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Change of physical properties of arable chernozem in the initial period of the after agricultural abandonment regime

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Abstract. A field experiment was conducted in the botanical garden of the South Federal University (Rostov-on-Don, Russia), which was aimed at converting the old arable land plot to the arable regime. Physical properties of chernozems were studied during the first years of the postagrogenic period in different plots, such as: a virgin steppe plot, an arable plot and an abandoned plot. During the course of the experiment it was revealed that physical properties of postagrogenic soils change due to vegetation development after tillage is discontinued. Within three years of research a biological diversity of the floristic composition in the abandoned plot increased from 9 species (during the first year) up to 38 species of plants (3 years later). Vegetation development served as a cause of changes in physical properties of chernozems. Temperature of the abandoned soils decreased along with soil moisture growth, if compared to the relevant indices of the arable plot of land. Owing to the root development and cessation of the agricultural impact, density of the upper horizon in the abandoned plot dropped by 10% on average. A positive correlation was revealed between the chernozem density and its penetration resistance ($r = 0.70$) and temperature ($r = 0.73$), whereas an inverse correlation was detected between the chernozem density and its moisture content ($r = -1.0$).

Key words: agrogenic impact, demutation, succession, soil density, soil penetration resistance, hydrothermal conditions.

INTRODUCTION

The official census of the land cadaster in Russia, conducted in 2016, revealed 44% of abandoned land plots, being unused in agriculture. Constant climate change and human anthropogenic activities reduce territories suitable for arable farming every day. Over 34% of the world's arable lands are more or less exposed to degradation (Kudeyarov, 2019). Large territories of the steppe land are transformed by people, with that entailing destruction of unique plants, depletion of the wildlife and changes in the soil cover.

Taking into account anthropogenic load on soils, physical properties of soil are an important factor that determines soil fertility (Kalinina et al., 2015; Gorbov et al., 2016). Soil fertility depends upon a constant need of plants in nutrients, optimal moisture, temperature and air access required for normal life of microorganisms. Hydrothermal regime of soil is an important factor of its fertility that determines development of various processes. Soil temperature along with its moisture content has a major impact upon the main soil-formation processes, biomass accumulation and biological productivity (Kechaikina, 2011; Myasnikova et al., 2013). Succession processes taking place in abandoned soils as a result of the abandoned land overgrowing with vegetation fall into the secondary postagrogenic successions category (reconstructive successions) (Kazantseva et al., 2008; Myasnikova et al., 2013). According to the definition (Vysotsky, 1923), reconstruction of the rooted vegetation on land plots where it was destroyed by artificial means (timber harvesting, development of land plots for agricultural purposes) or as a result of any natural disasters (attacks of pests, floods, fires) is a demutation process. Intensive overgrowing of hayland, pastures and abandoned land plots represents an initial stage in reconstruction of the natural vegetation cover.

Based on the earlier conducted research (Kechaikina, 2011; Myasnikova et al., 2013; Gorbov et al., 2016; Shchur et al., 2016) it is found out that, in general, uncultivated soils start to resemble similar virgin soils in a number of attributes. However, a damage caused to them is not eliminated within a long period of time. Owing to works of a number of scientists (Myasnikova et al., 2013; Shchur et al., 2016) it is known that reconstructive processes in postagrogenic soils do not stop 80 years after the arable regime. Succession changes of the initial years of the arable regime foster regeneration in arable soils: under the grassland vegetation, former arable horizons undergo transformation according to the sod type (Kechaikina, 2011), the soil density drops, penetration resistance and moisture grow, water permeability increases (Adhikari, 1989; Rao et al., 2014; Xiao et al., 2018), microbial population thrives. Soil development is accompanied by a growing content of organic matters (Shchur et al., 2016), which results in an increased amount of enzymes produced by microorganisms as well as improved immobilization capacity of soils (Khaziev & Gulko, 1991; Bandick & Dick, 1999; Acosta-Martinez & Tabatabai, 2000; Raiesi & Salek-Gilani, 2018).

The research was conducted with a purpose of studying changes in physical properties of arable chernozems under the grassland vegetation in the south of Russia during the first years of the arable regime.

MATERIALS AND METHODS

To observe changes in physical properties of postagrogenic chernozem, a test field was chosen that was located in the botanical garden of the South Federal University. The botanical garden is situated in the center of Rostov-on-Don city in the southwest of the Russian Federation. The research territory has a moderate continental climate. The average annual precipitation is 424 mm. Precipitation occurs mainly in the areas affected by cyclones along the weather fronts. The average air temperature is -7 °C in January and + 23 °C in July.

Profile of Chernozems is made of two main horizons, which are the humus and illuvial-carbonate ones.Typical features for the Chernozems are accumulation of great amount of haumate-calcic humus (up to 15%), good structurization, favorable water-physical properties, saturation with bases, neutral and weak alkaline reaction, stability of mineral soil mass (Glazovsky & Zaitseva, 2009). In 2016 the test field represented an arable plot being under black fallow condition. In spring, prior to the first plowing, the plot was divided into two parts. The first part ceased to be tilled and was converted into an abandoned plot with a purpose of restoring its biological properties. The second part was continued to be tilled, with data from that part further used as a negative control. Two abandoned plots located in the botanical garden (aged 27 and 72 years) and a virgin steppe plot in the Persianovskaya steppe natural sanctuary were used as positive control samples.

Observations were performed within 3 years from 2016 to 2018. A geobotanical description of the plot vegetation was made on 18.06.2016, 25.06.2017, 13.06.2018. Physical properties of the test plots were studied in three periods every year: in May (the active vegetation maximum), end of July (a drought season) and in September (a chilly weather period). Moisture of the test plots was measured in the field with DATAPROBE moisture meter, with 10 replications to a depth of 10 cm. Temperature of the soil surface was measured with HANNA CHECTEMP electronic thermometer (soil surface, 0 cm). Density of the test plots surface was defined by a gravimetric method in triplicate (top soil, 0–10 cm). Soil penetration resistance was defined in the field with Eijkelkamp penetrometer to a depth of 50 cm with 5 cm interval, with 10 replications.

Statistical data processing was performed with the correlation analysis and analysis of variance applied. Statistically significant difference at $p < 0.05$ was taken into account during discussion of the results.

RESULTS AND DISCUSSION

Flora of the abandoned plot in the first year of the research was represented by 9 species. The sward of the postagrogenic plot in the first year of the arable regime was dominated by weedy tallgrass plants: *Ambrosia artemisiifolia; Artemisia vulgari; Cyclachaena xanthiifolia; Chenopodium album*. *Asteraceae* family was dominating in this period (96% of the total species), the remaining families accounted for 4% of the total species. The total biomass on the test plot amounted to 0.76 g×cm^{-3}, the biomass value in the second year dropped by 10% ($p < 0.05$). The flora composition of the plot at the time of research in 2016–2018 and the projective cover of every species are represented in Figs 1, 2. *Asteraceae* family became dominating in the second year of the arable regime (45% of the total species). *Poaceae* grass family was detected as well (10% of the total species). The remaining families were represented by single species (45% of the total species). Flora of the test plot in the second year of the arable regime comprises 21 species.

Flora of the test plot in the third year of the postagrogenic regime comprised 38 species; if compared to the first year, the phytomass value decreased by 26% ($p < 0.05$), with that fact demonstrating a drop in the weedy tallgrass plants domination in the sward. An inverse correlation was detected between the phytomass of the test plot, on one hand, and duration of the arable regime (r = -0.97) and quantity of certain plants species (r = -0.98), on the other hand. In percentage terms, the plant community was dominated by such families as: *Asteraceae* (33%), *Poaceae* (14%), *Brassicaceae* (6%), *Apiaceae* (6%), *Polygonaceae* (6%), with the remaining families accounting for 36%. *Brassicaceae* (53.5%), *Asteraceae* (23%), *Poaceae* (10%), and *Aceraceae* (2.5%) families prevail in the community in terms of their percentage in the projective cover, whereas other families account for 11.5% of the community. The same plant families prevail in the community in terms of their percentage in the projective cover, but their content differs as follows: primary rooted rosette perennial grass plants constitute 55%, annuals make 17%, creeping stem and deep-rooted perennial grass plants account for 9%, large deciduous trees and scrubs amount to 5%, as well as annual and biennial grass plants account for 4% and perennial grass plants make 4%, whereas other life forms constitute 7%.

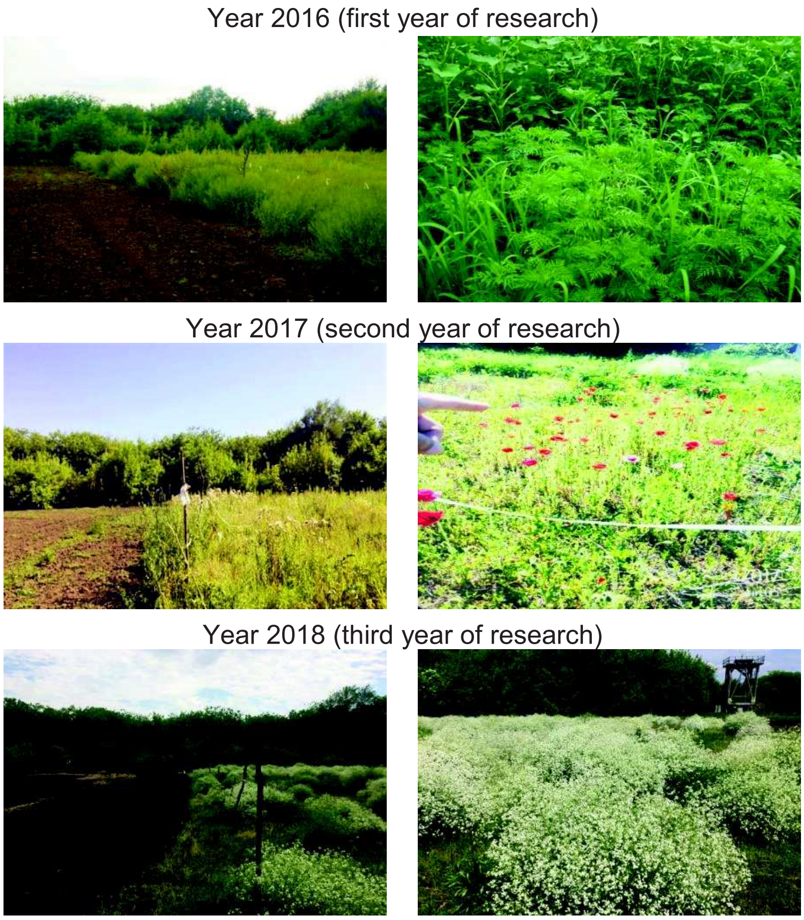

Figure 1. Changes in the floristic composition of the postagrogenic site during four years of research.

Steppe vegetation signs are less evident due to abundance of synanthropic plant seeds. A significant part played by *Ambrosia artemisiifolia* denotes the initial stage of the successive demutation. A dynamics is revealed towards domination of creeping stem and deep-rooted perennials along with a growing projective cover made of hardy-shrub plants. Due to the plot adjoining the forest plantations, there is an ecotonic effect traced in the form of trees and shrubs undergrowth. Subject to absence of the human interference, this factor will determine the future of the plot. After a while, a stable hardy-shrub phytocenosis will be formed in such conditions on the plot.

With appearance of vegetation on the postagrogenic plot in the first year, the soil moisture increased by 8% ($p < 0.05$), if compared to the moisture of the arable land.

Difference in moisture of the tested soil on the arable plot vs. postagrogenic plot grew progressively with every year of research; in 2018 this difference amounted to 17%

($p < 0.05$) (Table 1). Along with moisture growth and vegetation development, temperature on the surface of the test plot fell by 5% ($p < 0.05$), unlike the arable plot temperature.

A tendency of the moisture growth and the fall in temperature on the soil surface of the newly abandoned plot, if compared to the same parameters of the arable plot, was traced within the entire research period and was characterized by an inverse correlation (r = -0.77). It is connected to the vegetation development on the abandoned plot and a further litter formation, which results in shading of the soil, keeping it away from the sunlight. The temperature of the study area in the following years: 1.1–3.1–1.9 °C, no clear trend; however, always the temperature on young fallow is lower than on arable soil. In addition to that, cessation of a regular shuffling of soil during its tillage that entails drying of the surface layer, results in restoration of its structure as well as improvement of its air and water regime. The soil density is influenced by a proportion of organic and mineral matters (Myasnikova et al., 2013), structural aggregates, an amount of roots and a soil tillage degree. Within three years of the abandoned condition the density of the test plot dropped by 9% ($p < 0.05$), if compared to the negative control plot. Owing to the plant roots development, the soil density on the abandoned plot decreased by 11% ($p < 0.05$) during the first year of research. In the third year of research a difference in density between the postagrogenic plot and the steppe plot amounted to 22% ($p < 0.05$). Looking on the soil density (Table 1), there is the following difference between arable and young fallow: 0.15–0.13–0.10 kg×m^{-2} in subsequent years. It means the difference was the largest in 1st year and then continuously decreased. This is due to changing climatic conditions during the study period.

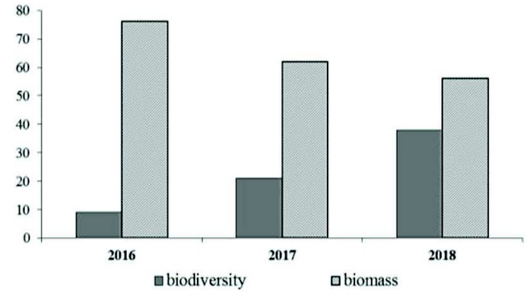

Figure 2. Dynamics of changes of the number of plant species and biomass (100 kg×ha^{-1}) on the fallow after the stop of tillage, 2016–2018.

Table 1. Parameters of the test areas

Research site	Soil density (g×cm^{-3})	Soil surface temperature (°C)	Moisture (%)
2016 year			
Arable	1.32	22.2	18.7
Young fallow	1.17	21.1	20.2
Steppe	0.95	19.7	32.1
2017 year			
Arable	1.29	23.9	14.1
Young fallow	1.16	20.8	16.1
Steppe	0.86	20.3	26.2
2018 year			
Arable	1.30	33.7	11.7
Young fallow	1.20	31.8	13.7
Steppe	0.94	29.7	15.1

An outgrowth of pioneer plants in the first year of the arable regime resulted in changes in a hydrothermal and physical condition of the tested soil. The soil penetration resistance reflects impedance encountered by the root system of plants during their growth. Minimum values for all years of research were detected on the arable plot. During the first year of research there was no significant difference in 0–10 cm plowed horizon of the arable plot vs. the newly abandoned plot (Fig. 3). Along with the development of the plants root system, the soil structure changes as well. A significant difference in penetration resistance of the upper soil layer of the arable plot vs. the abandoned plot was traced in the second year of research, at the depth of 0–20 cm, namely: 0.21 MPa on the arable land and 0.79 MPa on the newly abandoned plot.

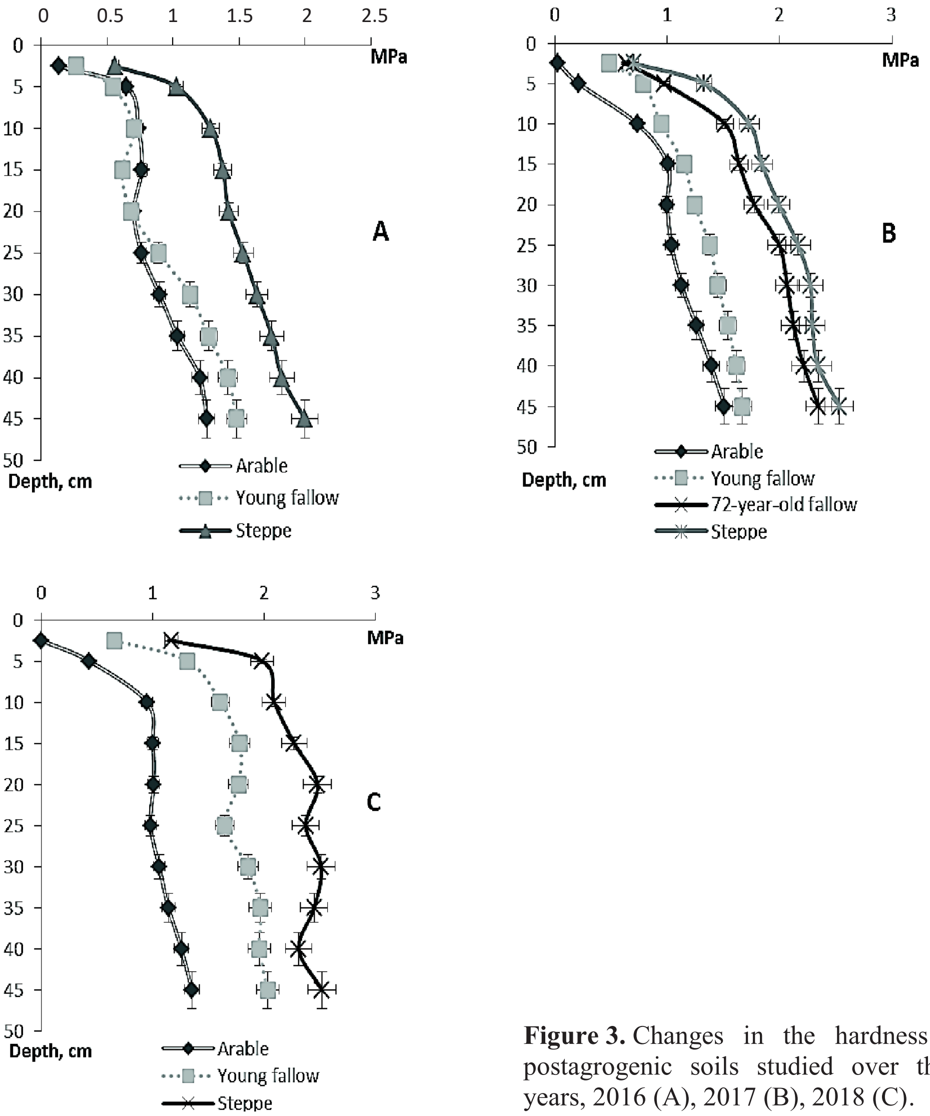

Figure 3. Changes in the hardness of postagrogenic soils studied over three years, 2016 (A), 2017 (B), 2018 (C).

A difference between those two plots has been increasing with the lapse of time. Within the framework of our research a positive correlation was detected between the chernozem density and its penetration resistance ($r = 0.70$) and temperature ($r = 0.73$), whereas an inverse correlation was detected between the chernozem density and its moisture content ($r = -1.0$). The same dependency patterns were revealed by other authors, who studied chernozems of various uses (Myasnikova et al., 2013).

CONCLUSIONS

A physical condition of postagrogenic chernozems begins to change from the first years of the arable regime. The indexes of physical properties of young fallow (during the first 3 years after abandonment) are better than in arable soil and worse than in steppe soil. In the upper horizon, being the most degraded, the soil temperature and density drop, whereas the soil moisture and penetration resistance grow.

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