ISSN 1028-334X, Doklady Earth Sciences, 2018, Vol. 483, Part 2, pp. 1539–1541. © Pleiades Publishing, Ltd., 2018.
Original Russian Text © Yu.V. Barkhatov, S.A. Ushakova, V.N. Shikhov, S.Yu. Evgrafova, A.A. Tikhomirov, A.G. Degermendzhi, 2018, published in Doklady Akademii Nauk, 2018, Vol. 483, No. 5.

The Influence of Temperature and Humidity on Greenhouse Gas Emission in Experiments on Imitation of the Full Vegetation Cycle of Tundra Ecosystems

Yu. V. Barkhatov[a,*], S. A. Ushakova[a], V. N. Shikhov[a], S. Yu. Evgrafova[b,c], A. A. Tikhomirov[a], and Academician A. G. Degermendzhi[a]

Received July 10, 2018

Abstract—Laboratory experiments were conducted in a hermetically sealed growth chamber with two soil samples obtained from the arctic tundra zone with different levels of moisture. Samples were maintained at a growing season typical of the region from which they were taken, and for the sample with a high level of moisture it was made twice: with the temperature in accord with natural conditions and one increased by 2°C. It has been shown that heating of the overmoistened tundra soil by 2°C can increased the average carbon dioxide emissions by almost two times (from 75 to 100–150 mg m^{-2} h^{-1}). Upon the application of heat, no significant increase in methane emission was observed.

DOI: 10.1134/S1028334X18120115

One of the typical landscapes of Arctic ecosystems is the polygonal tundra, which is characterized by ice-wedge polygons with an irregular shape, where vegetation grows along cracks, and microlakes or wetlands are formed at the center of the polygon at 8–30 m diameter. The polygonal tundra is typical for the arctic coastal plains of Alaska, the middle and lower latitudes of the Arctic part of Canada, and northern Russia [1, 2]. At the center of the ice-wedge polygon, there are conditions conducive to peat accumulation, which is also facilitated by standing water, drainage of which is limited by permafrost, and by low temperatures causing a slow rate of organic matter decomposition [2, 3].

The polygonal tundra plays an important role in the carbon balance of arctic ecosystems [4, 5], which contain around 15% of the total soil carbon [6]. It is difficult to predict the polygonal tundra reaction to climate change due to the complex interaction between its components: permafrost, water, vegetation, and peat deposits [7]. A comprehensive understanding of the polygonal wetland dynamics is essential for prediction of the tundra ecosystem response to climate change.

[a] Institute of Biophysics, Siberian Branch, Russian Academy of Sciences, Krasnoyarsk, 660036 Russia
[b] Sukachev Institute of Forests, Siberian Branch, Russian Academy of Sciences, Krasnoyarsk, 660036 Russia
[c] Siberian Federal University, Krasnoyarsk, 660041 Russia
*e-mail: barkh@ibp.ru

It is well known [8, 9] that methane and carbon dioxide fluxes from the arctic tundra have high spatial variability due to the complex microtopography. In particular, the polygonal tundra of the Central Siberian north emits from 4.9 to 100 mg of CH_4 m^{-2} day^{-1} and the difference between methane fluxes from the rim of the polygon and the flooded center can reach 10 to 20 times [10]. One of the main factors controlling methane emission from tundra soil ecosystems into the atmosphere is the soil temperature [11] and the groundwater depth [12].

The objective of this study was to estimate experimentally the difference between greenhouse gas fluxes in the full vegetation cycle of the tundra ecosystem under different hydrothermal conditions.

This work was carried out in a hermetically sealed growth chamber developed at the Institute of Biophysics, Siberian Branch, Russian Academy of Sciences, for physical modeling of mass-exchanging processes in artificial and natural ecosystems, with independent control of the air and soil temperature provided. A detailed description of the chamber is presented in [13, 14].

The objects of study were two samples of soil with different degrees of moisture, which were obtained from the polygonal arctic tundra zone near Chokurdakh (Sakha Republic (Yakutia), 70°49′ N, 147°29′ E). The surface area of the samples was 0.14 m^2, and the height was 0.28 m. The duration of each experiment was about 80 days, which was equivalent to the length of the growing season in the simulated area. The air and soil temperature in the chamber was kept close to the natural one for the whole growing season (for the

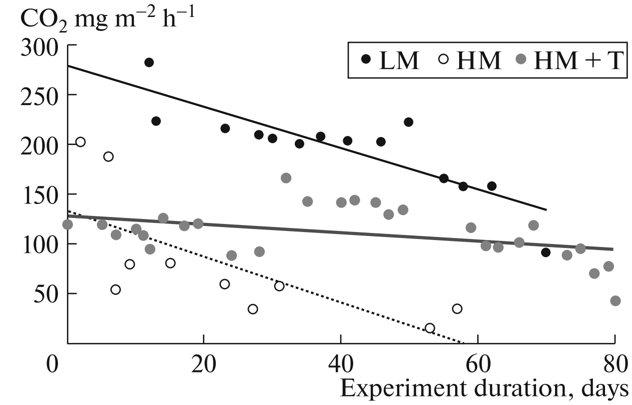

Fig. 1. Rate of CO_2 emission from arctic tundra soil samples in the experiments with imitation of the full growing season. Here and in Figs. 2 and 3, LM is the sample with a low level of moisture (depth of groundwater 0.2 m), HM is the sample with a high level of moisture (depth of groundwater 0.01 m), HM + T is a sample with a high level of moisture (depth of groundwater 0.01 m) and with a temperature rise by 2°C relative to the natural level.

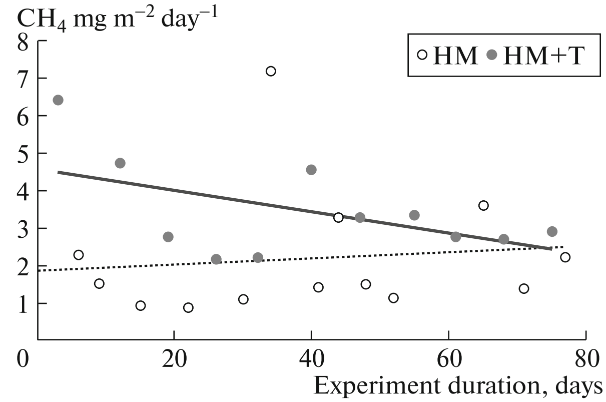

Fig. 2. Rate of the CH_4 emission from arctic tundra soil samples in the experiments with imitation of the full growing season.

second experiment with a moistened sample, it was increased by 2°C). So, for the formal midsummer, the air temperature was 15°C, one of the soil top layers was 10°C, and for the soil bottom layer it was 5°C. The light intensity on the soil level was from 80 to 100 W m^{-2} (360–460 μmol m^{-2} s^{-1} of photosynthetically active radiation). To estimate the CO_2 gas exchange and the rate of CH_4 emission from the soil, the growth chamber was sealed and periodically ventilated. Measurement of the CO_2 concentration was continuous (Li-840A gas analyzer, LiCOR, United States), and the methane concentration was measured periodically every two days after the chamber was sealed by a Picarro 2201-i gas analyzer (Picarro, Inc., United States). Emissions were calculated by changing the concentrations of greenhouse gases during the tightness period.

As can be seen from Fig. 1, CO_2 emission was significantly (more than 2 times) higher in the samples with low humidity. We also observed (and with the same rate) a decrease in emission by the end of the growing season: from 300 to 100 mg m^{-2} per hour in the case of low humidity, from 200 to 20 mg m^{-2} per hour in the case of high humidity. A 2°C increase in heating of the sample, which is equal to that predicted for the arctic tundra zone in the near future, increased the average emission from the soils with high humidity by about two times: from 75 mg m^{-2} per hour to 100–150 mg m^{-2} per hour. In addition, the difference between the rate of CO_2 emission at the beginning and the end of the growth season almost disappeared after heating.

Control of CH_4 release in the case of an experiment with a low-moisture soil sample showed that, during the experiment, the methane concentration in the chamber was in the range of 2.0–2.5 ppm, which is the equivalent of its concentration in the atmosphere, and led us to conclude that there was no methane emission. Experiments with high-moisture soil (Fig. 2) showed that during the first 30 days elevation of the air and soil temperature by 2°C led to an increase in the CH_4 emission rate compared to the emission rate under imitation of the natural temperature regime. In the first two weeks, there were especially significant differences: by more than three times. With time, these differences diminished, and by the end of the experiment we did not register any significant differences in the emission rates. Methane emission was more stable over time than carbon dioxide, and its average value was 3 mg m^{-2} per day. In general, we did not record any significant increase in methane emission when the samples were heated.

However, it should be noted that approximately in the middle of each experiment (30–40 days), both in the case of imitation of the natural temperature regime and during heating, we observed a sharp single rise in the methane emission rate: seven times in the first case and two times in the second case against the previous value.

We also determined the ratio of stable carbon isotopes $^{13/12}C$ in methane by the Picarro 2201-i gas analyzer. The results are presented in Fig. 3. Taking into account the standard estimate [15], the results obtained allow us to conclude that the methane released was mainly of biogenic origin, in other words, emitted by methanogenic microorganisms. In the experiment with heating, the carbon isotope ratio in methane was higher than that in the variant with imitation of the natural temperature regime.

Thus, we found that a temperature increase in the highly moistened tundra soil (heating of the sample by 2°C) leads to a twofold rise in carbon dioxide emission, persisting throughout the entire growing season.

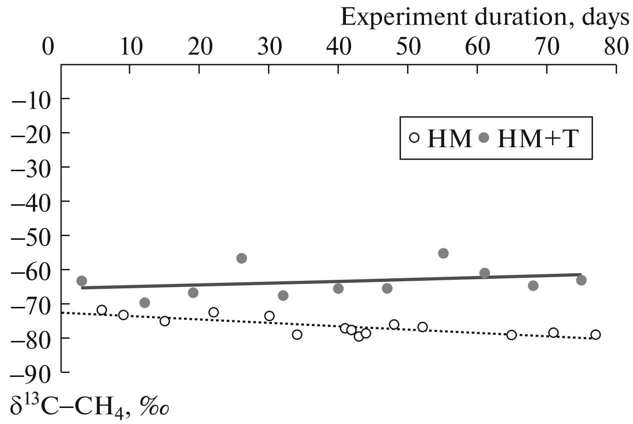

Fig. 3. The ratio between carbon isotopes from arctic tundra soil samples in the experiments with imitation of the full growing season.

The release of methane in the same experiment is stimulated only in the first few weeks of the growing season, and then soil ecosystem returns to the emission indicators characteristic of the natural temperature regime. Therefore, a temperature increase of 2°C is not sufficient for a sharp elevation in the methane emission into the atmosphere with the current length of the growing season.

ACKNOWLEDGMENTS

This study was supported by the Russian Foundation for Basic Research, the Krasnoyarsk Krai Government and the Krasnoyarsk Regional Fund of Science (project no. 17–45–240884), the Russian Foundation for Basic Research (project no. 16–04–01677-a), and the Institute of Biophysics, Siberian Branch, Russian Academy of Sciences, governmental assignment, theme no. 56.1.4. for 2013–2020.

REFERENCES

1. Y. M. Naumov, in *Cryosols,* Ed. by J. M. Kimble (Springer, Berlin, 2004), pp. 161–183.
2. M. Minke, N. Donner, N. S. Karpov, P. de Klerk, and H. Joosten, Peatlands Int. **1**, 36–40 (2007).
3. J. R. Mackay, Permafrost Periglacial Processes **10**, 39–63 (1999).
4. C. Tarnocai, Permafrost Periglacial Processes **10**, 251–263 (1999).
5. K. M. Walter, S. A. Zimov, J. P. Chanton, D. Verbyla, and F. S. Chapin, Nature **443**, 71–75 (2006).
6. P. Kuhry, E. Dorrepaal, G. Hugelius, E. A. G. Schuur, and C. Tarnocai, Permafrost Periglacial Processes **21**, 208–214 (2010).
7. P. Camill, Global Change Biol. **6**, 69–182 (2000).
8. C. S. Sturtevant and W. C. Oechel, Global Change Biol. **19**, 2853–2866 (2013).
9. D. Olefeldt, M. R. Turetsky, P. M. Crill, and A. D. McGuire, Global Change Biol. **19** (2), 589–603 (2013).
10. T. Sachs, M. Giebels, J. Boike, and L. Kutzbach, Global Change Biol. **16**, 3096–3110 (2010).
11. C. Wille, L. Kutzbach, T. Sachs, D. Wagner, and E. M. Pfeiffer, Global Change Biol. **14**, 1395–1408 (2008).
12. L. Kutzbach, D. Wagner, and E. M. Pfeiffer, Biogeochemistry **69**, 341–362 (2004).
13. A. G. Degermendzhi and A. A. Tikhomirov, Herald Russ. Acad. Sci. **84** (2), 124–130 (2014).
14. Yu. V. Barkhatov, A. A. Tikhomirov, S. A. Ushakova, V. N. Shikhov, S. I. Bartsev, and A. G. Degermendzhi, Dokl. Earth Sci. **471** (1), 1168–1170 (2016).
15. B. Fry, *Stable Isotope Ecology* (Springer, New York, 2006).

Translated by L. Krivenok