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GENERAL BIOLOGY

Carbon Emission by the Southern Tundra during Cold Seasons

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A variety of problems associated with global climate changes are a serious challenge inspiring detailed studies on carbon turnover in the biosphere. The global carbon budget assessment in typical ecosystems of various natural zones is an important area of these studies. In Arctic ecosystems, the carbon budget was usually assessed during the warm season, because the carbon turnover rate during the cold season was thought to be negligible. However, it was shown in the last decade that in Arctic ecosystems carbon emission during the cold season contributes significantly to the total annual budget [2, 7, 9, 11, 14]. However, estimates of the total rate of carbon emission in the cold season vary significantly, from 1.3–10.9 [9] to 131 g carbon per m^2 per season [14]. Neither seasonal dynamics nor patterns of the geographical distribution of carbon emission have been studied comprehensively enough, because all surveys were performed only in the lower Kolyma and Alaska. The goal of this work was to study the seasonal dynamics of carbon emission in the southern tundra of northeastern European regions of Russia in the cold period of year.

The studies were performed from October 1998 to May 1999 in the geographical subzone of the southern tundra [1, 6]. The field station was near the Tal'nik railway station 20 km south of the town of Vorkuta (67°20′ N, 63°44′ E). Dwarf–shrub moss–lichen tundra on the flat top of a small hill and a sedge bog between two hills were objects of this work. Five permanent experimental plots were set in each ecosystem and marked with pegs. The CO_2 concentration was measured using a cylindrical organic glass chamber (diameter, 42 cm; height, 30 cm) mounted on a steel base (height, 20 cm). The base had been dug in snow before the chamber was mounted at its top. The CO_2 concentration changes in the chamber were measured using a Li Cor-6200 portable infrared gas analyzer. The exposure time was 2–3 min. A total of four (October) or two (other months) measurements were performed at each experimental plot during one day of field work. Temperatures of the air, snow surface, and soil, as well as the snow cover thickness, were measured as additional parameters. The interval between the field measurements was 21 to 64 days.

The rate of carbon emission from ecosystems to the atmosphere was found to be significantly higher than zero throughout the period of observation. The rate of carbon emission exhibited pronounced seasonal dynamics (Fig. 1). The carbon emission rate in the dwarf–shrub tundra reached the maximum level (0.62 ± 0.06 g carbon per m^2 per day) in October. There was a sharp decrease in this value to 0.030 ± 0.002 g carbon per m^2 per day by early December, and the carbon emission rate reached the minimum level of 0.014 ± 0.002 g carbon per m^2 per day in January. The rates of carbon emission in March and April were statistically indistinguishable from the December level ($p = 0.11$–0.49). The rate of carbon emission by the dwarf–shrub tundra in May was increased to 0.10 ± 0.04 g carbon per m^2 per day.

The seasonal dynamics of carbon emission in the sedge bog (Fig. 1) was slightly different. The December and January rates were indistinguishable from one another ($p = 0.38$), whereas carbon emission in March was significantly higher than in winter ($p = 0.02$). By April and May, the rate of carbon emission in the sedge bog plots reached 0.11 ± 0.06 and 0.29 ± 0.11 g carbon per m^2 per day, respectively.

A close correlation was found between the rate of carbon emission and soil surface temperature, the shape of the correlation curve being close to exponential (Fig. 2). The correlation curve was well approximated by the following regression equation:

$$E = 0.018 + 1.52\exp(0.573TS),$$

$$n = 12, \quad R^2 = 0.986, \quad S.E. = 0.028,$$

where E is the carbon emission rate (grams of carbon per m^2 per day), TS is the soil surface temperature (°C),

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n is the number of measurements, R^2 is the determination coefficient, and $S.E.$ is the standard error.

Similar equations are often used for describing the temperature dependence of the soil respiration rate [10]. A rigorous dependence of the cold season emission rate on soil surface temperature was derived in [13] using experimental data obtained in boreal forests of North America.

The dependence of the carbon emission rate on the soil surface temperature allows us to explain the apparent discrepancy between the patterns of seasonal dynamics of carbon emission in the two ecosystems studied in this work. The mean thickness of the snow cover in the dwarf–shrub tundra and sedge bog in January–May was 22–40 and 112–130 cm, respectively, because the bog was located in a local depression. The difference between the snow cover thickness gave rise to a considerable difference between the seasonal patterns of soil surface temperature (Fig. 1). As a result, the carbon emission rates in these ecosystems differed from one another.

In this region, the cold season lasts from October to May. The mean air temperature during the season is below 1°C [5]. The total rate of carbon emission during this period was assessed by linear interpolation. The carbon emission rate in late May was approximated from the data as of May 18. During the 243 days of the cold season (October 1 to May 31), the rate of carbon emission in the dwarf–shrub tundra and sedge bog was 27.5 ± 3.7 and 40.1 ± 7.5 g carbon per m^2 per season, respectively. The carbon emission during the four coldest months (December–March) accounted for only 10% of the overall emission. The highest contribution to the total carbon emission was observed in October and November (51 and 59% in the dwarf–shrub tundra and sedge bog, respectively).

These findings, together with the data on carbon fluxes during the vegetation season in 1996 [3], allow us to assess the total annual budget of carbon in the ecosystems studied. The gross primary production and gross respiration rate in the dwarf–shrub tundra were 189 ± 31 and 237 ± 32 g carbon per m^2 per year, respectively. Therefore, as much as 48 ± 21 g carbon is lost from each square meter of tundra soil each year. Of these losses, 57% occur during the cold season and only 43%, during the warm season. The gross primary production and gross respiration rate in the sedge bog were 254 ± 31 and 241 ± 31 g carbon per m^2 per year, respectively. Therefore, during the warm season (June–September), the bog deposited 54 ± 22 g carbon per m^2, but 40 g carbon per m^2 were released to atmosphere during the cold season. The resulting loss of carbon is estimated at only 14 g carbon per m^2. The cold season emission is a substantial fraction of the gross annual respiration rate (12 and 17% in the dwarf–shrub tundra and sedge bog, respectively). It should be noted that these estimates are valid for the weather conditions of the summer of 1996 and the cold seasons of 1998 and 1999. Weather changes may have a significant effect on carbon balance parameters in southern tundra ecosystems [4].

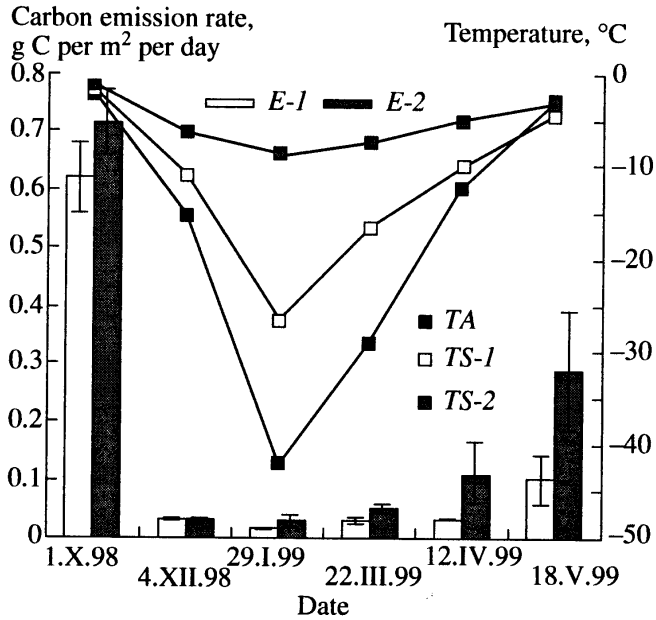

Fig. 1. Seasonal dynamics of daily carbon emission rate (E), air temperature (TA), and soil surface temperature (TS) in dwarf-shrub tundra (*1*) and sedge bog (*2*) during the cold seasons of 1998 and 1999. The emission rate is given as an arithmetic mean ± standard deviation (n = 5).

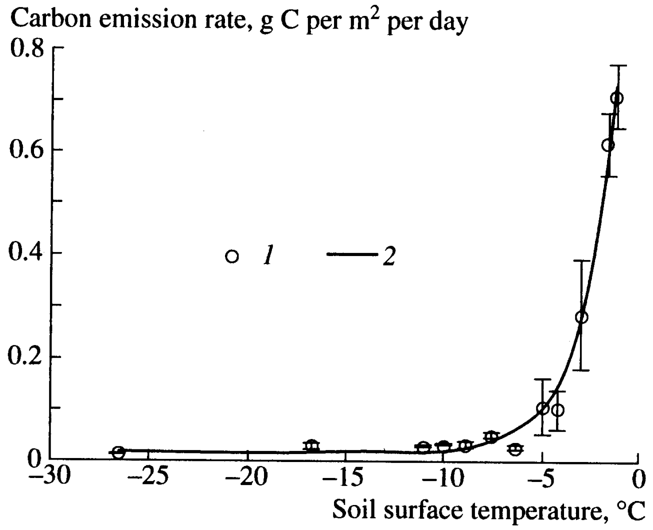

Fig. 2. Correlation between daily carbon emission rate and soil surface temperature in the ecosystems studied in this work: (*1*) results of measurements (arithmetic mean ± standard deviation, n = 5); (*2*) curve of regression equation $y = 0.018 + 1.52\exp(0.573x)$.

The estimates of the cold season emission rate obtained in this work (28–40 g carbon per m^2 per season) are consistent with similar values measured in the Alaskan tundra (19–69 g carbon per m^2 per season) [11] and the Alpine ecosystems of North America (41–

48 g carbon per m^2 per season [12] and 12–26 g carbon per m^2 per season [8]). The values calculated on the basis of spring measurements in Alaskan tundra (1.3–10.9 g carbon per m^2 per season) [9] seem to be underestimated. The estimates of the cold season emission rate obtained in the Kolyma lowland larch forest–tundra (131 g carbon per m^2 per season) [2] are representative of Arctic forest–tundra and thin forest zones.

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