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Evolution of Chernozems in the southern forest-steppe of the Central Russian upland under long-term cultivation examined in the agro-chronosequences

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ABSTRACT

Chernozems are the major component of soil cover in the forest-steppe of the Central Russian Upland. They underwent the most significant anthropogenic transformation in terms of duration and scale of development in profiles, due to ploughing. Despite the long list of experimental works, the obtained conclusions are often contradictory. From our point of view, the best way to observe the effect of ploughing on Chernozems is the examination of soils with different durations of cultivation based on an agrochronosequence approach which was used in this study.

The most appreciable changes occurred in the arable Chernozems for the first period after the beginning of cultivation. In the soils with 16 and <100 years duration of cultivation, the following changes are observed: 5–7 to 9 cm decreasing of the humus profile, compacting of the plough-layer and its initial enrichment by clay, 15–30% decreasing of the soil organic carbon (SOC) content and stocks in the 0–30 and 0–50 cm depths, about 40 cm uplift of carbonate accumulation, and increasing of soil inorganic carbon (SIC) content and stocks in the 0–100 and 0–200 cm depths. These changes occurred due to abrupt decreasing of the plant residues in agriculture, influence of machinery treatment resulting in destruction of the plough-layer structure and this layer compaction, and changes of water regime. In the arable soils with 100–150 and 150–200 years of cultivation, the further compaction of soil mass, loss of SOC and uplifting of carbonates are not observed. There is backfilling of the SOC along the cracks in the middle part of a profile, high activity of burrowing animals, and continuing redistribution of clay fraction in the deeper horizons. These processes resulted in stabilization of SOC stocks in the profile of the arable soils on the "new" reduced level and shifting of carbonates back to the initial (before cultivation) or even lower level of location, concentrations, and stocks in a profile. After 220–240 years of cultivation, high instability of the studied indicators of the humus and carbonate status can be emphasized. Relatively rapid changes occur in Chernozem properties after the beginning of ploughing, with subsequent slowing. The activity of burrowing animals introduces an ambiguity in the trends of development of the long-ploughed Chernozems in the agrochronosequences we studied. This factor was previously underestimated.

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1. Introduction

Chernozems are the major component of soil cover in the forest-steppe of the Central Russian Upland. They experienced the most significant anthropogenic transformation in terms of duration and scale of manifestation due to ploughing because at present more than 60% of their area is ploughed (Uvarov and Solovichenko, 2010), and this rate was maintained at least from the second half of the 19th century in the region (Oganovskiy, 1911). There is an opinion that Chernozems have undergone such considerable changes in the process of ploughing that it is impossible to consider them as true Chernozem-type soils (Gerasomov, 1983).

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The most conceptual and system ideas on the transformation of Chernozems under cultivation are expressed in the works by I.I. Lebedeva. In her point of view the replacement of natural biota by cultural ones is the trigger and the first step in the long series of interconnected changes in humus status, water-physical properties, water and temperature regimes in the arable Chernozems (Lebedeva et al., 2013). At first, the cultural vegetation radically changes the quantity of organic residues annually entered in a soil and their distribution within a profile which reduce the content of humus in arable soils. A direct consequence of vegetation replacement is the change of soil climate, which is most contrasting in the plough-layer. The temperature regime of soils becomes more continental because the amplitude of daily and annual temperatures increases. Then, the humidization of the water regime occurs. This regime still remains periodically percolative but due to a reduction of water consumption in autumn after harvesting the deficit of moisture is reduced, and in spring the precipitation penetrates to a greater depth than in the virgin Chernozems (Kokovina and Lebedeva, 1986; Shcheglov, 1999). Under long-term cultivation the water regime of arable Chernozems varies in two opposite directions (Lebedeva, 2002). In the upper part of the profile, the water regime becomes more arid due to the intense evaporation inside the soil profile, while the lower layers of profile including the parent rock are overwetted due to accumulation of precipitation unexpended by cultural vegetation. In addition, the water regime changes are closely related to the structural state of arable Chernozems. Ploughing of virgin Chernozems is accompanied by a disintegration of their natural granular structure and compaction of soil mass in the plough-layer. In the dry state, large polygonal blocks with 40–50 cm in diameter separated by cracks are formed. The density of soil mass in blocks reaches 1.35–1.40 g/cm_3 (sometimes, 1.6 g/cm_3), almost equal to the density of the parent rock. Using cracks between those blocks, water from precipitation is immediately drained down in the lower horizons, and in addition, humus material of the upper horizons is transferred to the middle part of the soil profile (Lebedeva et al., 2013).

Review of studies devoted to the particular aspects of the agrogenic transformation of Chernozems shows that researchers make contradictory and often mutually exclusive conclusions about the changes of soil properties and the reasons that led to these changes. Within a short article it is impossible to consider the problem in detail; we will focus only on those issues that are relevant to our work. For instance, there are three opinions on the changes of humus profile thickness in arable Chernozems: the thickness decreases (Aderikhin, 1964; Agroecological state of Chernozems in the Central Chernozemic Region of Russia (1996); Ushacheva and Zvyagintsev, 2000; Ivanov and Tabanakova, 2003), does not change (Afanasyeva, 1964; Natural and anthropogenic geosystems of the central forest-steppe of the Russian plain, 1989; Akhtyrtsev, 1991), or increases (Denisov, 1935; Lazarev, 1936; Brook, 1979; Sinkevich, 1989). The decrease of thickness is explained by long-term erosion together with the effect of arable compaction. The rate of anthropogenically-provoked water denudation is estimated at 1.0–1.2 cm/100 years (Ivanov and Tabanakova, 2003). Invariability of thickness is explained by enhancement of accumulation of humus in the subsurface horizons. An increase of thickness of humus profile is supposed to be a result of an intensification of illuviation of humus in the process of ploughing.

All researchers agree that the ploughing of Chernozems is definitely accompanied by a loss of their organic matter. However, the authors' opinions regarding the intensity of dehumification in arable Chernozems diverge significantly. Together with the view of the rapid, almost catastrophic dehumification of arable Chernozems in the 20th century (Sidorov et al., 1983; Zonn and Travleev, 1989), there are ideas that the loss of humus in arable soils within the steppe and forest-steppe zones is grossly exaggerated (Afanasyeva, 1964; Kokovina and Lebedeva, 1990; Orlov et al., 1996; Akhtyrtsev and Akhtyrtsev, 2002). There is no consensus on the question of the duration of dehumification in arable Chernozems. Some researchers (Afanasyeva, 1966; Ponomareva, 1974; Akhtyrtsev and Akhtyrtsev, 2002) think that the loss of humus was very intense in the first decades after the beginning of the ploughing and in the long-term cultivated soils it is completely stopped. Other researchers believe that the dehumification continues over centuries (Aderikhin, 1964; Gedymin and Pobedintseva, 1964).

There are three points of view on change in depth of carbonate location in the arable Chernozems: their occurrence became lower as a result of agro-anthropogenic leaching (Agroecological state of Chernozems in the Central Chernozemic Region of Russia (1996)); depth does not change, but the seasonal pulsation of calcium carbonate has greater amplitude in a new hydrothermal regime (Shcheglov, 1999; Brekhova and Shcheglov, 2001); or the level of carbonates rose due to increasing physical evaporation from the surface of arable fields at the beginning and end of vegetation period as well as on fallow fields (Afanasyeva, 1964, 1966; Pobedintseva, 1989; Lebedeva, 2002).

The depletion of the plough-layer by clay fraction in the zonal row from the northern sub-types of Chernozems to Kastanozems has been noted by various authors (Brook, 1979; Shcheglov, 1999; Akhtyrtsev and Akhtyrtsev, 2002; Kozlowskiy, 2003 and others). Removal of clay as a result of agro-lessivage occurs in the subsurface part of the soil profile and is implemented in a layer of “sole shoe” (Akhtyrtsev and Akhtyrtsev, 2002; Kozlowskiy, 2003). However, according to other observations in arable steppe Chernozems, the balance of clay fraction in relation to the parent rock is moved in the negative direction for the whole soil profile (Shcheglov, 1999). The joint action of processes of argilization and agro-lessivage in arable Chernozems of steppe and forest-steppe zones are also noted (Agroecological state of Chernozems in the Central Chernozemic Region of Russia (1996); Butova et al., 1996).

Thus, long-term and unbalanced agricultural impact has led to the disturbance of Chernozems under the influence of a whole range of negative processes which reduced their fertility. To develop measures for the rational use and protection of Chernozems and to predict their ecological status in future, a wide range of scientific data is needed including information about the changes of soil properties and processes as a result of their long-term agricultural development. Despite the long list of experimental works, the obtained contradictory conclusions hamper the development of theory of agrogenic evolution of Chernozems. This theory is far from complete, is composed of individual fragments, and only partially reflects the general trends that need to be verified, and does not cover all the diversity of soil changes occurring under cultivation (Ivanov et al., 2013).

From our point of view, the best way to investigate successfully the effect of cultivation on the changes of Chernozems' properties is to study the soils with different durations of agricultural use based on an agrochronosequence approach. This research methodology was already previously used (Gedymin and Kharitonychev, 1964; Gedymin and Pobedintseva, 1964; Akhtyrtsev and Shchetinina, 1969; Kozlowskiy, 2003). However, the soils studied were located far from each other, and similar lithologic and geomorphological conditions for those soils were not guaranteed.

According to the approach suggested (Chendev, 2008) and used by us, the study area before the ploughing was a single landscape with identical vegetation, soil, relief, and parent rocks. Different plots of each site were under ploughing for different times and are adjacent. We use the archival large-scale cartographic materials

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