Post-agrogenic transformation of texture-differentiated soils of the northern forest-steppe near the Irtysh River in the Omsk region

Yu V Aksenova
Omsk State Agrarian University, 1, Institutskaya Sq., Omsk, 644008, Russia
E-mail: yuv.aksenova@omgau.org

Abstract. Weak or blind drainage of the territory, changing hydrothermal conditions and water regime, high volumes of lime materials used in the 1990s contributed to carbonate salinization of soils and accumulation of ready soluble salts in the profile of texture-differentiated soils. In sod-podzolics gleyic soil, the maximum amount of carbonates (14.3–17.2%) is accumulated in horizons BT_{ng} at a depth of 73–104 cm. In grey gleyic soil, their content reached the highest values (14.5–14.8%) in sod (AY_{dc}) and humic eluvial (AEL_{dc}) horizons, gradually decreasing to the parent rock. The presence of carbonates shifted the medium reaction to the alkaline interval throughout the entire soil profile. In sod-podzolics gleyic soil, the reaction of the medium was within the range of 6.9–8.1; in the horizons of maximum accumulation of carbonates, it reached 8.5–9.1. In the profile of grey gleyic soil, the pH value varied within the range of 8.1–9.2 units. Ready soluble salts of chlorides and bicarbonates were present at a depth of 61–73 cm, but their content did not exceed 1 mmol/100 g of soil. The morphological structure of the soil profile corresponded to their type affiliation. In the sod-podzolics gleyic soil, eluvial horizon EL was clearly distinguished, in the grey gleyic soil; humus-eluvial AEL horizon was clearly picked.

1. Introduction
Human economic activity is a combination of different anthropogenic factors, the result of which is the appearance of various changes occurring in soils [1, 2]. These changes affect the chemical and physical properties of soils, their composition, regimes, morphology and can lead to the destruction of the soil profile [3]. In many cases, soil transformation occurs with the combined participation of natural and anthropogenic factors. Anthropogenic impact usually activates natural processes that were absent or depressed before human exposure. For example, the mechanical treatment causes changes in the internal organization of the soil profile. With prolonged and regular application of fertilizers, pesticides and ameliorants, it becomes possible to contaminate soils with heavy metals and pathogenic microorganisms. Soil irrigation is often accompanied by the development of secondary salinization and solonization [4].

For texture-differentiated soils formed under conditions of washing and periodically washing types of water regime [5], the presence of ready soluble salts and calcium carbonates is characteristic of parent rocks or the lower part of the texture horizon only. The process of secondary accumulation of these compounds in the soil stratum is possible when they are precipitated from mineralized groundwater with a change in the water regime of the territory.

The change in hydrothermal conditions is accompanied by an increase or decrease in the groundwater level, the development of a number of hydro-accumulative processes, and dynamic fluctuations in the...
depth of soil new structures. The accumulation of ready soluble salts and calcium carbonates affects the formation of the soil profile and leads to a change in soils’ taxonomic affiliation at the subtype level [6]. The accumulation of the substances can be both surface and subsoil, affecting any part of the profile and any of the formed or emerging genetic horizons.

The greatest danger to arable soils is represented by various types of salinization (carbonate, gypsum, and by ready soluble salts). The potential risk of salinization may arise in the case of bilateral water regime when there is an alternation of periods of partial washing of surface horizons to a shallow depth and periods of pulling up saline solutions from the bottom [4]. Carbonates influence humification processes by the formation of stable organo-mineral complexes — calcium humates, soil reaction, soil saturation with bases, and soils’ nutritional regimes [7, 8].

The processes of accumulation and migration of carbonates play a significant role in soil formation processes and determine the formation of a carbonate profile, acting as one of the main diagnostic features [8]. Depending on the relationship between carbonate ions and bicarbonate ions with particular cations, alkali and alkaline earth metal carbonates can have a negative effect on plants and soil properties. Thus, calcium carbonates are harmless for most plants, but carbonate horizons are often highly cemented and difficult to penetrate plant roots.

Magnesium and sodium carbonates are highly alkaline and toxic to plants. The toxic effect of ready soluble salts of chlorides and sulphates is manifested in an increase in the osmotic pressure of soil moisture, a decrease in its availability to plants, a violation of the normal ratio of mineral nutrients, and a negative effect on soil properties [9]. Texture-differentiated soils of the forest-steppe zone of the Omsk region are formed in areas where saline soils are distributed and are predisposed to the development of various adverse processes in them. Due to the limited distribution of highly productive arable soils in the region [10], control over their fertility and evolution under the influence of long-term use, as well as managing plant nutrition [11] is a priority for agricultural production.

2. Materials and methods

The objects of the study are located in the northern part of the forest-steppe zone on the right bank of the Irtysh River. Soils are formed in the south of the Muromtsevo district of the Omsk region and are represented by the types included in the group of texture-differentiated soils.

A common diagnostic feature for the soils of the group is the presence of texture horizon BT in the profile, which is combined with eluvial horizon EL or with humus-elsuvial horizon AEL. The parent rocks occur on saline neogene clays and are represented by heavy carbonate, often saline, loams. The research area combines the landscapes of the northern forest-steppe and the southern taiga forest zone, with small islands of birch-aspen groves and pine forests.

Soil sections were established in key areas represented by types of sod-podzolic and grey soils. At an elevation of the relief, sod-podzolic, surface-bleached, surface-gley, calcareous, low-thick, medium-humic, light loamy soil was identified. Previously, the soil was used as arable land; at the present stage of development, it is in a fallow state. In the slope part, under the forest, there was a grey surface-gley calcareous, medium-humic, low-thick light loamy soil. In the area of groundwater discharge, in lowering relief, peat-gleyzem has formed. In the rest of the territory, groundwater lays deeper than 3 m. According to the cationic-anionic composition, the water is low-mineralized with bicarbonate calcium composition.

The assessment of morphological features and properties of the texture-differentiated soils was carried out according to the following indicators:

- carbon of organic matter (Tyurin's method in the modification of Simakov);
- carbonate content (acimetric method);
- soil reaction (potentiometric method);
- cationic-anionic composition of groundwater and soil (GOST 26423-85–26428-85);
- particle size distribution (organoleptic method).

The researches were carried out using the equipment of the collective use center of the Omsk State Agrarian University «Agricultural Technological Research».
3. Results and discussion

3.1 Morphological features of soils

The “classical” profile of texture-differentiated soils is defined as eluvial-texture-differentiated one. In soils with such a profile, under the influence of the podzolic soil formation process, the transformation and redistribution of the components that form their material composition occurs. The profile is characterized by the presence of a pronounced eluvial EL or humus-eluviul AEL horizon and conjugated texture horizon BT. By the presence and accumulation of various substances, one can go by the current or previous elementary soil processes that have formed or are forming the appearance of modern soils.

As a result of the superposition of the carbonate process on the podzolics and sod soils, they acquired a new specific character “calcareous”, which is unusual for soils of the podzolics type of soil formation.

The morphological description of the profile of the sod-podzolics surface-bleached surface-gley calcareous low-thick medium-humic light loamy soil was carried out throughout the section established in the idle land. Previously, the soil was used as arable land. The profile had a structure \( \text{AY}_{dc}-\text{EL}_{dc}-\text{BEL}_{dcg}-\text{BT}_{1dcg}-\text{BT}_{2ncg}-\text{BT}_{3ncg}-\text{BT}_{4ncg}-\text{BT}_{5ncg}-\text{C}_{ncg} \) and outwardly corresponded to the type of sod-podzolics soils. Sod horizon \( \text{AY}_{dc} \) (2–36 cm), grey in colour, with light loamy granulometric composition, marked out along the line of ploughing. Eluvial horizon \( \text{EL}_{dc} \) (36–46 cm) underlay, whitish, sabulous due to the destruction and removal of the least stable minerals of the silt fraction and sesquioxides to the underlying horizons. Subeluvial horizon \( \text{BEL}_{dcg} \) (46–52 cm) is distinguished by light brown colour and the presence of siliceous powder. Carbonates in horizons \( \text{AY}_{dc}, \text{EL}_{dc}, \text{BEL}_{dcg} \) were represented by a diffuse form and were diagnosed by the interaction of the soil with 10% hydrochloric acid. Texture horizons \( \text{BT}_{1dcg}-\text{BT}_{2ncg}-\text{BT}_{3ncg}-\text{BT}_{4ncg}-\text{BT}_{5ncg} \) with a relative accumulation of fine particles lay under horizon \( \text{BEL}_{dcg} \), which confirms their heavier, medium loamy, granulometric composition. In this part of the profile, carbonate accumulations were presented in the form of white soft spots, iron oxides in the form of ochre-rust spots and ferromanganese formations were present. At a depth of 149–190 cm, a carbonate parent rock was deposited (\( C_{ncg} \) horizon).

A morphological description of the profile of grey surface-gley calcareous low-thick medium-humic loamy soil was carried out throughout a section in the forest. Horizons \( \text{AY}_{dc}-\text{EL}_{dc}-\text{BEL}_{dcg}-\text{BT}_{1dcg}-\text{BT}_{2ncg}-\text{BT}_{3ncg}-\text{BT}_{4ncg}-\text{BT}_{5ncg}-\text{C}_{ncg} \) corresponding to the type of grey soils are picked in the soil profile. Sod horizon \( \text{AY}_{dc} \) (2–20 cm) of grey colour, light loamy granulometric composition turned into a light grey, medium loamy humus-eluviul horizon \( \text{AEL}_{dc} \) (20–43 cm). Below it subeluvial horizon \( \text{BEL}_{dcg} \) (43–61 cm) is picked by heterogeneous brown colour and the presence of siliceous powder. In these horizons, carbonates were determined by the interaction of soil with 10% hydrochloric acid. The horizons are noticeably depleted in fine particles as compared with the underlying texture horizons \( \text{BT}_{1dcg} \) (61–92 cm)-\( \text{BT}_{2ncg} \) (92–120 cm)-\( \text{BT}_{3ncg} \) (120–151 cm) with clay particle size distribution. The horizons differed in colour, structure, and contained carbonates in the form of white soft spots, ferromanganese formations and iron oxides in the form of ochre-rust spots. The parent carbonate rock is allocated at a depth of 151–176 cm by yellow-brown colour and a lighter, medium loamy, granulometric composition.

3.2 Change in physicochemical and chemical properties of soils

Soils are formed with the participation of the podzolic process, which is accompanied by the destruction and removal of soil-formation products to the lower part of the profile or beyond. Under the conditions of washing and periodically washing water regimes, ready soluble compounds primarily migrate with downward water flow. Therefore, one of the diagnostic features of sod-podzolics and grey soils is the absence of carbonates and ready soluble salts in the profile, the presence of which is characteristic of the parent rock or the lower part of the texture horizon of residual-calcareous soils of the forest-steppe zone. The entry of salts into the soil profile and ground flow is closely related to modern soil formation processes, geochemical features of water-resistant and water-bearing rocks, and hydro-accumulative processes due to the geological and hydrogeological conditions of the territory.

In the sod-podzolics gleyic soil, a gradual increase in the carbonate content throughout the profile was observed with its maximum accumulation in the texture horizons (BT) and a subsequent decrease
to the parent rock (Figure 1). In the profile of grey gleyic soil, the carbonate content gradually decreased from the humus horizon to the parent rock (Figure 2).

Carbonate salinization could occur during the interaction of weakly mineralized groundwater with calcium bicarbonate in its composition with water-soluble salts located in the solid phase of parent rocks, their transition to soil solution with subsequent movement and sedimentation in the soil profile. Precipitation of calcium and magnesium from the soil solution is observed in the summer when the soil solution is heated, and the solubility of carbon dioxide decreases. In the wet period or season, the soil solution is diluted, which is accompanied by the additional dissolution of calcium carbonates, which are in the solid phase of the soil. The solubility of calcium carbonates increases with increasing solubility of carbon dioxide due to lower temperatures compared with higher summer temperatures.

Another cause of soil calcareous invasion could be high doses of lime used to eliminate acidity. Against the background of poor and blind drainage of the territory, changes in its hydrothermal conditions the accumulation of calcareous materials and compounds formed after liming and interaction with weakly mineralized groundwater occurred in soils. During spring snowmelt, the most profound wetting of soils took place and soluble compounds migrated with downward water flow. In the summer, as a result of desuction and physical evaporation in the soils, ascent water enriched by carbonates and bicarbonates of alkaline earth metals dominated. Ascent water returned substances carried away in spring into the soil profile. These compounds include ready soluble salts detected in the texture (BT) horizons and parent rock (C).

Analysis of water extracts showed the presence of anions of ready soluble chlorides and bicarbonates in the soil profile. During 2012–2013, in sod-podzolics gleyic soil salts laid deeper than 1 meter, evenly distributed in the lower part of the profile. The amount of chlorides in horizons BT_{4n}g-BT_{5n}g-C_{ng} was 0.26–0.28 mmol/100 g, hydrocarbonates – 0.5–0.9 mmol/100 g. According to the “total effect” of toxic ions during this period, the soil was non-saline. In 2014, the presence of salts was detected from the...
depth of 73 cm: in BT_{2ncg}-BT_{3ncg}-BT_{4ncg}-BT_{5ncg}-C_{ncg} horizons. The amount of bicarbonates remained at the level of 0.6–0.8 mmol/100 g, the chloride content increased twofold (to 0.5–0.81 mmol/100 g) and the degree of salinization turned into a weak one.

In grey gleyic soil, chlorides and bicarbonates occur from 61 cm, directly beneath the eluvial-illuvial (BEL_{dc}) horizon, in amounts of 0.46–1.06 mmol/100 g and 0.5–0.7 mmol/100 g, respectively. In 2014, a chloride content decreased on average by 0.3 mmol/100 g. During the research period, the degree of soil salinization remained weak.

Soils formed during the development of the podzolic process under the conditions of leaching of soluble compounds have an acid reaction in the diagnostic eluvial (EL) and humus-eluvial (AEL) horizons. The presence of acidity in these horizons is a sign of their type. During carbonate salinization of soil, a shift in the reaction of the medium in the alkaline interval occurred. Only the sod horizon (AY_{dc}) in the sod-podzolics gleyic soil had a neutral reaction (pH 6.9–7.3). In the rest of the profile, the reaction of the medium was in the alkaline (pH 7.6–8.1) range. In the horizons of the maximum accumulation of carbonates, the pH reached 8.5–9.1 units. In the profile of grey gleyic soil, the pH value over the years of the study varied in the alkaline range (8.1–9.2).

The amount of humus in soils did not change over the years of the study (data on humus are given on average over 3 years). Sod-podzolics gleyic soil was characterized by its low availability and a sharp decrease with the depth: from 3.28% in the humus horizon (AY_{dc}) to 0.37% in the eluvial (EL_{dc}) and 0.25% in the subeluvial (BEL_{dcg}) horizons. The grey gleyic soil had an average humus content and its gradual decrease with the depth: the indicator value decreased from 4.46% in horizon AY_{dc} to 2.09% in humus-eluvial horizon AEL_{dc} and 0.91% in horizon BEL_{dcg}.

4. Conclusion
Carbonate salinization of the soil profile occurred against the background of accumulation of chemical reclamation products and changes in the water regime of the territory, as evidenced by the presence of compounds of oxide iron and ferromanganese formations in the middle part of the profile. With a shallow occurrence of groundwater, the capillary fringe was within the soil profile, and water-soluble compounds rose with rising moisture flow and precipitated in the profile in the form of calcium carbonates and bicarbonates when the water regime changed. An important role in the redistribution along the profile and transformation of the forms of carbonate accumulations was played by the podzolic soil formation process. In sod-podzolic gleyic soil, partial neutralization of carbonates by acidic products formed under the conditions of the podzolic process occurred, followed by their partial leaching and accumulation in the underlying horizons. In grey gleyic soil, the podzolic process is weakened, so the maximum accumulation of carbonates was detected in the upper part of the profile.

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