

Emission of Carbon Dioxide from the Dark Chestnut Soil in West Kazakhstan



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Abstract: *The necessity of studying and assessing emissions of carbon dioxide from the agricultural soils is related to the important role played by the soil in their formation. Active release of carbon dioxide shows changes in the content of the organic matter in the soil and its biological activity. Carbon dioxide emissions can be influenced both by biotic and anthropogenic factors. Due to the negative effect of grazing and arable plots on the soil respiration, unequal emission of carbon dioxide is noted. The research was aimed at assessing the dynamics of carbon dioxide emissions from the dark-chestnut soil, depending on the nature of the soil use in agriculture. The studies for determining the carbon dioxide flow rate were performed according to the standard variant of the closed dynamic chamber method. The results of studying the content and emission of carbon dioxide from the dark-chestnut soil of the agricultural lands in Western Kazakhstan are shown. The content and reserves of humus in the 100 cm layer of the studied soils are low, and the soil is characterized by low humus content. The total annual flow of carbon dioxide from the virgin lands is higher than that from the arable lands but is less than that from the pastures.*

Keywords: *dark-chestnut soil, emission, carbon dioxide, virgin land, pasture, arable land.*

I. INTRODUCTION

Studying the carbon cycle in soil ecosystems is of great scientific significance due to increased anthropogenic effect and insufficient knowledge of the issue. The soil cover is one of the main long-term reservoirs of carbon on the planet. Estimates of the global soil reservoir of organic carbon vary largely, since these estimates may or may not include data about the reserves of carbon in carbonates, the thickness of the studied soil layer usually varies from half a meter to a meter and a half, and the characteristics of various soil types are often not taken into account. The key to understanding the global carbon cycle is assessing CO₂ emission from the soil as an integral indicator of their biological activity [1]-[6]. The daily dynamics of soil respiration (by CO₂ emission) depend on the type of the ecosystem and the bioclimatic zone, which in turn determine the biological activity and the thermodynamic conditions of the process. During the year, the maximum respiration is usually noted in mid-summer, and the minimum — in the winter, due to low temperatures and poor permeability of frozen soil for gaseous substances [7].

Revised Manuscript Received on October 30, 2019.

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Despite the huge role of soil respiration in the global carbon cycle, the estimates of the total CO₂ flows from the soil in most regions of our planet remain very approximate [8]-[11]. Steppe ecosystems of the arid territory in the West Kazakhstan region are intensively used in agricultural production. Preservation and increasing their productivity must be substantiated by a complex of environmental factors, including measurement of CO₂ emissions from the soil. Works on studying the spatial variability of greenhouse gas emission and the content of organic carbon in the soils of the dry steppe zone of Western Kazakhstan, which are required for reliable estimation of the carbon fluxes, are virtually non-existent. The issue of the direct effect of carbon dioxide on the biological activity of the soil also remains insufficiently studied. In this regard, there is a clear need for quantifying greenhouse gas emissions, as well as for examining their dependence on the environmental factors in various conditions. This work was aimed at resolving the fundamental problems of soil science associated with the assessment of carbon fluxes in the soils of the dry steppe zone in the conditions of the sharply continental climate.

II. METHODS

A. General description

The studies were performed on the dark chestnut soil with various use modes (virgin soil, pasture, arable land) in Western Kazakhstan:

Cross-section 1. (51°15'48.8" N, 50°04'52.9" E). Dark-brown medium-thick normal heavy-loamy soil on loess-like loams of diluvial and eluvial deposits, virgin soil;

Cross-section 2. (51°16'32.0" N, 50°04'47.9" E). Dark-brown medium-thick normal heavy-loamy soil on loess-like loams of diluvial and eluvial deposits, pasture;

Cross-section 3. (51°24'89.2" N, 51°22'33.3" E). Dark-brown lightly washed-off normal heavy-loamy soil on loess-like loams of diluvial and eluvial deposits, arable land.

The content of carbon in the samples was determined in accordance with international standard ISO 10694:1995. The content of organic and total carbon was determined by the method of dry combustion (elemental analysis), and according to the instructions for using the elemental analyzer of series Multi, model Multi N/C 2100. The essence of the method was in oxidizing carbon (C) in the soil to carbon dioxide (CO₂) in the stream of oxygen-containing gas upon heating the soil to 9000C, and subsequent determination of the amount of CO₂ with the use of infrared spectrometry.

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The method of determination involves defining the total content of carbon, including carbon in carbonates, and defining the content of organic carbon. The speed of the CO₂ stream from the soil surface was measured according to the standard variant of the closed dynamic chamber method (CDC) using field respirometer Li-8100A (Li-Corbiosciences, USA).

B. Algorithm

The weight of the sample used for analysis depends on the carbon content in the soil and on the type of the device used. Calibration was performed following the manufacturer's instructions to the device. The required amount of air-dry soil (m1) was weighed and placed in a special crucible. The analysis was made according to the instructions of the manufacturer of the device. The total content of carbon, i.e., organic, inorganic and atomic carbon, was determined in the sample. The sample was automatically introduced into the reactor tube for burning. After that, the resulting amount of carbon dioxide was determined.

The amount of inorganic carbon was determined analytically. For this purpose, a soil sample was placed in a special flask, to which three tubes were connected. The first tube injected the carrier gas into the flask. The second tube was used for injecting a 10 % solution of phosphoric acid. The third tube was used for transporting the mixture of carbon dioxide and the carrier gas into the chamber of the infrared analyzer, with subsequent determination of carbon dioxide in the sample.

Analytical measurement of organic carbon determined the content of organic carbon in the sample. To do this, the difference method was used. The process was described by the following equation:

$$\text{CorgC} = \text{CtotC} - \text{CinorgC} \quad (1)$$

where CorgC was the content of organic carbon;
CtotC was the content of total carbon; and
CinorgC was the content of inorganic carbon.

For measuring carbon dioxide emission, steel rings with a diameter of 10.5 cm and a height of 5 cm were set into the soil to the depth of 3 cm, after cutting all the plants. After that, the chamber of the device was placed on a ring. After setting the measuring chamber on a ring, the air circulates inside a closed system, which consists of a chamber, a pump, a flow speed sensor, and an infrared gas analyzer connected to a laptop computer. The intensity of emission (g of CO₂/m²/day) was calculated by the slope of the linear section of the CO₂ accumulation curve (in all cases, linear approximation was used) concerning the volume of the system, the chamber base footprint, and the soil temperature. For the calculations, the longest linear section of the curve was taken, after leaving some time from the start of measurement (15). The CO₂ concentration in the system grows linearly (until the saturation point), which allows calculating the emission speed by the slope coefficient. When using Li-8100A, stainless steel rings with a diameter of 10.5 centimeters and a height of 5 cm were embedded in the soil to the depth of 5 cm immediately before measuring; green parts of plants had been cut beforehand. Then the chamber of the device was placed on a ring for 1 min; the airflow speed was 1,700 ml/min-1. The temperature of the soil was measured with a soil thermometer enclosed with the

respirometer with the accuracy of 0.10C; the volumetric moisture of the soil was measured with sensor ThetaProbe ML2 (Delta-T Devices, UK) connected to the respirometer control unit with the accuracy of 0.1 %. Humidity and temperature were measured at the respiration measuring point at the depth of 5 cm.

III. RESULTS

Due to the increasing anthropogenic effect and insufficient familiarization with the organic matter in agricultural soils, studying carbon is of great scientific importance (Figure 1).

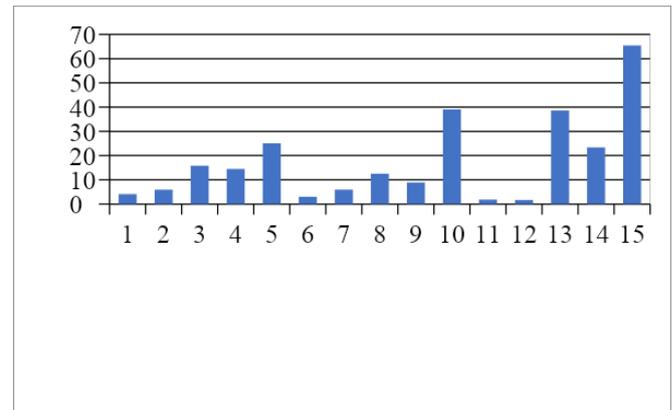


Fig. 1. Profile distribution of Ctot stock in the layers of the soil, t/ha

The stock of Ctot in the humus horizon (A+B1) was almost equal in the virgin lands and pastures and differed in the arable lands (1.68 – 1.84 t/ha). The significant stock in the lower layers is explained by the fact that at low temperatures Corg is contained in stable compounds, and its accumulation below the half-meter layer is not directly related to enriching with organic matter. The data obtained from the studied soils showed that the largest stock of Ctot was observed in the underlying soil layers, which was to the maximum degree represented in the arable lands (23.38 – 65.46 t/ha), followed by the lower degree in the virgin lands (14.48 – 25.00 tons/ha) and pastures (8.92 – 39.01 t/ha). The maximum stock of Corg is observed in the surface layer of the virgin lands (2.4 %), the minimum sock — in the arable lands (1.3 %). It should also be noted that the thickness of the horizons with the maximum stock is much greater than the thickness of the top layers.

During the study in 2018, the seasonal and annual CO₂ flow dynamics from dark chestnut soil of virgin, arable land, and pastures in the experimental plots were studied (Fig. 2, 3).

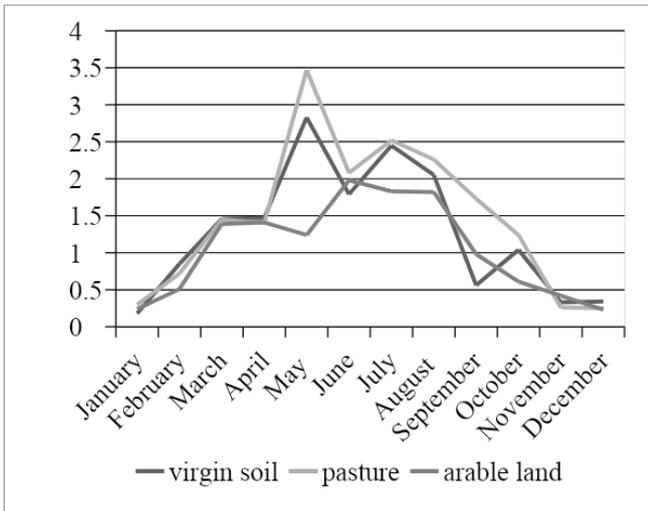


Fig. 2. The CO2 emission from the dark-chestnut soil on the lands in 2018

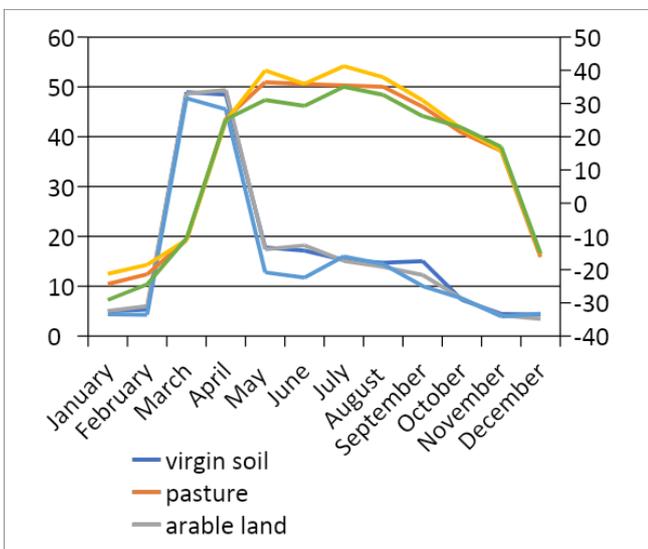


Fig. 3. Humidity and temperature of the dark chestnut soils in 2018

The beginning of the maximum carbon dioxide flow was characterized by indicators of respiration in the dark-chestnut soil in warm periods. In the virgin lands, the maximum flow of CO₂ was noted in May (2.83 g of CO₂/m²/day) and July (2.45 g of CO₂/m²/day), with subsequent reduction of the flow in September (0.56 g of CO₂/m²/day) with the soil moisture in the summer months of up to 17.77 %, with the maximum soil temperature of 36.41oC; a decrease in the soil moisture to the minimum was noted from October to December (from 7.25 % to 1.83 %). The pasture lands differed from the virgin and arable lands by a higher flow (3.47 g of CO₂/m²/day), while in the arable lands it amounted to only 1.24 g of CO₂/m²/day. However, on arable land, an increase in the flow from 1.82 to 1.98 g of CO₂/m²/day was noted during warmer months. The low flow of carbon dioxide was observed in all lands during the autumn and winter periods. On virgin land, it reduced to 0.21 – 0.91 g of CO₂/m²/day, in the pasture lands — to 0.26 g of CO₂/m²/day, and in the arable lands — to 0.23 – 0.42 g of CO₂/m²/day, where soil humidity was 7.25 – 1.83 %, the temperature of the soil was 7.5oC in the autumn, and reached minus 8.1oC in the winter. The

difference in the carbon dioxide flow rates from the soils in the lands during observations under various plants in equal climatic conditions is perhaps due to the fact that the most important is the total stock of the biomass and the nature of its spatial distribution; an important factor should also be noted, which is the humus content in the soil. As is well known, the main soil disturbance under the pasture load is increasing soil density. This temperature is also extreme in the summer; therefore, the soil respiration rate of this plot affects the flow rate of carbon dioxide [12].

Monitoring CO₂ emission over seasons showed that the maximum value was observed in the summer due to the hot weather conditions, the density and the species composition of the vegetation, and the state of plants and microbial communities, while the minimum value was observed in the winter due to soil cooling and freezing (Figure 4).

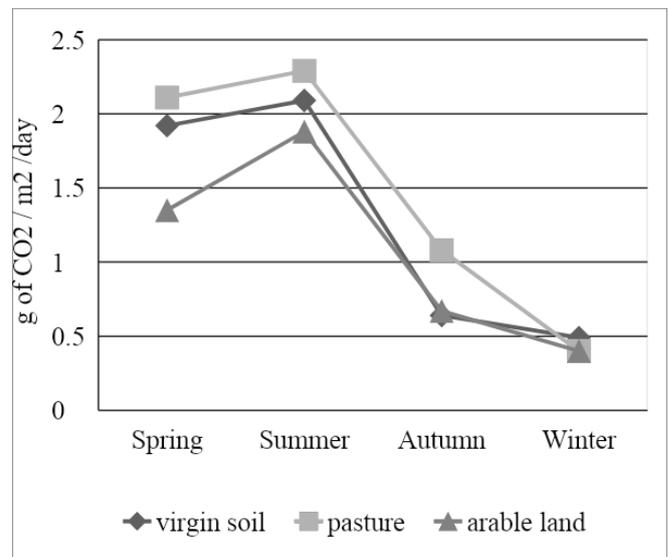


Fig. 4. Seasonal dynamics of CO2 emission from the dark-chestnut soil of various lands

In warm periods, with increasing the temperature in the spring and the summer, a sharp increase in CO₂ emissions was noted, which was characterized by an apical curve with the maximum in late May and mid-July. Throughout the spring observation, higher degree of carbon dioxide flow was noted in the pastures than in arable land; however, this value was lower than in the virgin lands, which was probably due to the differences in soil characteristics, including the composition of organic matter and the variety of vegetation. The minimum value over the periods of seasonal observation of CO₂ emission in the autumn after a hot summer was noted in the virgin lands within 0.64 g of CO₂/m²/day, in the pastures — 1.08 g of CO₂/m²/day, in the arable lands — 0.67 g of CO₂/m²/day; in the winter, in the arable lands, it was within 0.49 g of CO₂/m²/day, in the pasture and arable lands — 0.4 g of CO₂/m²/day in each of them. Comparatively, between the lands in a single season — in the autumn, a sharp decrease in the flow was noted in the pasture, which remained almost at the same level in the winter.

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The total annual flow of carbon dioxide from the virgin lands is higher than that from the arable lands but is less than that from the pastures. The intensity of CO₂ emission from virgin soils, rather than from arable soils, is explained by the species composition of herbs, their significant aboveground and underground mass, and a significant share of root respiration in the total CO₂ flow from the soil under natural vegetation. Also, these lands had not been used for many decades, which resulted in the preservation of the natural state of the soil and the carbon stocks; the soil system in the course of natural succession evolved to the virgin state, thus changing the direction of not only physical and chemical processes but also biological ones. The pasture soils during the period of the study were characterized by higher emission of carbon dioxide, where the main soil disturbance under intense loads was increasing soil density, and decreased aboveground biomass, which could not significantly worsen the existing severe conditions, which confirmed the data obtained earlier, where the difference between the pasture and the reference plot was not noted [12], which in the opinion of the authors was due to the total stock of microbial communities and their spatial distribution.

The presented results of comparative flow of carbon dioxide in the winter and the spring months were characterized as follows: while in 2018, they had had apical nature in the warm period, in 2019, they had smooth apical nature, which was explained by the changes in the temperature and humidity (Figure 5, 6).

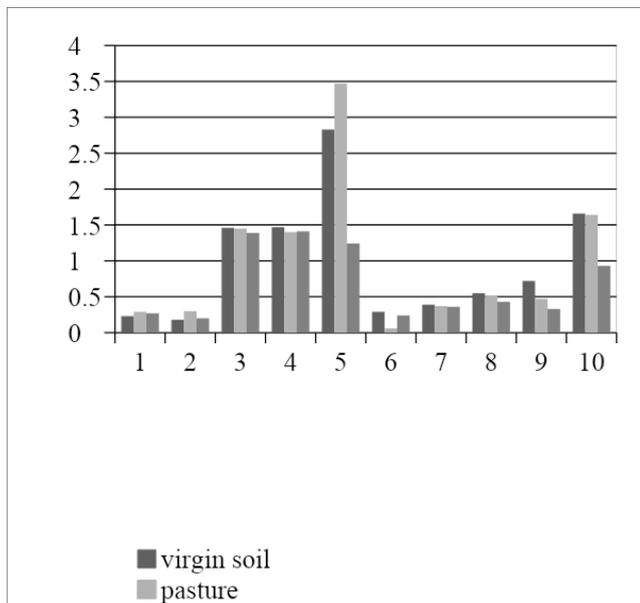


Fig. 5. Dynamics of CO₂ emission from the dark-chestnut soil of various lands

A favorable peak of carbon dioxide emissions in 2018 was noted at the beginning of spring: in March, in the virgin lands, it was 1.46 g of CO₂/m²/day; in the pastures — 1.45 g of CO₂/m²/day, and in the arable lands — 1.39 g of CO₂/m²/day; in April, the emissions were almost at the same level; in the last month of spring, a sharp increase in the flow from the virgin lands was noted — 2.83 g of CO₂/m²/day, from the pasture — 3.47 g of CO₂/m²/day; and from the arable lands emissions decreased to 1.24 g of

CO₂/m²/day. In 2019, a significant decrease in the flow of CO₂ was noted: in January, the flow from the pasture lands was critically minimal — 0.06 g of CO₂/m²/day, compared to the virgin and arable lands (0.29 and 0.24 g of CO₂/m²/day), in February, on the same plot, the flow increased to 0.37 g of CO₂/m²/day. Compared to the previous year, the spring measurements of emissions in 2019 on the lands showed the minimum values; for instance, the flow from the pasture lands exceeded that from the arable lands but was lower than that from the virgin lands. However, compared to the spring months of the year 2019, the peak was observed in May: in the virgin lands — 1.66 g of CO₂/m²/day, in the pastures — 1.64 g of CO₂/m²/day, and in the arable lands — 0.93 g of CO₂/m²/day.

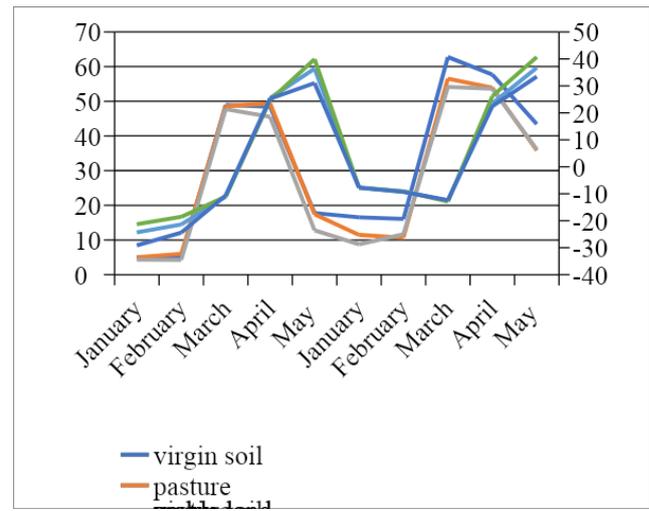


Fig. 6. Humidity and temperature of the dark-chestnut soils by the lands

In general, the winter months of the compared years showed low flow due to deep freezing of the soil in the winter and slow warming in the spring, which confirmed the results previously obtained by the authors and during foreign studies, where the mean annual values of seasonal CO₂ flow from the soils of different ecosystems in the moderate zone pointed to a decrease of the values in the following sequence: summer — autumn — spring — winter. Flows of carbon dioxide from the soils during the cold period were minimal in all ecosystems without exception, compared to CO₂ flows in the warm periods, since upon gradual attenuation of the biological processes, a decline of emission was observed in the soil [13], [14]. The non-uniform difference of the values of CO₂ emission from the soils of various land plots during the observation period is also associated with the species composition of the vegetation, its density, and the physiological state of the plants and microbial communities.

The soils in the dry-steppe zones are characterized by relatively small stocks of organic carbon, high heat, and low humidity; therefore, the low stock of biological activity may be associated with the load on the arable and pasture areas, especially during the hot period.

The average rate of CO₂ emission over the season describes the biological activity of soils and is used for calculating carbon dioxide emission from the soil cover. The hydrothermal conditions of soils are important components of the ecological conditions for the development of soil microorganisms. Soil humidity varies within different limits over seasons. Heavy rainfall creates the anaerobic conditions in the soil due to the heavy granulometric composition. The maximum warming of the top soil layers (0 – 20 cm) to 20 – 22°C for a short period does not provide optimal conditions for the microorganisms and biochemical processes.

IV. CONCLUSION

The most active emission has been noted in the pastures and virgin lands in late spring, with a gradual decrease in the summer, since hot summer and the lack of moisture affect the carbon dioxide flow rate. The intensity of carbon dioxide emission in the pasture lands is associated with excessive cattle grazing, which eat the aboveground biomass; at the same time, manure and urea increase the flow of organic carbon into the soil, thus stimulating the soil biota, and, accordingly, increase soil respiration. Trampling increases the number of soil bacteria and fungi, thereby accelerating carbon losses. Consequently, grazing and trampling are the key factors that accelerate the carbon cycle under loads [11]. CO₂ emission in the virgin lands is higher than in the arable lands, which is explained by overgrown vegetation, the absence of plants in the right-of-way virgin lands in the form of harvest, which results in gradual restoration of the natural state of the soil upon changes in the physical, chemical and biological processes, and upon carbon accumulation. The intensity of carbon dioxide emission also depends on many factors, one of which is vegetation, which directly regulates the microbial biomass and all other microbiological processes in the soil. The amount of carbon dioxide emission in the arable lands depends on the species composition and the density of vegetation, on the physiological state of the plants, and microbial communities as well as on the physicochemical state of the soil. The studies show the considerable specificity of CO₂ soil flows in dark chestnut soils across the types of lands, with strong seasonal dynamics with the same trends between the lands, but different inside the lands, as well as their dependence on the measured operating parameters, which should be considered when analyzing their existing and predicted regional balances.

ACKNOWLEDGMENTS

The research was funded through a grant of the Committee of Science of the Ministry of Education and Science of the Republic of Kazakhstan on the following topic: "Studying the Carbon Stocks and Emissions of Carbon Dioxide in the Dark-Chestnut Soils, Depending on the Land Use Type in the Agroecosystems in the TransUral Area of Kazakhstan".

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