The Influence of Soil Use on the Intensity of Soil CO₂ Emission in the Conditions of Moderately Arid and Forest-Outlier Steppe of the Altai Krai

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Abstract. The climate changes of recent decades are mainly due to human activities and an abnormal increase in greenhouse gas concentration in the atmosphere. Carbon dioxide released by the soil during emission is of particular importance. Soil carbon dioxide emissions are closely associated with the microbiological activity of the soil and the intensity of the mineralization of organic matter, which depends on the technologies used in agriculture. One of the ways to reduce the level of CO₂ in the atmosphere is to increase its content in soils. Based on experimental studies, the paper provides a comparative assessment of methods of soil use influencing the intensity of soil CO₂ emission under a moderately arid and forest-outlier steppe of the Altai Krai. The paper reveals that the traditional technology of soil use significantly enhances the intensity of CO₂ emission. It negatively affects the humus state and soil fertility indicators and increases carbon dioxide content in the atmosphere. The use of minimal technology contributes to the conservation of carbon in the soil.

Keywords: Soil · Fertility · Soil respiration · Traditional technology · Minimal technology · Fallow land · Soil CO₂ emission · Climate effect

1. Introduction

One of the main factors of rational nature management under the conditions of climatic changes of the last decades is the study of anthropogenically transformed ecosystems. Of particular note is anthropogenic stress on the soil covering because the soil performs several environmental functions, primarily maintaining the cycle of elements, including carbon.

The central natural carbon reserves, which affect the concentration of CO₂ in the atmosphere, are concentrated in terrestrial biomass and soil organic matter. According to IPCC, the reserve of soil organic carbon is 1,500 Gt, which is significantly larger than in terrestrial biocenoses (550 Gt), while 296 Gt of soil organic carbon is concentrated in the soil covering of Russia. According to the SCOPE-62 report, carbon stocks in the world’s soils are twice more massive (3,000 Gt) [3, 9].

Studies in various climatic zones established that CO₂ emission from the soil is the most potent carbon dioxide source. Therefore, soil breathing disturbances can lead to serious changes in greenhouse gas concentrations in the atmosphere [11]. Soil carbon dioxide emission is closely related to the soil’s microbiological activity and the intensity of the mineralization of organic matter, which, in turn, depends on the technologies used in agriculture, which substantially determined the relevance of this study.

Modern agricultural technologies for crop cultivation (intensive, minimal, direct sowing, no-till) are actively introduced in agriculture. Soils are influenced by striking combinations of elementary soil
formation processes modified by anthropogenic impacts. First of all, this applies to agricultural systems, in which the intensification of mineralization processes under conditions of anthropogenesis increases the emission of CO₂ into the atmosphere.

A generalization of the research results [5] shows that traditional soil cultivation leads to a significant release of carbon dioxide, which leads to an increase in average annual temperature and the formation of a greenhouse effect. One of the methods to reduce the level of CO₂ in the atmosphere is to increase its content in the soil.

When CO₂ is lost in the soil, the redox processes and the enzymatic composition of the soil change. It affects humus content and, therefore, soil fertility [10]. Organic carbon contained in the soil is a valuable resource helping to increase the efficiency of agricultural production. Therefore, it is necessary to consider low-emission technologies as one of the ways to accumulate carbon in the soil, which is of scientific and practical interest.

The research aims to study the effect of various methods of soil use on CO₂ emissions and to assess the flow of carbon dioxide into the atmosphere during the growing season.

2. Materials and Methods

Studies related to determining the intensity of soil CO₂ emission were carried out in the conditions of a moderately arid and forest-outlier steppe of the Altai Krai, based on the FSUE “Komsomolsky” (Pavlovsky District), and the experimental fields of the Educational farm “Prigorodnoe” (the village of Prigorodnoe) during the growing season of 2019.

Field experiments were carried out on leached medium-power low-humus medium-loamy chernozem. We studied four methods to use the soil: (1) traditional technology, (2) minimal technology, (3) perennial fallow land (16 years), and (4) virgin land (natural haymaking).

Soil respiration is a multifunctional natural phenomenon that characterizes gas exchange between the main components of the biosphere. The soil respiration in the experiment was determined by the method of L. O. Karpachevsky [4]. In the field, following the methodology, in the absence of an insulator vessel, ten glass cups 6 cm in diameter with 2 cm³ of a 0.1 M KOH solution were installed on the soil surface of the experimental plot. After 20 minutes, the alkali was titrated with a 0.05 M solution of H₂SO₄ from the phenolphthalein microburet [4].

This paper presents the results of determining CO₂ emissions during the growing season simultaneously in wheat crops (traditional and minimal technologies) on perennial fallow land and virgin land. The experiment was carried out in five replicates for each plot.

The general theoretical and methodological basis of the study was the work on the microbiological activity of soils in different farming systems by S. D. Litsukov [5], O. V. Melnikova [6], A. G. Stupakov [10], and several other scholars. To summarize the research results, we used the methodology of comparative and system analysis.

3. Results

In modern soil science, there are extensive data characterizing changes in the soil’s biological activity under various factors. Practical interest arises in the intensity of soil emissions of carbon dioxide as an indicator of soils’ biological activity.

According to E. A. Narusheva and L. V. Pomazkina, the amount of CO₂ emitted by the soil depends on many factors. However, the temperature in the 0–10 cm layer is the most crucial indicator of the ground “respiration” [7, 8].

According to agroclimatic zoning [2], the subzone of the moderately arid and forest-outlier steppe of the Altai Krai belongs to the warm, insufficiently moistened region, which is marked with a period with stable snow cover – 155–170 days; frost-free period lasts 115–120 days. The height of snow cover on average does not exceed 25–30 cm, the maximum depth of soil freezing is 200–250 cm. The average July temperature is 18–19 °C. The sum of temperatures above 10 °C is 2,000–2,200 °C. The annual rainfall does not exceed 150–200 mm. The moisture supply of arable soils in spring depends on the fall-
winter moisture reserves. The hydrothermal coefficient of Selyaninov \([\text{HTC}]\) equals 1.0–0.8. The sum of the temperatures at a depth of 10 cm is 2,100–2,300 °C.

The results of studies in the experiment based on the FSUE “Komsomolsky” showed that the most intense carbon dioxide emission occurs for the entire growing season on the variant using traditional technology (table 1).

The data analysis showed that \(\text{CO}_2\) emission for all research options was minimal at the beginning of the growing season. Then, with increasing temperature during the growing season, the emission of carbon dioxide gradually increased.

When applying traditional technology, the intensity of carbon dioxide emission is higher: during seedlings – by 44.36 g/ha per hour, in the tillering phase – by 273.16 g/ha per hour, in the degree of stem elongation and ripening – more than two times than when applying the minimum technology for cultivating crops.

**Table 1.** The intensity of “respiration” of the soil according to the wheat development phases in the moderately arid and forest-outlier steppe of the Altai Krai (FSUE “Komsomolsky” (g/ha per hour)).

| Wheat development phases   | Soil use method         | Traditional technology | Minimal technology |
|----------------------------|-------------------------|------------------------|--------------------|
|                            | Traditional technology  | Minimal technology     |                    |
|                            | seedlings               | 308.17                 | 263.81             |
|                            | tillering               | 567.32                 | 294.16             |
|                            | stem elongation - heading stage | 677.04                 | 310.51             |
|                            | ripening                | 625.68                 | 289.49             |

**Source:** Compiled by the authors.

A similar tendency of carbon dioxide emission is characteristic of soils and the experimental field of Educational farm “Prigorodnoe” using traditional technology (figure 1).

![Figure 1.](image)

**Figure 1.** The intensity of “respiration” of the soil according to the wheat development phases in the conditions of a moderately arid and forest-outlier steppe of the Altai Krai (Educational farm “Prigorodnoe” (g/ha per hour)). **Source:** Compiled by the authors.
The maximum values of the released CO₂ are characteristic of the development phase – stem elongation. This indicator decreases by 7.6% for traditional technology and 6.8% for minimal technology in the ripening stage, which indicates that the relationship between soil emission and soil temperature is changing throughout the growing season.

In studying the effect of the soil cultivation system on the dynamics of CO₂ emissions, G. N. Cherkasov, N. P. Masyutenko, and M. N. Masyutenko also found that the intensity of gaseous carbon loss from soils of agro landscapes is caused by the features of using various processing technologies and environmental factors, the main of which is temperature [1].

At the same time, phytocenoses of perennial fallow land and virgin land were involved in studies on the intensity of CO₂ emissions (table 2).

Table 2. The intensity of the “respiration” of the soil in a moderately arid and forest-outlier steppe of the Altai Krai (“Educational farm “Prigorodnoye” (g/ha per hour)).

| Determination period | Soil use method          |                |
|----------------------|--------------------------|----------------|
|                      | Perennial fallow land    | Virgin land    |
|                      | (16 years)               | (natural haymaking) |
| May–June             | 196.11                   | 191.44         |
| June–July            | 205.45                   | 196.11         |
| July–August          | 217.12                   | 207.78         |
| August–September     | 200.78                   | 198.44         |

Source: Compiled by the authors.

It was experimentally found that the emission of carbon dioxide from leached chernozem during the growing season (May–September 2019) did not change significantly (within 10–15 g/ha per hour), while the values of CO₂ emission in these areas increased from July to August, and by September its decrease was observed.

The intensity of soil emission in the fallow land is higher than in the virgin land. However, a comparison of the emission’s quantitative features in the different studied cenoses allows us to predict its gradual decrease with further overgrowth of the fallow land, combined with an increase in the humus content and its mineralization.

Thus, when applying the traditional technology, soil carbon is lost in the form of CO₂ emission into the atmosphere. When using minimal technology, the CO₂ flow is reduced. This indicates that minimal cultivation technology can be characterized as low emission, and its use contributes to the conservation of carbon in the soil, stabilizing the environment.

4. Discussion
Currently, the issues of “respiration” of soils of anthropogenically transformed landscapes of the Altai Krai remain practically unexplored.

An objective assessment of the negative consequences of increasing the intensity of soil CO2 emissions due to climate change is possible when conducting monitoring that considers regional features, soil properties, and their use methods.

5. Conclusion
The influence of soil use on the intensity of soil CO₂ emission in agroecosystems was studied in field experiments under conditions of a moderately arid and forest-outlier steppe of the Altai Krai.

The nature and direction of the dynamics of carbon dioxide evolution from leached low-power low-humus low-loamy chernozem during May–September differ depending on the technology of use and soil temperature.
A minimal technology for the cultivation of crops had a positive effect on reducing CO₂ emissions than traditional ones. The activity of carbon dioxide emission in wheat crops increases since spring, reaching its maximum value in summer and gradually decreasing by fall.

CO₂ flows from the soil in July–August 2019 in spring wheat crops (traditional technology) exceeded those in the perennial fallow land and virgin land by three times.

To preserve and rationally use land resources and maintain ecological balance in climate change, it is necessary to study the soil emission of CO₂ and assess it in agroecosystems to introduce integrated low-emission technologies.

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