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Discriminating between biotic and abiotic contributions to CO_2 efflux from permafrost soil

Albina A. Danilova [a,b,*], Natalia B. Barashkova [c], Aleksandra P. Arjakova [c], Basiona B.Ustinova [c]

[a] Siberian Research Institute of Soil Management and Chemicalization for Agriculture, Novosibirsk oblast, Russia
[b] Institute of Applied Ecology of the North, North- Eastern Federal University Yakutsk, Russia
[c] Institute for Biological Problems of Cryolithozone Siberian branch of RAS (IBPC), Yakutsk, Russia

Abstract

The rate of carbon dioxide efflux (CDE) from permafrost cryoarid floodplain sandy loam soil were determined without roots and crop residues contribution. The research site was located at the Experimental Station "Marhinsky" near the city of Yakutsk (62°08′51′′N 129°45′45′E). Fallow systems: conventional (CnF, found in 2003) where weeds were removed by cultivation and conservation (CnsF, found in 2008) – where soil has not been treated after ploughing perennial grasses and weeds were removed manually. CDE was measured in one week intervals during growing season using static chamber methodology. Each chamber (n=3) was placed in the middle of a square with 1m side length. CO_2 was absorbed by 1n NaOH and the amount of C-CO_2 was determined by titration. The duration of each exposition amounted to 48 hours. Cumulative production of C-CO_2 was calculated on the basis of daily average speed of CO_2 emissions by the method of linear interpolation. In the CnF from 6th to 11th year of the experiment (2008-2013) CDE was about 800-900 kg/ha annually during the vegetation period. In CnsF after the first year of ploughing up CDE amounted 2,500 $\pm$ 190 (mean $\pm$ 095 confidence interval), in the next 2-5 years has stabilized at a level of 1,500$\pm$150 kg C-CO_2 ha^{-1}. In the 6th year (2013), which was characterized by an unusually early warm spring (2 weeks earlier than average) and humid summer (annual norm was exceeded in 1.5 times), CDE on the CnsF reached 2,100$\pm$150 kg C-CO_2 ha^{-1}. In CnF changes were not detected. Thus, in the present climatic conditions of Central Yakutia lower steady state of CDE from the investigated soil makes up about 800 – 900, the upper level makes up 1300 – 1500 kg C-CO_2 ha^{-1}. The increase in CO_2 production by soil with increasing warmth and moisture vegetation period (approximately 500 kg C-CO_2 ha^{-1}) was negated by the same increase carbon sequestration in plant biomass.

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Introduction

The greenhouse gas produced by soils is of great interest in the context of climate change in high latitudes. CO_2 is a significant part of the greenhouse gases. As is known, carbon dioxide efflux (CDE) from soil includes biotic and abiotic components. According to Ball et al (2009), Shanhun et al. (2012), Risk et al., (2013), in cryoarid soils, abiotic sources can be a significant part of CDE. Ma et al. (2013) demonstrated that this pattern is common for saline/alkaline soils especially when they are dry. Information about quantitative ratio between the two sources CDE from soils is important in order to evaluate the role of biological factors in the function of permafrost ecosystems. There is still little experimental data on CDE from permafrost soils

* Corresponding author.
Siberian Research Institute of Soil Management and Chemicalization for Agriculture, Novosibirsk oblast, Krasnoobsk a/b 356, 630501 Russia
Tel.: +73833485730 E-mail address: danilova7alb@yandex.ru
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in situ. Field CO_2 flux measurements have been so far mostly performed punctually which limits extrapolation to the annual timescale (Fouché et al., 2014). Currently most scientists are focusing on the cold, moist polar tundra soils, because that is where most of the world's frozen organic matter is located. Meanwhile, cryoarid soils with low organic matter content can be found in higher latitudes. In Central Yakutia, these soils are prevalent in the high floodplain terrace and are used in agriculture.

We have hypothesized that these soils can be convenient for exploring the components of soil CDE by observing organic matter depletion in conditions of long-term fallow.

Material and Methods

Study area

The research site was located at the Experimental Station "Marhinsky" of IBPC near the city of Yakutsk (62°08´51´´N 129°45´45´E). The site lies within the continuous permafrost zone; permafrost thickness is estimated to be in excess of 400 m. The mean annual air temperature (1981-2010) is - 8,7^0 C. The mean monthly temperatures ranged from -38,6^{0}C in January, with a daily minimum of -64,4^{0}C, to + 19 ^{0}C in July and a daily maximum of + 38,4^0 C. The mean annual precipitation is 238 mm, including 162 mm during May – September, and evaporation reaches 420–500mm (http://seakc.meteoinfo.ru/links). Permafrost cryoarid floodplain sandy loam soil on Lena River second floodplain terrace: SOC 1,32 - 2 %,. TON – 0,13-0,21%, pH $_{H2O}$ 7,5 – 8, the sum of salts 0,06%, exchangeable Na 2,5 mg 100 g^{-1}, carbonate horizon is below 70 cm, the active layer of permafrost reaches 1.5 m.

In order to estimate the rate of soil organic matter mineralization without root and crop residue contributions from 2008 to 2013 we determined the CDE in two fallow systems: conventional (CnF, found in 2003) where weeds were removed by cultivation and conservation (CnsF, found in 2008) – where soil has not been treated after ploughing perennial grasses and weeds were removed manually. CDE was measured in one week intervals during growing season using static chamber methodology. Each chamber (n=3) was placed in the middle of a square with 1m side length. CO_2 was absorbed by 1n NaOH and the amount of C-CO_2 was determined by titration. The duration of each exposition amounted to 48 hours. Total production of C-CO_2 was calculated on the basis of daily average speed of CO_2 emissions by the method of linear interpolation (Sharkov, 1987). Soil temperature was determined using chips DS1921H/Z Thermochron™.

Results and Discussion

Table 1 presents information on hydrothermal conditions of the vegetation period of the observation years. All the years 2008-2012 were close to mean multiyear values. 2013 differed with unusually early onset of air temperatures above 10^{0}C (approximately 2 weeks), and high rainfall exceeding the multiyear average by 2.5 times.

Table 1. Hydrothermal conditions of the vegetation period (HMS "Yakutsk")

Month	Annual norm	Investigation year			
		2010	2011	2012	2013
Air temperature (˚C)					
May	7,3	9,7	7,5	9,5	13,3
Jun	15,9	16,8	16,1	19,3	19,6
Jul	19,0	21,8	22,5	21,0	21,2
Aug	15,0	16,2	17,4	14,7	18,8
Sep	5,8	5,5	3,8	8,2	3,9
Precipitation (mm)					
May	17,0	41,0	6,0	10,1	42,0
Jun	39,0	29,0	24,0	19,6	62,6
Jul	39,0	30,0	40,0	20,2	65,5
Aug	35,0	10,0	73,0	50,8	19,9
Sep	31,0	23,0	19,0	21,2	44,6
The sum of precipitation, (mm)	161,0	133,0	162,0	121,9	235,7

In the initial period of vegetation soil temperature (0-20 cm) was not dependent on the air temperature and every year reached 10^{0}C during the last week of May. In autumn, soil temperature usually passed this threshold in the first decade of September and decreased to 0^{0}C in the first week of October. Thus, the period of active temperatures in the studied soil reached approximately 100 days. For example the soil temperature dynamic during the 2012 year is presented in (Figure 1).

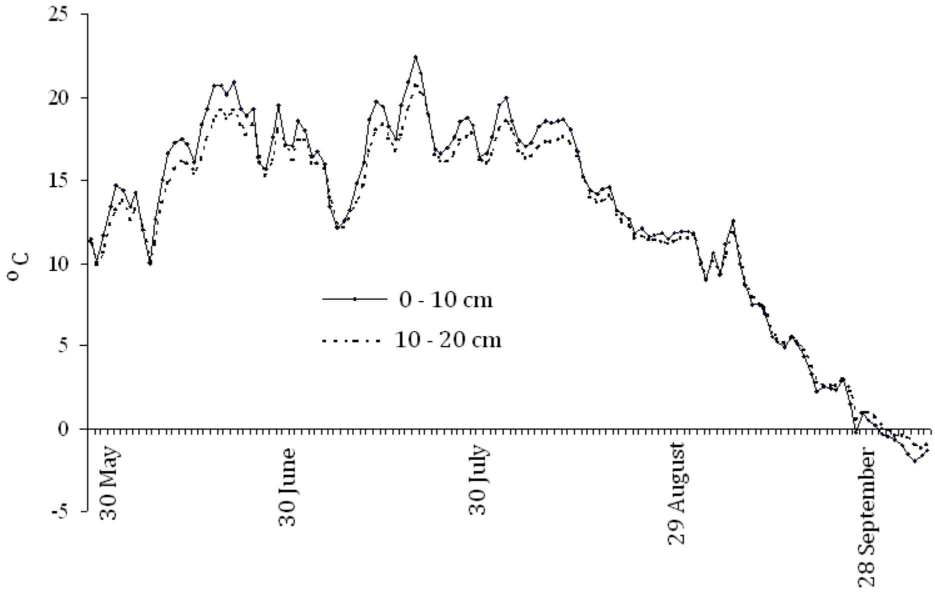

Figure 1. Soil temperature during the vegetation period

The dynamic of soil respiratory activity in CnsF correlated with that of temperature and represented a curve with a maximum in July-August (Figure 2). In contrast, for CnF such a pattern was not seen in all the years of observations.

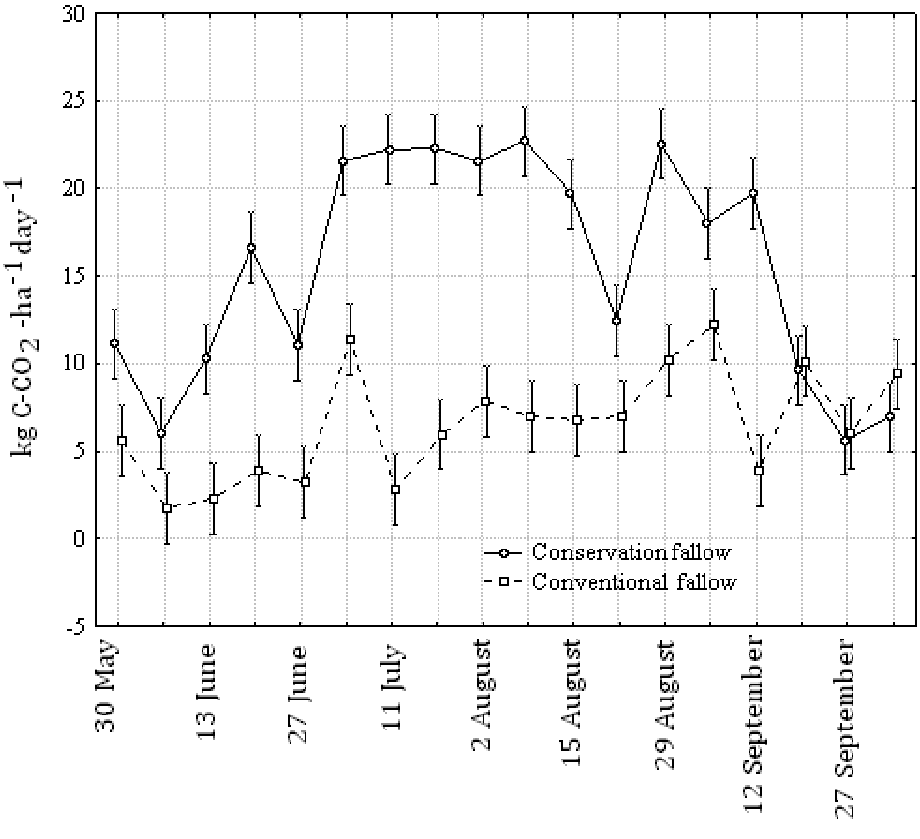

Figure 2. Dynamic of soil respiratory activity during the vegetation period (2013)

It was found that 60% of carbon received from plant and root biomass (7 t d.w. ha^{-1}) emerged from the soil in the form of CO_2 in the first year of experiment. In the CnF from the 6th to the 11th year of the experiment (2008-2013) CDE was about 800-900 kg C-CO_2 ha $^{-1}$ annually during the vegetation period. In CnsF after the first year of ploughing, CDE amounted 2,500 $\pm$ 190 kg C-CO_2 ha^{-1}, in the next 2-5 years of the experiment CDE had stabilized at a level of 1,500$\pm$150 (Figure 3). In the 6th year (2013), which was characterized by an unusually early warm spring (2 weeks earlier than average) and humid summer (annual norm was exceeded by 1.5 times), CDE on the CnsF reached 2,100$\pm$150 kg C-CO_2 ha^{-1}. In CnF changes were not detected. Thus, in the present climatic conditions of Central Yakutia, lower steady state of CDE from the investigated soil makes up about 800 – 900, the upper level makes up 1300 – 1500 kg C-CO_2 ha^{-1} which may rise along with increasing temperature and humidity during the vegetation period.

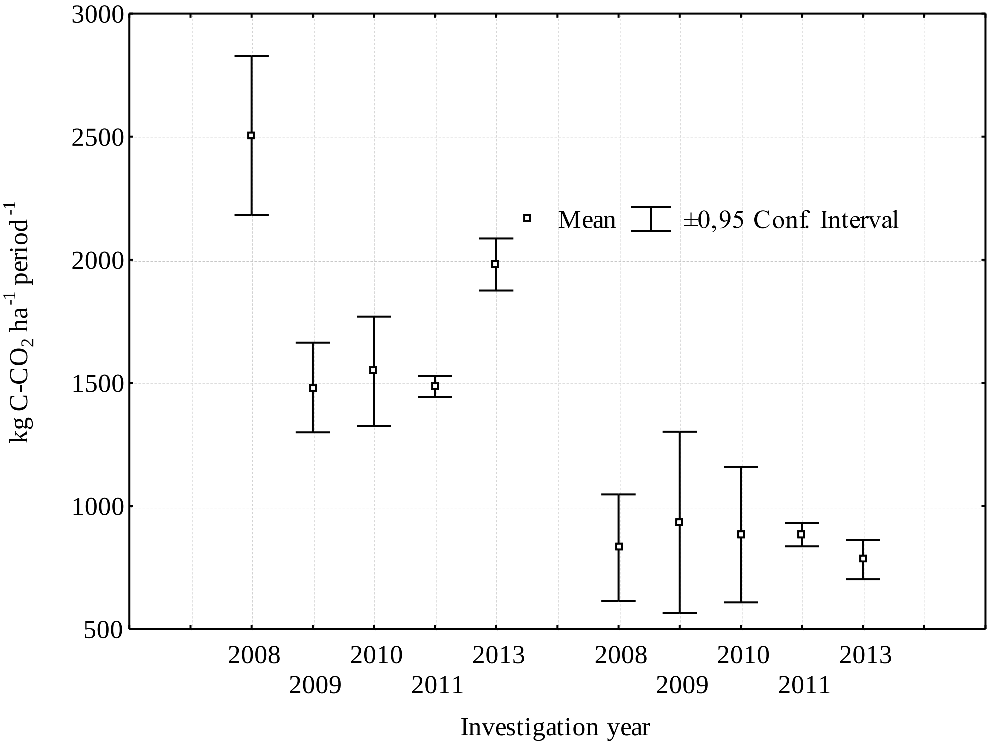

Figure 3. Annual cumulative production of C-CO_2 during the field experiment (left – CnSF, right - CnF)

Thus, the paper presents new data on long-term field observations of CDE from permafrost soil. This data provides a basis for comparing ecosystem functionality between sites. Cumulative CDE from the studied soil was significantly lower than that of permafrost forest soil of Central Yakutia after a forest fire (2810 – 2900 kg C- CO_2 ha^{-1} per 3 months) (Takakai et al., 2008). This pattern correlated with content of SOC.

The CDE from cryoarid (cashtanovaya) soil of Transbaikalia was higher than that of the studied soil (2000 - 3500 t C-CO_2 ha^{-1} per May–Sept.) (Chimitdorzhieva, 2010). It is difficult to explain this fact by the content of SOC, which amounted 0,9%. That is why we can assume that in CDE from this soil, the role of abiotic factors is quite substantial.

In 10 years of observations with on-field experience, we have achieved two relatively stable levels of CDE from the studied soil. This is lower, varying 800-900 kg C-CO_2 ha^{-1} per season, top - 1500 kg. In the lower level of the dynamics, CO_2 emissions independent of hydrothermal conditions were not expressed during the vegetation period. We can assume that this value was mainly due to abiotic CDE from the soil.

We have achieved the lower steady-state of CDE from the studied soil relatively quickly, probably due to light granulometric composition of soil and low initial SOC content. In soils with higher SOC content , formed in more favorable conditions (Leached Chernozem of West Siberia) for over 10 years of CnF, CDE level was 2 times lower than the initial one (1500 kg versus 3000). However, the role of biological factors remained quite substantial, as evidenced by the presence of pronounced curve dynamics with the maximum in July-August (Sharkov et al., 2007).

Thus, according to our results, the share of the abiotic component in CDE from investigated soil may be about 1000 kg C ga^{-1} for the vegetation season; this is approximately two-thirds of the total CDE. This value was stable in all the years of monitoring.

With temperature and moisture increasing in the vegetation period, the amount of biotic component increased nearly to 500 kg C ha^{-1} due to mineralization of the available pool of soil organic matter. That is, we might conclude that this value is the percentage increase in greenhouse gas emissions. However, in our experience, we were able to determine how this may increase the amount of bound carbon due to increased herbs yields. From experience, in years with hydrothermal conditions close to the multiyear mean, the average yield of perennial grasses amounted to 640 – 1420 kg ha^{-1} of dry biomass, in 2013 – 2000 kg ha^{-1}. That means the amount of bound carbon rose by about 500 kg C ha^{-1}. Therefore, in our experiment, increased respiratory activity of the soil from the temperature and humidity of the vegetation period was offset by the increase in the number associated in plant biomass carbon.

Our conclusion is consistent with the literature data. So, in particular, according to Schuur et al. (2009), on the results of 15 years of observations in tundra soils, climate warming's contribution to the increase of CO_2 emissions from soil was completely offset by increasing plant productivity. The same conclusion was made by Fouché et al. (2014) after the warming tests in Canada cryosols.

Conclusion

- In the present climatic conditions of Central Yakutia lower steady state of CDE from the permarfrost cryoarid floodplain sandy loam soil makes up about 800 – 900, the upper level makes up 1300 – 1500 kg C-CO_2 ha^{-1} which may raise along with increasing temperature and humidity during the vegetation period.
- Lower steady state of CDE from studied soil was probably due primarily to abiotic processes.
- The increase in CO_2 production by soil with increasing warmth and moisture vegetation period (approximately 500 kg C/ha) was negated by the same increase carbon sequestration in plant biomass

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