underlined, that water can become the main instrument to measure the quality and the quantity of the soils’ specific surface area. He thought, that in the nearest future agriculture would have the closest correlation with the active physical and chemical processes, which take place in the interfacial surfaces. The wettability is one of the most common natural phenomena occurring on the interfacial boundary.
Since the development of new devices to measure the contact angle (CA) such as the drop shape analyzer system DSA100 (KRÜSS, GmbH, Germany), many researchers have focused on the studying of wettability of porous solid medias have been presented in the literature [2-6].

It is well known that soil solid phase consists of three components: mineral phase, organic substances and organo-mineral compounds. Mineral part of soils has hydrophylic surface properties, its contact angle is less than 90 degrees. Soil organic matter is characterized by amphiphilic properties and it is one of the leading factor determining the wettability of the solid phase of soils [7-9].

In addition to determining wettability as soil solid phase property, there are other important factors, that need to be considered to obtain correct contact angle data. One of the most important groups of factors is the features of sample preparation. For this reason, the comparative analysis of the experimental data obtained from literature is not always possible, because of the dependence of contact angle values on the methods of contact angle measurement or even on the type of sample preparation.

Intensive tillage affects the properties of soil: decrease in content of soil organic matter and in hydrophobicity of the soil solid phase, the reduction of amount of water stable aggregates - all this leads to deterioration of the structure of the soil and affects the process of movement of moisture in the soil profile.

One of the hypotheses of structure formation ascribes the formation of water stable aggregates with the presence of hydrophobic organic substances on the surface of the soil solid phase [10]. The aim of this work is to study the effect of tillage on wetting properties of Typical Chernozems (Pachic Voronic Chernozems, Haplic Chernozems) (Russia, Kursk region), located under forest and under the arable land use.

2. Objects and methods
The objects of the study were the Haplic Chernozems located under at the arable field and under the forest (Russian Federation, Kursk region, Central Chernozemny Nature Reserve, 51°8′49″N 36°25′48″E), with A_arable-A1-AB-B profile composition. Studied soils were located in upland conditions [11] on the western slopes of Central Russian Upland, on the loess sediments.

The contact angle measurements were performed using drop shape analyzing system DSA-100 (KRÜSS, GmbH, Germany). Conceptually this system consists of three parts: the table for samples, which has three mobile axes, moving in three directions; the camera with the optical system and the source of light, which records the drop behavior to photo- or video-file; and the automatic dozing system. The process of contact angle measurement can be described as follows: the needle deposits the drop of liquid with the certain parameters to the surface of samples. After deposition the needle moves up, remaining the droplet on the surface. Digital video camera recording all this process in macro mode. Using the special software, the drop shape is analyzed, and the contact angle between the drop and sample’s
surface is measured. For measurement, we used deionized deaerated water and following measurement conditions: drop volume – 1.5 µl, speed of drop formation – 200 µl/min.

The studied soil sample was separated from stones, roots and other plant residues, ground using a pestle with a rubber tip, sifted through a sieve with the mesh diameter 0.25 mm. Sifted samples were moved to the drying box with the temperature 45-50°C. Strips of double-sided adhesive tape (approximately 0.5 x 0.5 cm) was glued to the glass slide. Thin layer of soil was sprinkled onto adhesive layer, soil was covered by another glass slide and gently pressed down with the 300 g weight for 1 minute. Not adhered soil was carefully removed. To obtain the most even layer the sample was applied and shaken off several times.

For all samples the content of total carbon (TC) and soil organic carbon (SOC) by dry combustion in oxygen flow [12] and the particle size distribution by the laser diffraction method on the device Analysette 22 comfort (FRITCH, Germany) [12] were determined. The estimation of aggregate composition was performed by dry sieving (AS 200, Retsch, Germany) [12], the content of water stable aggregates was estimated by the Savvinov method via sieving in stagnant water [13].

3. Results and discussion

Particle size distribution of studied soils is presented in figure 2. Studied soils had loamy composition, the prevailing fraction for both profiles was the fraction 10-50 µm. Profiles had similar aggregate composition with differences in the top layers (figure 3). The amount of agronomically valuable aggregates with diameter 0.1-10 mm at the depth 0-10 cm in the profile under the arable land use was 75.6 %, in the profile under the forest – 95.7 %. The content of water stable aggregates with diameter > 0.1 mm in profile under the forest was 2-2.5 times more than in the profile at the arable field. The percentage of water stable aggregates > 0.25 mm under the forest was 5-8 times more than under the arable land use.

![Figure 2. Particle size distribution of Typical Chernozem located under the arable land use (a) and under the forest (b).](image-url)
Figure 3. Aggregate composition and percentage of water stable aggregates of Typical Chernozem located under the different land use.

The profile distribution of the soil organic carbon is presented in figure 4. There was a gradual decreasing of SOC percentage in Chernozem under the forest from 6.41% at the topsoil to 1.9% at the depth about 1 m. The small amount of carbonates (up to 1%) was presented at the bottom part of the profile (figure 4). The values of contact angle have a similar profile distribution with SOC – the maximum of hydrophobicity was in the topsoil (78.1° at the depth 0-10 cm) with decreasing of contact angle down the profile to 50.2° at the depth 100 cm (figure 4). Chernozem at the arable field had almost two times smaller percentage of soil organic carbon at the top 10 cm layer. But with the depth the content of SOC in studied profiles became equal. The maximal hydrophobicity was found at the sub-top layer 10-20 cm (CA reached 67.2°).

There was a pronounced correlation between the content of SOC and CA in profile located under the arable land use (the Spearman's rank correlation coefficient, $R_s > 0.8$, with p-value < 0.05). But we can obtain the same correlation coefficient in the profile under the forest only reducing the probability value to 0.2. There was also a positive correlation (for arable soils $R_s = 0.94$ and $R_s = 0.69$ for forest soils) between the percentage of agronomically valuable aggregates and the wettability of studied soils.
4. Conclusions
The intensive tillage reduces the amount of agronomically valuable aggregates in the top 10 cm layer by 13% and the percentage of water stable aggregates with diameter less than 0.1 mm by 18%. Simultaneously the reduction of soil organic carbon in soil affected by tillage was observed. Studied profiles had the tendency of hydrophilization with the depth. The maximum of hydrophobicity (78.1°) was observed at the depth of 5 cm under the forest. In the profile at the arable field the contact angle value at the same depth was 50°. The obtained data have shown a pronounced correlation between the wettability of soils and the content of organic matter. There is a positive correlation between soils’ solid phase hydrophobicity and the percentage of agronomically valuable aggregates. So we can talk about the influence of hydrophobic organic matter on the formation of good structure of soils, as well as the negative impact of tillage on the analyzed characteristics.

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Figure 4. Content of C (CaCO₃) and soil organic carbon (%), and wettability (degrees) of Typical Chernozem under different land use.
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