Changes in soil carbon content and reserves under long-term field experiments in the steppe zone of the Southern Urals

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Abstract. The identification of factors determining the stability of soil organic carbon is an important step in managing the volumes of greenhouse gases and crops entering the atmosphere. The greatest influence on the soil organic carbon (SOC) pool in the soils of agroecosystems is exerted by oxidation processes under intensive agrotechnical action, decomposition, mineralization and humification by soil microorganisms, and also transformation under the influence of enzymatic activity of soils. The studies were conducted on the sites of a long-term field hospital and virgin soil located in the zone of distribution of steppe chernozems of the Southern Urals. During field and laboratory studies, the intensity of soil emission of CO2 (adsorption method), the activity of peroxidase and polyphenol oxidase (colorimetric method), and the soil organic matter content (dichromate oxidation technique) were determined. The indicators of the content and reserves of soil organic matter in different experimental variants showed a high dependence on the intensity of mineralization processes as a result of active mechanical treatment, aeration and increased activity of microorganisms, as well as the activity of soil enzymes involved in the carbon cycle (C).

1. Introduction
The sustainability of agricultural production is determined by the pool of plant nutrients, the dominant role of carbon in which determines the quantity and quality of the crop, as well as the environmental sustainability of soils.

Recovery of organic carbon (SOC) in agricultural soils can not only improve soil quality, but also affect climate change and agronomic productivity [1].

The decomposition of organic matter plays an important role in the cycling of carbon (C) and nutrients in terrestrial ecosystems around the world. Climate change is accelerating the rate of decomposition, potentially increasing greenhouse gas emissions and further increasing global warming in the future. The identification of the mechanisms that determine the transformation of soil organic carbon in soils of agrolandscapes will mitigate the emission of greenhouse gases by the land surface and increase the sequestration of C [2].

The most important in the search for mechanisms of influence on carbon stabilization is the study of management of organic carbon reserves (SOC) in agricultural practice. It uses various methods of soil treatment, using fertilizers and ameliorants, cultivation methods [3].
Due to the high responsiveness of soil organic matter to the influence of a complex of natural and agrogenic factors, as well as the need to maintain the stability of its pool in regions producing crop plants of primary food value, the study of factors affecting the content and reserves of SOC is especially relevant. Therefore, the aim of our research is to study the processes of transformation of soil organic carbon (SOC) under the conditions of many years of field experiments conducted in the steppe zone of the Southern Urals.

2. Materials and methods

Research was conducted in 2018 in the Orenburg Urals region within the Orenburg region (Orenburg region, Russia). The average monthly air temperature ranges from –24.3 to –27.4 °C in January to +19.9 to +22.4 °C in July, and the average annual temperature is +5.3 °C. The average annual rainfall is 350–450 mm. The soil is classified as black soil (Russian Soil Classification, 2004) or Calcic Pachic Chernozem (IUSS Working Group WRB 2014), with 44 % clay, and an average pH of 7.1.

The object of the study was virgin and arable plots of chernozem (51.775776 N, 55.311166 E). Soil samples were selected in the first ten days of June using the envelope method in the following land use options: 1) perennial two-field sowing of wheat and peas; 2) permanent steam (over 29 years); 3) monoculture of corn; 4) monoculture of wheat; 5) black steam under crop rotation; 6) virgin plot. The layout of the study plots is shown in Figure 1.

In the field, soil production of carbon dioxide was studied by the closed chamber method [4]. Soils were taken for analysis (from depths of 0–20 cm and 20–40 cm) from each plot of 5–7 samples, and then they were analyzed in the laboratory in 3–7 replicates. Total organic carbon (TOC) was analyzed using the dichromate oxidation technique (GOST 26213-91). The main principle of Tyurin’s method is wet combustion of the sample by K₂Cr₂O₇ solution in sulphuric acid followed by determination of oxidizer value by photocolorimetry method using Mohr’s salt [5]. The samples were determined by the activity of soil enzymes involved in the carbon cycle (peroxidase (PO) and polyphenol oxidase...
(PFO) by the colorimetric method using hydroquinone and alcohol extraction of reaction products. The results were analyzed by calculating the humification coefficient [6]. Statistical analysis of the data was performed using software packages "Statistica 10.0" ("StatSoftInc.", USA).

3. Results and discussion
Organic matter in the soil mass during arable use is affected by various factors because soil is an open system. The conditions of the relief and mesoclimat of the study area make it possible to exclude the processes of erosion and intraspecific downward migration from consumable items of the balance of humic acids of the soil. The main ways of humus loss by arable land soils are determined by the processes of mineralization by microorganisms and absorption of nutrients by plants to produce phytomass and create crop mass [7]. Peculiarities of managing each site affect the intensity of soil production of carbon dioxide [8]. Respiration of the soil is one of the most important indicators of the biological activity of soils, the rate of release of which can be used to judge the rate of mineralization of organic matter in arable soils (Fig. 2).

![Figure 2](image)

**Figure 2.** Carbon dioxide production according to various experimental options
Note: see Fig. 1

The works of Wildungetal. (1975) [9], Kuzyakov et al. (2006) [10] and Kong et al. (2019) [11], it was shown that the intensity of carbon dioxide production is determined by the type of vegetation cover, water-thermal regime, agrochemical and biological properties of the soil.

Thus, the maximum intensity of soil production of carbon dioxide (CO2) was observed in the arable layer in the area with maize monoculture. The values of the carbon dioxide (CO2) index in the soil layer of 0-20 cm in the variants of wheat monoculture, floating crop rotation fields and perennial steam varied from 149.5 to 165.7 mg CO2 per gram of soil per day and did not differ significantly in these areas. The highest indicators of CO2 production by the soil layer of 20-40 cm were noted in the areas of crop rotation, binary sowing and perennial steam (245.4, 237.4, 225.7 mg CO2 per gram of soil per day, respectively). The area of virgin soil was characterized by the minimum values of the indicator, which is associated with the absence of intensive mixing of the humus horizon and weak processes of mineralization of plant residues and SOC.

It should be noted that when the amount of organic matter entering the arable land decreases, the amount of CO2 emitted by it naturally decreases. The size and composition of plant residues determines the intensity of soil respiration [12].
The biochemical processes of transformation of polycyclic organic molecules are determined by the activity of soil enzymes involved in the processes of neoplasm (PFO) and decomposition of humic molecules (PO) [13]. Sources of soil enzymes are microorganisms, plant root systems, and soil biota [14]. The level of enzyme activity is always a function of the transformation of organic residues and it reflects the environmental conditions of the processes of soil formation. A study of the activity of enzymes demonstrated their dependence on the type of farmland and the nature of vegetation cover (Fig. 3).

![Figure 3](image)

**Figure 3.** The activity of polyphenol oxidase and peroxidase in the soils of the study sites

Note: see Fig. 1

A feature of all arable areas is the low activity of polyphenol oxidase in the layer of 20–40 cm, which is associated with a decrease in the supply of plant residues to this part of the soil profile. For peroxidase activity, this trend is not observed. Monoculture sections of corn and wheat are characterized by a significant decrease in enzyme activity in the subsoil horizon. In other areas (except virgin), we noticed an increase in PO activity in the layer of 20–40 cm.

The ratio of the activity of PFO to PO was calculated coefficient of humification (K_gum). Exceeding K_gum values of more than 1 was noted in the layer of 0–20 and 20–40 cm of the virgin area, which indicates the predominance of neoplasm processes of humic molecules over their decomposition [6]. Similar values of the indicator were characterized by soils in a layer of 0–20 cm sections of unchanged pairs and black steam under crop rotation. This is a very interesting phenomenon from the point of view of stabilizing the decomposition of organic matter during the growing season and the soil ecosystem in equilibrium [15].

Soil fertility depends on the presence of humic substances in the soil, which are an important source of nutrients and a factor in the stability of the physical and water-physical properties of soils [15].

Studies have shown that the highest SOC content was detected under constant steam (3.6 %) and virgin soil (3.8 %) (Fig. 4). An unreliable decrease in the organic carbon content in arable soils cannot be explained by the high resistance of soils and soil organic matter to mineralization during arable use. This fact is more likely due to the lack of a full-fledged virgin area, since the remaining so far virgin lands cannot be fully considered as a reference. During the agricultural development of the steppe...
zone of the Urals, the area of plowed land approached the maximum possible values. Therefore, soil monitoring is currently complicated by the lack of complete standards, which is an urgent methodological problem of such studies.

A correlation analysis of the results revealed a negative relationship between the content and reserves of soil organic matter with indicators of soil CO2 production ($r^2 = -0.66$, at $p < 0.01$) and peroxidase activity ($r^2 = -0.77$, at $p < 0.01$) in the 0–20 layer and in the 20–40 cm layer with corresponding correlation coefficients –0.78 and –0.76 (at $p < 0.01$). Thus, we can conclude that the decomposition of soil organic matter of steppe chernozems is of primary importance under conditions of arable use. For indicators of content (SOC) ($r^2 = 0.82$, at $p < 0.01$) and soil organic matter reserves (SOR) ($r^2 = 0.58$, at $p < 0.01$), we noticed a dependence on the calculated indicator of the coefficient of humification.

4. Conclusion
Studies have led to the conclusion that the organic matter content of arable land chernozems depends on the intensity of vital processes of soil biota. The activity of mineralization and humification of organic molecules is determined by the processes of mineralization and activity of soil enzymes.

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