Change of CO₂ Emission in Dark Chestnut Soil of Transurals

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Abstract. The article presents data on carbon reserves of dark chestnut soil and describes the influence of agricultural land on CO₂ emissions in the arid territory of the Ural region. According to the study, the largest carbon stock in the humus horizon was observed on virgin soil, the smallest - on arable land. Emission of carbon dioxide can be influenced by both biotic and anthropogenic factors. Due to the negative impact of pasture and arable plots on soil respiration, there has been noted a significant release of CO₂ emissions.

1. Introduction

Soil cover is one of the main long-term carbon reservoirs on the planet. The reservoir of soil organic carbon is much larger than the same of the ground. Estimates of the global soil reservoir of organic carbon vary greatly. Since such estimates may contain or not contain data on carbon stocks in carbonates, the thickness of the soil layer under study usually varies from half a meter to one and a half meters, and the features of various soil types are not always taken into account. The key to understanding the global carbon cycle is to estimate the emission of CO₂ in soil as it is an integral indicator of its biological activity [1-6].

In all of the studied fallow lands in Russia, carbon fixation by vegetation exceeded carbon losses of soils due to CO₂ emissions into the atmosphere. The value of this flow was determined by the age of the fallow land, vegetation type and weather conditions of the research year [7].

The average CO₂ concentration of the soil aerosphere is about 0.25 %, which is 7-8 times higher than that for the atmosphere [8]. Daily dynamics of soil respiration (in terms of CO₂ emission) depends on the type of ecosystem and bioclimatic zone which in turn determines biological activity and thermodynamic conditions of the process. During the season, maximum respiration is usually observed in the middle of summer, and minimum – in winter, due to low temperatures and poor permeability of frozen soil for gaseous substances [9].

Despite the enormous role of soil respiration in the planetary carbon cycle, estimates of the total CO₂ fluxes from the soils of most regions of our planet remain very approximative [10–13].

The study of carbon as organic substance of agricultural soils is of great scientific importance due to the increased anthropogenic impact and insufficient knowledge of the issue.

Steppe ecosystems of the arid territory of the region are intensively used in agricultural production. The preservation and enhancement of their bioproductivity should be justified by a complex of environmental factors including assessment of the volume of CO₂ emissions from the soil. Unfortunately, there are no studies on the spatial variability of greenhouse gas emissions and on organic carbon content in the soils of the steppe zone of Kazakhstan, which are necessary for reliable estimates of carbon fluxes.
2. Objects and methods of research

The measurements were carried out on experimental fields in the West Kazakhstan region in 2016-2018. The objects of research were dark-brown heavy loamy soils of the Volga left bank province being under various types of land use (virgin land, pasture, arable land).

Sampling taking points:
51.15.48.8.
50.46.52.9
Section 1. Dark chestnut medium thick normal heavy loam on loess-like loams of deluvial and eluvial sediments, virgin soil
51.16.32.0.
50.45.47.9
Section 2. Dark chestnut medium thick normal heavy loam on loess-like loams of deluvial and eluvial sediments, pasture
51.24.89.2.
51.22.33.3
Section 3. Dark brown, slightly washed out, normal, heavy loam on loess-like loams of deluvial and eluvial sediments, arable land.

Carbon content analysis in samples was carried out in accordance with international standard ISO 10694:1995 Determination of organic and total carbon after dry combustion (elementary analysis) and Operations manual of the elemental analyzer of the Multi N/C 2100 series. The method is oxidation of carbon in the soil (C) to carbon dioxide (CO₂) in a stream of oxygen-containing gas by heating the soil up to 9000 °C and followed by CO₂ amount analysis using infrared spectrometry. The method involves determination of the total carbon content, including carbon and organic carbon. The CO₂ flow rate of the soil surface was measured by the standard version of the closed dynamic chamber method (Closed dynamic chamber method (CDC)) using a Li-8100A field respirometer (Li-Corbiosciences, USA). To do this, all the plants were cut and steel rings with a diameter of 10.5 cm and a height of 5 cm were placed in the soil to a depth of 3 cm. Then the camera was installed on the ring. After the measuring chamber was mounted on the ring, the air circulated inside a closed system consisting of a chamber, a pump and an infrared gas analyzer. At the same time, the concentration of CO₂ increased, which made it possible to calculate the rate of gas emission from the soil using the slope coefficient. The measurement time was 1 minute. The soil temperature was measured with a soil thermometer included in the respirometer kit, with an accuracy of 0.10 °C. The volumetric soil moisture content was measured with a ThetaProbe ML2 sensor (Delta-T devices, United Kingdom) connected to the respirometer control unit with an accuracy of 0.1 %. Hygrometry and thermometry were performed at the respiration measurement point at a depth of 5 cm. Carbon balance was considered by the difference between the input part in the form of the primary productivity of the ecosystem and the output part in the form of carbon dioxide emission from the soil surface.

Furthermore, some agrochemical indicators of the soil were studied for the general characteristics of the plots. When characterizing soils, humus, nitrogen, phosphorus and potassium reserves are usually considered as an informative indicator of soil fertility. The content and reserves of humus in the 100 cm layer in the studied soils are low, such soils are considered as low-humus soils. In respect of nutrients, concentration of nitrogen and phosphorus is low, as opposed to potassium which is high.

3. Results and discussion

A summary estimate of the Cgen reserves in the studied area is presented in table 1
Table 1.Carbon content and reserves of dark chestnut soil.

| Object          | Horizons, sm | Percentage, % | Reserves Cgen, t/ha |
|-----------------|--------------|---------------|---------------------|
|                 | Cgen         | Corg          | Cnon-org            |
|                 |              |               |                     |
| Virgin land     | A₁ (0-14)    | 2.48          | 2.48                | 4.10|
|                 | B₁ (14-33)   | 2.40          | 2.40                | 5.93|
|                 | B₂ (33-69)   | 3.07          | 1.01                | 15.80|
|                 | BC (69-107)  | 2.31          | 0                   | 14.48|
|                 | C (107-200)  | -             | -                   | -   |
| Pasture         | A₁ (0-12)    | 1.99          | 1.99                | 3.01|
|                 | B₁ (12-33)   | 2.13          | 2.13                | 5.95|
|                 | B₂ (33-59)   | 3.32          | 0.79                | 12.52|
|                 | BC (59-79)   | 2.67          | 0                   | 8.92|
|                 | C (79-200)   | -             | -                   | -   |
| Arable land     | A₁ (0-12)    | 1.45          | 1.35                | 1.84|
|                 | B₁ (12-24)   | 1.37          | 1.27                | 1.68|
|                 | B₂ (24-95)   | 3.72          | 0.85                | 38.56|
|                 | BC (95-135)  | 3.63          | 0                   | 23.38|
|                 | C (135-200)  | -             | -                   | -   |

Cgen reserves in the humus horizon (A+B₁) are almost equal on virgin soil and pasture, except for the arable land (1.68-1.84 t/ha). A large supply in the lower layers is explained by the fact that in conditions of low temperatures Corg is contained in stable compounds and its accumulation below a half-meter layer is not directly related to their enrichment with organic matter. In addition, according to N. S. Mergelov, as a result of gravitational and cryogenic migrations, sliding humus substances penetrate deep into the soil column to the permafrost [17].

Measurements of the seasonal and annual dynamics of CO₂ fluxes from dark-chestnut soils of virgin, arable and pasture research sites were made as part of the study (figure 1).

Thus, underlying soil layers have large Cgen reserves, which are represented in maximum amount in arable lands (23.38-65.46 t/ha), followed by virgin soil (14.48-25.00 t/ha) and pasture (8.92-39.01 t/ha). The active layer of the virgin land (2.4 %) has the maximum reserves of the Corg, while the arable land (1.3 %) has the minimum. It is likely that humus substances with a slow decomposition rate at low temperatures gradually accumulate down the profile. It is worth to note that the thickness of horizons with maximum reserves is significantly higher than the capacity of the upper ones.
Figure 1. Depthwise distribution of $C_{\text{gen}}$ reserves on soils layers, t/ha

The results of a year-long monitoring of $\text{CO}_2$ emissions within the sites showed the occurrence of its maximum emission in the winter season, the minimum – in summer (figure 2).
In the virgin area, the flow of CO$_2$ was recorded to the maximum (428.9 mmol CO$_2$ / m$^2$/s) in December, followed by a gradual decrease in the flow in August (385.4 mmol CO$_2$ / m$^2$/s); soil moisture dropped to minimum values in November (24.17 %) and in late spring and early summer periods (in May (32.27 %) and June (32.43 %)), the maximum (68.38 %) was in December. The maximum soil temperature was noted in hot period – July (37.6 °C), the minimum (-24.6 °C) in January. As known, the increase in soil density is considered to be the main disturbance of the soil during grazing. Also, this temperature is extreme in summer, so the soil respiration rate in this area affects the flow rate of carbon dioxide. This corresponds to the results obtained earlier on the pasture plot in the Buldurta village, where the increase in density and decrease in elevated phytomass could no longer significantly worsen the already pessimal conditions and where was no difference between the pasture and the control check [14].

The results of foreign studies are opposite to our data, where a comparative analysis of the average long-term value of seasonal CO$_2$ fluxes from the soils of various ecosystems in the temperate zone showed a decrease in the value in the following sequence: summer-autumn-spring-winter. The average data of the summer flow in the soils of all ecosystems were significantly higher than those of the autumn and spring. Winter CO$_2$ fluxes were low in all ecosystems without exception and differed significantly from the spring, summer and autumn CO$_2$ fluxes [15, 16]. Differences in the magnitude of seasonal CO$_2$ fluxes divided by the type of soil and its land use were unreliable due to their rather high variability.

The analysis of the measured values on the arable plot showed: maximum CO$_2$ emission (430.97 mmol CO$_2$ / m$^2$/s) in December, minimum (380.18 mmol CO$_2$ / m$^2$/s) in August; soil moisture recorded its maximum (71.35 %) and its minimum (40.13 %) at the same time; soil temperature was maximum in July (35.0 °C), minimum (-26.3) in January. Monitoring measurements of CO$_2$ flux in the pasture area: maximum (429.23 mmol CO$_2$ / m$^3$/s) was in December, minimum (387.12 mmol CO$_2$ / m$^3$/s) – in July; soil moisture in January was 69.24 %, in November – 25.43 %; the soil temperature was recorded at the maximum (41.2 °C) in July, the minimum (- 25.8 °C) in January.

Analysis of the measured values showed that, in general, the spring-summer period was steadily hot and dry, and the winter period was not only the coldest, but also the wettest.

Annual monitoring measurements of CO$_2$ emissions and regime soil parameters showed that temperature and moisture values are significant factors for CO$_2$ emissions. The correlation between CO$_2$ and humidity on the virgin soil showed a direct connection (r = 0.858), whereas CO$_2$ and
temperature showed a high inverse relationship \((r = -0.884)\). The average straight line \((r = 0.625)\) is observed on the arable land between \(CO_2\) and humidity, and high inverse correlation is observed between \(CO_2\) and temperature \((r = -0.906)\). There is high direct and high inverse interrelation between \(CO_2\) – humidity and \(CO_2\) – temperature \((r = 0.919\) and \(r = -0.922\)) on the pasture lands.

The correlation coefficients between carbon dioxide emission, soil temperature and soil moisture over the entire observation period have been calculated. Correlation analysis of seasonal measurements of \(CO_2\) fluxes and regime soil parameters showed that humidity is a highly significant environmental factor during certain periods of observations, while a prominent high inverse correlation is observed in soil temperature.

Thus, in the spring period on the virgin soil, a positive relationship with humidity and reverse relation with temperature were established \((r = 0.925\) and \(r = -0.926\), respectively); the summer period was characterized by an inverse positive relationship with both humidity \((r = -0.773)\) and temperature \((r = -0.839)\); the correlation with humidity is set to medium \((r = 0.564)\) and with temperature to a high straight line \((r = 0.830)\) in the autumn period; the winter was characterized by a generally positive relationship with the regime parameters \((r = 0.937\) and \(r = 0.964)\). On arable land in spring, there is a higher correlation with humidity \((r = 0.727)\) rather than with temperature, where a weak correlation is expressed \((r = 0.489)\); in the summer period, a high inverse correlation with humidity is observed \((r = -0.903\) and a weak inverse with temperature \((r = -0.578)\); for the autumn period, the values are similar in both cases \((r = 0.984\) and \(r = 0.953)\); the winter period is similar to spring \((r = 0.997\) and \(r = 0.204)\).

In the pasture areas, the positive correlation of \(CO_2\) emissions with humidity and temperature \((r = 0.997\) and \(r = -0.993\); \(r = 0.775\) and \(r = -0.951\), respectively) was established for the spring and summer periods; the autumn and winter periods were characterized by positive humidity \((r = 0.987\) and \(r = 0.997)\) and weak correlation with temperature \((r = 0.997\) and \(r = -0.0198\), respectively).

Since pre-industrial times to the present day, a source of \(CO_2\) in the atmosphere has been agrocenoses attributed to ecosystems with a negative balance of organic matter, which adds more value to the knowledge of carbon balance in arable soils. Plowing up of virgin soils and replacing perennial vegetation with crops leads to an increase in the mineralization of humus and a decrease in the intake of plant residues in the soil. Since the emission rate cannot be considered separately from other factors of the carbon state, such as carbon content in the main pools and carbon balance in the ecosystem, it was considered necessary to calculate the carbon balance in the system. The carbon balance was calculated by considering the net carbon flow between the atmosphere and ecosystems determined by the balance between total photosynthesis or ecosystem’s gross primary productivity \((GPP)\) as well as its total respiration \((R)\) (table 2, figure 3).

| Lands types    | \(C\) reserves in biomass centner/ha a year | Respiration, centner CO\(_2\)/ha/year | Balance \(C\), centner/ha |
|---------------|------------------------------------------|-----------------------------------|--------------------------|
| Virgin lands  | 32.30                                    | 15.14                             | +17.16                   |
| Pastures      | 17.88                                    | 15.25                             | +2.63                    |
| Arable lands  | 24.47                                    | 15.21                             | +9.26                    |
As a result of the calculation, the C balance is marked positive, which indicates the functioning of the system with carbon accumulation. The maximum supply of C was in the virgin area (17.16 c/ha), characterized by forb grasses on virgin lands. The minimum balance (2.63 centners per hectare) is marked on pasture, where overgrazing occurs leading to deterioration of pasture properties as a result of anthropogenic and natural impact and decrease in the natural and economic importance of pastures. Additional integrated negative effect is soil compaction and depletion of vegetation – soils covered predominantly with weed vegetation. Short-term or long-term periods of non-use of pasture plots for grazing of agricultural agronomic animals are not provided, leaving no time to revegetation.

It should be noted that the soils of the dry-steppe zones are characterized by relatively low reserves of organic carbon, high heat supply and low moistures, therefore there is low level of biological activity due to the load on the arable and pasture areas, especially in hot months. The seasonal average CO₂ emission rate characterizes the biological activity of the soil [17] and is used to calculate carbon dioxide emissions by the soil cover [18]. Hydrothermal soil conditions are important components for the ecological situation in the development of soil microorganisms. Soil moisture varies seasonally between different limits. A large amount of precipitation creates anaerobic conditions in soils due to heavy particle size distribution. Maximum warming of the upper soil layers (0-20 cm) to 20-22 °C for a short time does not provide optimal conditions for microorganisms and biochemical processes.

4. Conclusions

Thus, soil fluxes of CO₂ emissions in dark chestnut soils, depending on the type of land use, have a prominent seasonal dynamics with the same trends between lands, but different trends within land areas: dominated by CO₂ emissions on virgin lands in winter, summer and spring periods. The most active emission was recorded in all types of land use during the winter period, with a gradual decrease in the warm period and a noticeable increase in the late-autumn period. Considering the positive carbon balance on dark chestnut soil in such land use types as virgin, pasture and arable land, a significantly low carbon balance was noted on pasture due to negative complex effects. The impact of land use type affected both the monthly value of CO₂ fluxes and their distribution among the individual seasons of the year.

The release of carbon dioxide within one soil type varies depending on the phytocenosis. The intensity of carbon dioxide emission depends on many factors, one of which is vegetation cover,
which directly regulates microbial biomass and all other microbiological processes occurring in the soil. Prolonged use of the soil in arable land leads to a deterioration of the physicochemical properties of the soil - depletion of its available nutrients for plants and, as a consequence, a decrease in the microbiological activity of the soil.

The studies outline significant specificity of soil CO$_2$ flows in dark chestnut soils, depending on land use, have prominent seasonal dynamics with the same trends between lands, but different inside lands, as well as their dependence on measured regime parameters, which must be taken into account when analyzing their current and projected regional balances.

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