Influence of long-term plowing on water permeability of light-gray forest soils of taiga-forest zone of Western Siberia

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Abstract. Light-gray forest soils are of particular value to agricultural enterprises in Western Siberia. These soils have a number of advantages relative to semi-hydromorphic soils, which have high potential fertility, but unfavorable water-physical properties. The involvement of light-gray forest soils in agriculture leads to a change in the balance of organic matter and moisture regime. This affects water permeability, which characterizes the main indicators of water-physical properties. The deterioration of the conditions for the movement of water deeper into the soil leads to surface water saturation and the manifestation of water erosion.

The purpose of scientific research was to study the influence of long-term plowing on water permeability of light-gray forest soils. It is established that in the virgin state, light-gray forest soils are characterized by the best water permeability. The illuvial horizon has a minimum infiltration and filtration rates, which reach 3.1 and 1.8 mm/min, respectively. Plowing and prolonged use of light-gray forest soils in arable land leads to a deterioration in the speed of movement of water in the arable horizon. The infiltration and filtration coefficients reach 2.8 and 1.1 mm/min, which is almost three times less than the values of virgin soil. Under the influence of an anthropogenic factor, a layer is formed in the upper part of the illuvial horizon with a minimum filtration rate (1.0 mm/min). The ratio of the water speed between the initial and final measurement points indicates the presence of a non-water-stable structure in the humus-eluvial and arable horizons. Therefore, to prevent deterioration in arable land, it is necessary to create all conditions for the formation of a water-stable structure by applying organic fertilizers and lime.

1. Introduction

Gray forest soils hold fifth place in the soil cover of the Tyumen region. Their total area is 1 million hectares [1]. The main areas of gray forest soils developed for agricultural land and are actively used in the agricultural sector of Russia [2]. Losing in humus reserves and nutrients, gray forest soils, while not been water saturated, have always been and remain promising for agriculture, in contrast to semi-hydromorphic soils [3-5]. The total area of light-gray forest soils is 161.2 thousand ha, of which 40% is used as the plow fields in the Tyumen region. Gray forest soils occupy elevated relief elements that are well provided with surface runoff and have a deep level of groundwater. They are formed under small-leaved birch and aspen forests under the simultaneous action of two modern soil formation processes - humus-accumulative and podzolization.
Nowadays, Western Siberia and the southern part of the Tyumen region in particular, are promising for the development of agriculture. The development of breeding science and scientifically-based agriculture allowed obtaining high crop yields with high quality indicators [6-10].

The high intensity of using light-gray forest soils in arable land has led to serious changes in the main indicators of fertility, one of which is the water regime. A detailed examination of arable soils showed a change in the quantitative and qualitative humus characteristics, and also made it possible to establish an increase in the illuviation processes under the influence of the anthropogenic factor [11-13].

Water permeability is one of the main water-physical indicators. It depends on many factors, such as structural and aggregate composition, water stability of soil units, composition density and particle size distribution [14, 15]. In Western Siberia, aeration of the root zone, migration of nutrients, and the degree of leaching of alkaline earth metal cations from the soil-absorbing complex depend on the speed of water movement [16, 17, 18]. To improve the physicochemical and water-physical properties of gray forest soils in Western Siberia, organic fertilizers in the form of peat or compost are systematically applied. As noted by A.S. Motorin and A.V. Iglovikov, the use of such fertilizers can stabilize the soil system for moisture availability and nutrition [19, 20].

The aim of the paper was to study the change in water permeability of light-gray forest soil under the influence of long-term plowing.

2. Materials and methods

Long-term studies of the dynamics of fertility of arable light-gray forest soil (Greyic Phaeozems Albic, WRB, 2006) were carried out on a stationary site (No. 28), which was founded in 1994 by the Tyumenskaya agrochemical station, three kilometers away from the village of Usalka, Yarkovsky district, in taiga-forest zone. Its coordinates are 57°18′24″; 66°56′25″. The soil is light-gray forest, medium loamy, formed on loess-like loam. It was plowed in the 30s of the twentieth century. From the establishing of the stationary site to the present time, grain-cultivated crop rotation is used (potatoes - spring wheat - spring wheat - barley - oats) with a moldboard plowing system for primary tillage.

For a comparative analysis of the influence of the anthropogenic factor on the dynamics of the humus state of light-gray forest soil, a virgin site located 200 meters away from the station was used. Therefore, soil formation factors, except for the anthropogenic ones, are identical. The morphological description of the soil section of virgin light-gray forest medium loamy soil is given below.

- $A_0$ – Forest litter.
- $A_1$ 1-12 cm. Light-gray, dry, medium loamy, lumpy, silty, friable, with many roots. The transition is gradual.
- $A_1$:$A_2$ 12-22 cm. Light-gray with a pale tone, dry, medium loamy, laminated, slightly densified, roots.
- $B_1$ 22-50 cm. Dark-brown, fresh, heavy loamy, nuciform, dense, finely porous, roots. The transition is noticeable.
- $B_2$ 50-100 cm. Brown, fresh, medium loamy, coarse nuciform, dense, finely porous, roots. The transition is gradual.
- $B_C$ 100-160 cm. Light-brown, fresh, medium loamy, slightly nuciform, unstructured in the lower part, single roots.
- $C > 160$ cm. Yellow-light-brown, fresh, medium loamy, compacted, structureless.

Our analysis of the particle size distribution of the type profile of gray forest soils showed that the studied subtypes belong to a silty-clay medium loamy variety formed on a cover and loess-like lacustrine-alluvial loam, which is characteristic of the eastern outskirt of the Trans-Ural Plateau. The profile of light-gray forest soil in terms of particle size distribution is clearly differentiated into eluvial-illuvial horizons. The upper part of the profile is significantly depleted in the sludge fraction. The content of sludge particles (<0.001 mm) in the illuvial horizon of light-gray forest soils reaches almost 50%, characterizing it with a heavy loam particle size distribution. In deeper layers, the content of sludge particles again decreases to 31-35% and slightly varies to a depth of 250 cm.
The total water permeability of light-gray forest soil was determined in the field using the Kachinsky site flooding method, and the water permeability in individual genetic horizons was determined using the tube method [22]. To calculate the coefficient of infiltration (absorption), the indicators were determined during the first hour with an interval of 10 minutes; for filtration - the interval was 1 hour, with a total time of 3 hours. The studies were carried out on arable land and virgin land in one day. The repetition of the experiment is 6 times. The research results were subjected to statistical processing by B.A. Dospekhov using Microsoft Excel software product.

3. Results and discussion

The process of water movement in the soil is quite complex and depends on many factors. Conventionally, water permeability is divided into two stages. The movement of water in conditions of voids unfilled with liquid - infiltration or absorption. It is characterized by high speed in the first minutes, followed by a decrease to the minimum values. At this stage, water passes through large cracks or pores, the volume of which gradually begins to decrease due to the destruction of structural aggregates and swelling of clay particles. As the voids fill with water and their volume decreases, the water speed becomes constant over a long time. This process is called filtering.

The infiltration rate of the humus-eluvial horizon at the beginning of the first hour of observations was maximum and reached 12.2 mm/min, which corresponded to an excessively high mark according to the Kachinsky scale (Table 1). Such a high infiltration rate is caused by the relatively light particle size distribution, low bulk density and satisfactory structure [9]. After 30 minutes, the infiltration rate decreases to 5.3 mm/min and remains at the same level for 20 minutes. Subsequently, the coefficient of infiltration reaches a minimum value of 3.8 mm/min. A 3-fold decrease in the water speed in the first hour of observations is caused by the presence of structural units with low water stability [18]. The reason for this is the lack of soil organic matter, which acts as a structure-forming agent, and the depletion of the humus-eluvial horizon with clay particles due to the manifestation of the eluvial-illuvial soil-forming process [1, 2].

In the A1A2 horizon, infiltration at the beginning of the first hour was lower than the overlying horizon, since it was initially characterized by a higher density and a large amount of non-aggregated material. After 20 minutes, the infiltration rate decreased from 8.0 to 3.0 mm/min. Within an hour, water permeability decreased to 2.2 mm/min. According to the Kachinsky scale, the A1A2 horizon was characterized by the best permeability in the first hour of determination. The upper part of the illuvial horizon (B1) during the course of natural soil formation accumulates clay particles washed away from the overlying layer, thereby reducing the total porosity and preventing the movement of water deeper. In the first minutes of the analysis, the infiltration rate was 5.4 mm/min, which is more than 2 times less than the values of the humus-eluvial horizon. During the first hour, the water speed slightly decreased, reaching a minimum of 3.0 mm/min. Despite the general decrease in infiltration, the upper part of the illuvial horizon of the virgin light-gray forest soil was characterized by good water permeability.

| Lands  | Soil horizon | Minutes of the first hour of research (infiltration) | Hours of observation (filter) |
|--------|--------------|---------------------------------------------------|------------------------------|
|        |              | 10 20 30 40 50 60 | 1 2 3                        |
| Arable | A1           | 12.2 10.4 5.3 5.0 3.8 3.8 | 3.5 2.5 2.2                  |
|        | A2           | 8.0 3.0 2.8 2.8 2.5 2.2 | 2.2 1.8 2.0                  |
|        | B1           | 5.4 5.0 3.0 3.2 3.2 3.0 | 1.8 1.8 1.7                  |
|        | B2           | 3.4 2.0 2.0 2.2 1.8 1.8 | 1.8 1.8 1.7                  |
|        | C            | 2.3 2.3 2.2 2.0 1.8 1.8 | 1.8 1.5 1.5                  |
|        | Aar          | 8.4 3.8 3.7 2.4 1.8 1.8 | 1.2 1.0 1.0                  |
| Virgin | B1           | 4.5 3.0 3.0 2.2 2.0 2.0 | 1.1 1.0 0.8                  |
|        | B2           | 2.4 2.0 2.0 2.0 1.5 1.5 | 1.5 1.5 1.4                  |
Sludge particles also accumulate in the lower part of the illuvial horizon (B2), so the infiltration rate is 3.4% already in the first minutes. Subsequently, it decreases to 1.8 mm/min, which is the minimum over the entire profile of virgin light gray forest soil.

In general, this subtype is characterized by the Kachinsky classification as good water permeability, which, for the conditions of the Northern Trans-Urals, gives favorable conditions for moisture accumulation in the meter layer and reduction of water loss due to physical evaporation. In the taiga-forest, the high speed of water movement in the soil prevents the processes of water saturation and the creation of surface waterlogging of the territory. This makes light-gray forest soils the most promising compared to podzolic soils from an agronomic point of view.

The involvement of virgin soils in agriculture leads to a change in the conditions of soil formation. This is especially true for light-gray forest soils. The change in vegetation is reflected in the nature of the supply of organic matter and the formation of other humic substances than on the virgin soil. Annual mechanical treatments form the arable layer, combining the humus and eluvial horizons, and maintain a high degree of aeration in it. Agricultural activity on light-gray forest soils in the Northern Trans-Urals increases the movement of water inland, thereby accelerating the process of anthropogenic illuviation. As a result of this, a decrease in the permeability of individual soil horizons is possible.

The infiltration rate of the arable horizon of light-gray forest soil in the first minutes was 8.4 mm/min, but after 20 minutes, it decreased by more than 2 times (Table 1). Such a sharp decrease in speed is caused by the presence of a non-water-stable structure of the arable horizon. At the end of the first hour, water infiltration in the arable horizon took place at a minimum speed of 1.8 mm/min. In 1 hour, the movement of water decreased by almost 5 times, which is evidence of the presence of an unfavorable structure in the anthropogenically transformed horizon.

The subsurface layer located in the upper part of horizon B1 was characterized by a higher bulk density than the virgin analogue [6]. Therefore, the infiltration rate in the first 20 minutes was lower and amounted to 3.0–4.5 mm/min. At the end of the first hour, it reached 2.0 mm/min, which is one third less than the values in the natural state. The lower part of the illuvial horizon (B2) is not directly affected by the working bodies of agricultural implements. The infiltration rate in the first minutes is 2.4 mm/min. By the end of the first hour, the movement of water decreases to 1.5 mm/min, which is 17% slower compared to virgin soil.

The second phase of water permeability, which is called filtration, is characterized by a minimum deviation of the water speed for three or more hours. Therefore, it is more convenient to analyze it by the filtration coefficient, taken as the average value for the study period.

The humus horizon (A1) of virgin soil is characterized by high filtration ability - water passes inland at a speed of 2.7 mm/min. The reason for this is the light particle size distribution and low density. The ratio of the filtration coefficient and the water speed in the first minutes is 4.5 units, which indicates the formation of structural aggregates with low water stability. The use of such soils without any measures to improve agrophysical indicators will lead to a serious decrease in fertility.

The arable layer, as our studies have shown, was characterized by a significantly lower filtration rate - the deviation relative to the virgin soil was 61%, which is convincing evidence of the deterioration of the physical properties of light-gray forest soil when it is used as an arable land. Water filtration in the A1A2 horizon in the virgin land was lower and reached 2.0 mm/min, which leads to the smooth movement of water deep into the soil profile during heavy rains or snowmelt.

The illuvial horizon formed due to the accumulation of sludge particles can be a significant obstacle to the movement of water, which is observed in podzolic soils. However, as our studies have shown, filtration of the virgin soil is 1.8 mm/min, which indicates good capacity of the horizon. The filtration coefficient of the upper part of the illuvial horizon (B1) of arable light-gray forest soil was 1.0 mm/min, which is the minimum value and indicates the formation of an over-compacted horizon with very low permeability. In the conditions of the Northern Trans-Urals, during the period of
snowmelt and heavy rains, this horizon may turn out to be an obstacle to the downward flow of water and disrupt the moisture regime of arable light-gray forest soil. This can cause water erosion if the field is on a slope. In low areas, excessive water saturation of the upper layer may occur, which will lead to difficulties in field work in spring and autumn. In arable soil, the filtration coefficient is 45% less than the values of the virgin land. Changes in water permeability also affected horizon B2, although not so much. The filtration coefficient was 1.5 mm/min, which is 17% less than in the virgin land.

4. Conclusion
Thus, the subtype of light-gray forest soils in Western Siberia is concentrated mainly in the taiga-forest zone and is found mainly in combination with podzolic soils. In the forest-steppe zone, they are found in small areas and are not the most promising for agriculture. In the southern taiga-forest zone, light-gray forest soils are involved in agriculture and are actively used in arable lands. In the virgin state, light-gray forest soils are characterized by the best permeability, which distinguishes them from podzolic soils. The illuvial horizon is characterized by a minimum infiltration and filtration rate, which reaches 3.1 and 1.8 mm/min, respectively. This is enough for the smooth movement of water deep into the profile. Plowing and prolonged use of light-gray forest soils in arable land leads to a decrease in the permeability of the arable horizon - the infiltration and filtration coefficients reach 2.8 and 1.1 mm/min, which is almost three times less than the values of the humus-eluvial horizon of virgin soil. Under the influence of an anthropogenic factor, a layer with a minimum filtration rate (1.0 mm/min) is formed in the upper part of the illuvial horizon, which can cause a violation of the moisture regime of arable light-gray forest soil and cause water erosion in sloping fields. To restore the initial speed of water movement in the soil, it is necessary to use chisel treatment to destroy the over-compacted layer. The ratio of the water speed between the initial and final measurement points indicates the presence of a non-water-stable structure in the humus-eluvial and arable horizons. Therefore, to prevent deterioration of arable land, it is necessary to create all conditions for the formation of a water-stable structure by applying organic fertilizers and lime.

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