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Biological activity and emission of carbon dioxide from dark chestnut soil of Western Kazakhstan

Nurlan Sergaliyev[1], Aliya Nagiyeva[2] and Anvar Tlepov[2]

[1]Makhambet Utemisov West Kazakhstan State University, 162 Dostyk Str., Uralsk, 090000, Kazakhstan
[2]Zhangir Khan West Kazakhstan Agrarian-Technical University, 51 Zhangir khan Str., Uralsk, 090009, Kazakhstan

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ABSTRACT

Steppe ecosystems of the arid region of Western Kazakhstan are widely used in agricultural production. Therefore, it is important to study the emission of carbon dioxide from agricultural soils. The authors studied seasonal and annual emissions of carbon dioxide from the agricultural soil of Western Kazakhstan. The difference in the most active emissions recorded in late spring with a gradual decrease in the summer period is reflected in the obtained results over the years. The reason for this was a very hot summer with a moisture deficit, which affected the rate of carbon dioxide emission.

***Key words** : Emissions, Carbon dioxide, Dark chestnut soils, Agricultural soils, Temperature, Humidity, Soil microorganisms.*

Introduction

Assessment of CO_2 emissions from soils is important for characterizing carbon cycles in the biosphere. The CO_2 emission rate characterizes the tendency of changes in the content of organic matter in soils, the ratio of the processes of mineralization and humification of organic matter, and biological activity of the soil (Sergaliev *et al.*, 2019).

Because of the agricultural pressure, changes that make up the biological activities occur in the arable horizons, which characterize the microbiological, physiological and biochemical properties, characteristics of soils and their condition. The intensity of soil respiration, the abundance and species composition of microbocenoses (determined by the metagenomic method) are indicators of biological activity. These indicators are important and are subject to seasonal and diurnal dynamics, they depend on hydrothermal conditions and can differ in various states (Zvyagintsev *et al.*, 2005).

Steppe ecosystems of the arid region of Western Kazakhstan are intensively used in agricultural production (Sergaliyev *et al.*, 2019). The need to estimate greenhouse gas emissions from agricultural soils is associated with the crucial role that soils play in their formation (especially CO_2) (Raich, Potter 1995).

Materials and Methods

Dark chestnut soils in tillage were used for research. Dark chestnut is a carbonate minor normal heavy loamy soil on loess-like loams of deluvial-eluvial deposition. The CO_2 flow rate from the soil surface was measured using the standard version of the closed dynamic chamber (CDC) method using a Li-8100A field respirometer (Li-Corbiosciences, USA). Soil temperature was measured using a soil thermometer in the respirometer set with an accuracy of

0.1°C; soil volume water content was measured with an accuracy of 0.1% using a ThetaProbe ML2 sensor (Delta-T devices, UK) connected to a respirometer control unit. Humidity and temperature were measured at the respiration measuring point at a depth of 5 cm (Kurganova 2010).

Algorithm. To evaluate carbon dioxide emissions, steel rings (d = 10.5 cm; height = 5 cm) were installed in the soil to a depth of 3 cm (after cutting all the plants). A measuring chamber was mounted on the ring. After the measuring chamber was installed on the ring, air circulated inside a closed system, which consisted of a chamber, a pump, a flow rate sensor and an infrared gas analyzer connected to a portable computer. Emission intensity (g $CO_2/m^2/day$) was calculated based on the slope of the linear portion of the CO_2 accumulation curve, with regard to the volume of the system, the area of the base of the chamber, and the temperature of the soil.

Results and Discussion

The CO_2 flow rate was measured from the soil surface using the CDC method all year round with a frequency of once every seven days from January 2018 to December 2019 (Figure 1).

The main portion of carbon dioxide emissions occurred in the upper horizons of the soil. In 2018, the maximum value of CO_2 emission from agricultural soils was observed in the summer months and amounted to 1.98-1.82 g $CO_2/m^2/day$; it was slightly different in the spring (1.39-1.411 g $CO_2/m^2/day$), which was due to adequate humidity and favorable temperature, compared to the hot months of summer.

The lowest carbon dioxide emission was observed in the autumn-winter period (0.98-0.23 g $CO_2/m^2/day$), soil temperature was –15.16 °C-–29.13 °C and humidity was 7.54-4.29%. In 2019, carbon dioxide emissions were different: the highest flow was recorded in May – 0.93 g $CO_2/m^2/day$, and in July and October – 0.74 g $CO_2/m^2/day$.

Differences in carbon dioxide emissions from agricultural soils can be associated with the variety of crops, its total biomass, and spatial distribution. The CO_2 flow rate from the soil is determined by significant factors – temperature and soil humidity. In May, a critical temperature for a spring month (33.43 °C) was observed with sufficient humidity (36.15%); critical weather conditions were observed during the summer period – humidity deficit (9.48-16.76%) and high temperature (30-36 °C); in the autumn humidity was 7.65% and soil temperature was 11.79-15.54 °C. The lowest carbon dioxide emission from agricultural soils during the winter period (0.18 g $CO_2/m^2/day$ in 2018 and 0.23 g $CO_2/m^2/day$ in 2019) was observed at the beginning of the winter month, when the soil temperatures were low (–21.54 °C in 2019 and –29.13 °C in 2018) and the humidity was 8.74% in 2018 and 4.35% in 2019, then the flow gradually increased to 0.51 g $CO_2/m^2/day$ in 2018 and 0.36 g $CO_2/m^2/day$ in 2019. Despite the cold period, CO_2 emission from seasonally freezing dark chestnut soils did not stop, and even this small portion of the total seasonal CO_2 emission was taken into account during the estimation of the annual CO_2 emission from soils. The seasonal summer dynamics of CO_2 emission were characterized by maximum flows due to critical hot weather conditions and critical condition of plants and microbial communities. The winter dynamics were characterized by minimum flows due to cooling and freezing of soils. The seasonal dynamics of CO_2 emissions from agricultural soils can be presented as following sequences (in descending order): summer > spring > autumn > winter for 2018 and spring > summer > autumn > winter for 2019 (Figure 2).

A significant difference in CO_2 emissions was observed in the summer period of the two years of the study – 1.88 g $CO_2/m^2/day$ in 2018 and 0.46 g $CO_2/m^2/day$ in 2019. The reason for such a difference in the values of CO_2 emission from agricultural

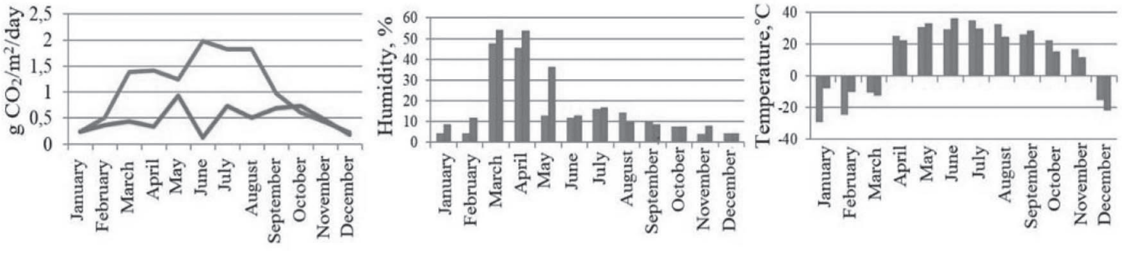

Fig. 1. Dynamics of CO_2 emissions, temperature and moisture content in arable soils

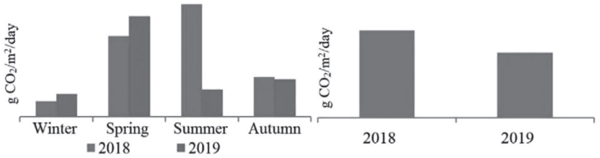

Fig. 2. Comparison of seasonal and annual CO_2 emissions from agricultural soils

soils was a change in vegetation, its features, hydrothermal conditions and soil fertility, high temperature and deficit of precipitation, which led to a significant decrease in the carbon dioxide flow rate in 2019. There were no significant differences between the spring periods of the two years, but compared with the summer period in 2018 and 2019, the difference was sufficient. In the autumn periods after hot summers, the emission values were 0.67 g CO_2/m^2/day in 2018 and 0.63 g CO_2/m^2/day in 2019, and in the winter periods, the emission values were 0.26 g CO_2/m^2/day in 2018 and g CO_2/m^2/day in 2019. In general, the peaks of CO_2 emission coincided with changes in temperature and humidity, which are important factors. The highest number of microorganisms was involved in soil respiration. The main part of microbiological studies is devoted to anthropogenic impact on the soil and ecosystem, and its sustainability, including the effect of agriculture on the microbial structure of soils. To detect soil microorganisms in agricultural soil, molecular genetic studies were performed: soil DNA was isolated and quantitative analysis of soil microbiota using real-time PCR was carried out (Figure 3).

The number of soil microorganisms varied in the soil profile from upper horizons to deeper horizons. The abundance of microorganisms in agricultural soil samples reached 3.3x10^{10} in the lower horizons and was significantly lower in the upper horizons. It is important to study the impact of agricultural land use on soil microbiome, the dependence of the abundance and diversity of microbiota on soil factors that determine the stability of agricultural soil characteristics. Continuous and prolonged use of soil on arable land ultimately leads to the deterioration of the physicochemical properties of the soil (deficiency of nutrients available to plants and a decrease in the microbiological activity of the soil).

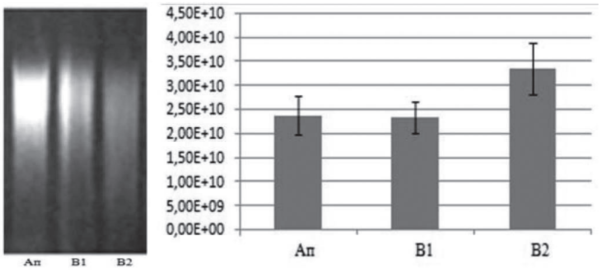

Fig. 3. Detection of soil DNA and the dynamics of the number of microorganisms in soil samples of agricultural soil

The study showed that the values of annual CO_2 flows in 2018 were significantly higher than in 2019, which can be explained by the differences in temperature and humidity. The freezing and subsequent thawing of soils give a significant but short burst of CO_2 emission during thawing of soils. The magnitude of this burst depends on soil humidity and the features of the land use. The most stable indicator that characterizes the features of ÑÎ$_2$ emission from soils is the proportion of the total spring emission in the annual ÑÎ$_2$ emission from soils, which allows us to recommend using this indicator to calculate annual carbon dioxide emissions from soils. The low proportion of the summer emission in the annual CO_2 emission was associated with increased air temperature, which negatively affected the emission of carbon dioxide from the soil. High soil temperatures and precipitation deficit in the summer of 2019 led to soil aridity, and diversification led to a decrease in carbon dioxide emissions. The maximum values of CO_2 emissions in the spring can be explained by warm weather and adequate humidity after thawing. In summer, with a dense vegetation cover, the values of carbon dioxide emission were minimal and practically did not differ from the cold periods when cooling occurs and soils are frozen. The type of crop in the agricultural land significantly affected the amount of CO_2 emissions from soils.

Conclusion

The most active emission was recorded in late spring, with a gradual decrease in the summer period of 2019 compared to 2018. Consequently, hot summers and humidity deficit had an impact on the flow rate of carbon dioxide. Carbon dioxide emission from agricultural soils depended on the species composition and density of the vegetation cover, the physiological state of plants and microbial communities, and the physicochemical state of the soil. The conducted studies showed the significant specificity of CO_2 soil flows in dark chestnut soils of agricultural land, which have pronounced seasonal dynamics, as well as their direct dependence on the measured regime parameters – temperature and humidity, which must be taken into account during the analysis of their current and projected regional balances. It was established that the content of bacterial communities in agricultural soils varied depending on the depth of the horizon. In addition, the lowest emission of CO_2 is characteristic of soils of agrocenoses (compared to natural ones), which is due to a decrease in the amount of organic substrate available to microorganisms in anthropogenically disturbed agricultural soils.

Acknowledgments

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