Temperature effect on the rate of decomposition of peat-forming plants: results of a model experiment

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Abstract. The decomposition of the prevalent peat-forming plants of oligotrophic bogs in the southern taiga subzone of Western Siberia is quantified in a model experiment. The decay rate (DecR) of Sphagnum fuscum, Chamaedaphne calyculata, Eriophorum vaginatum, and mixed sample (60% of Sph. fuscum and 40% of C. calyculata) is estimated as a C(CO₂) emission from plant samples over 3 months at different temperatures (2, 12, 22° C) and at a moisture level corresponding to 60% of their water holding capacity. The dynamics of DecR of the prevalent peat-forming plants during the experiment is considerably influenced by both factors: the temperature and the type of plant litter. A remarkable increase in the C(CO₂) emission rate is observed for all plant samples at the initial stages of decomposition. An increase in the DecR for all types of plants is observed first at 22° C and 1-2 weeks later at 2°C. During the 3 months of the experiment, the Sph. fuscum loses only 3-5% of the initial amount of C, whereas the C-losses from the C. calyculata and E. vaginatum vary from 6 to 18% depending on the temperature. The effect of plant species on the DecR is more pronounced and explains about 61% of the DecR variability. The temperature coefficient Q₁₀ depends on the type of plant and varies from 0.97 to 1.3 in the low temperature range of 2-12°C and from 1.34 to 2.16 in the temperature range of 12-22°C.

1. Introduction

The total bog area in Russia is among the first ones in the world. The greatest area of bogs is in Western Siberia. A feature of the bog ecosystems is their ability to accumulate a significant amount of carbon in the form of peat deposits [1, 2]. The current climate changes in the territory of Western Siberia cause an increase in the temperature and a lowering of the bog water level (WL). Both trends can result in accelerating the processes of peat decomposition [3]. In this context, estimate of the effect of temperature as the most important abiotic factor on the decay rate of plant residues in bog ecosystems requires special attention.

The study is aimed at quantifying the effect of temperature on the decay rate of the prevalent peat-forming plants of oligotrophic bogs in the southern taiga subzone of Western Siberia in a laboratory experiment.

2. Material and methods
Samples of the prevalent peat-forming plants (Chamaedaphne calyculata Moench., Eriophorum vaginatum L., and Sphagnum fuscum Klinggr.) were collected on the oligotrophic bog "Bakhcharskoye" (Bakcharsky district, Tomsk region, 56°26' N, 84°50' E) in September 2017. Besides individual plant species, a mixed sample was prepared from Sph. fuscum (60%) and C. calyculata (40%) in accordance with the share of each species in the vegetative litter of the most typical phytocenosis in the territory of the Bakhcharskoe bog.

Some characteristics of the plant samples were determined before incubation: the ash content, the pH values (water and 1M KCl extracts at substrate: solution ratio = 1:25), the hygroscopic humidity, and the water holding capacity (WHC, %). The content of carbon and nitrogen (N) was determined in the plant samples using an automatic CHNS analyzer (Leco, USA).

For the experiment, the plant substrates (1-3 g of the air-dry mass) were placed in 110 ml glass vials and moistened to 60% of their water holding capacity (WHC). We used the bog water for wetting, because it contained the native microflora characteristic for the plots where the plants grew. After wetting, flasks with the plant materials were kept for 7 days at room temperature (pre-incubation period), and then placed into the thermostats and incubated for 3 months at 2, 12, and 22 °C. Every 2-3 weeks some amount of bog water was added to each flask to sustain a constant level of moisture of the plant material. The experiment was performed in three replicates.

The decay rate (DecR) of peat-forming plants was estimated as the C(CO₂) emission rate and measured 3-5 times per week during the first month of the experiment and 2 times per week during the next months. On the day of the measurement, the flasks were removed from the thermostat, ventilated for 10 minutes in a stream of air, sealed with rubber covers, and again placed in a thermostat. The C(CO₂) concentration was determined after 3-4 hours using an infrared gas analyzer LiCor-820 (USA). Between the measurements, the flasks with the plant material were covered with films permeable for air but preventing moisture evaporation and kept in the thermostats.

The DecR value (mg C kg⁻¹ of substrate h⁻¹) was calculated according to the following equation [4]:

\[
DecR = \frac{dC \times 12 \times V_{\text{flask}} \times 1000}{m} \times 22.4 \times t \times 100
\]

where \(dC\) is the change in the C(CO₂) concentration in the flask, volumetric %; \(V_{\text{flask}}\) is the flask volume, ml; \(t\) is the incubation time, hours; and \(m\) is the absolute dry weight of the plant substrate, kg.

In this study, the temperature sensitivity of the plant litter DecR was expressed as a \(Q_{10}\) function, which indicates the change in the DecR for a 10°C rise in the temperature. The \(Q_{10}\) value was calculated from the formula [5]:

\[
Q_{10} = \left(\frac{DecR_2}{DecR_1}\right)^{\frac{10}{(T_2-T_1)}},
\]

where \(DecR_2\) and \(DecR_1\) are the decay rates of the organic matter at the temperatures \(T_2\) and \(T_1\), respectively. The total losses of C(CO₂) from the plant materials (\(C_{\text{cum}}\), mg C / g of substrate) during the entire experiment were calculated.

To quantify the effect of the temperature (T) and the substrate quality (P) on the total loss of C(CO₂) during the entire experiment (the value of \(C_{\text{cum}}\) was carried out using two-factor analysis of the variance (ANOVA). Statistical analyses were performed using the STATISTICA 6 Software at the \(\alpha = 0.05\) level of significance.

### 3. Results

The chemical characteristics of the plant samples under study were significantly varied. Sph. fuscum was characterized by low pH values, low content of C and N, and high C/N ratio, which had a negative effect on the rate of the decomposition processes. The chemical properties of C. calyculata were more
favourable for the decomposition processes and characterized by higher pH values and lower C/N ratio in comparison with *Sph. fuscum*.

Temperature and type of the plant material had a pronounced effect on the dynamics of the DecR of main peat-forming plants (Fig. 1). A marked acceleration of the C(CO\(_2\)) release from the plant materials was observed at all temperatures during the first 2-3 weeks of the experiment. This phenomenon was most visible for *E. vaginatum* and the mixed sample at 22°C (Fig. 1). The period with a high rate of C(CO\(_2\)) release was influenced by both the type of plant substrate and the temperature. The period with the highest DecR values for *E. vaginatum* and the mixed sample was 1-5 days at 22°C, and it increased to 10-12 days in the mixed sample and to 25-30 days in *E. vaginatum* at 2 and 12°C. For *C. calyculata*, we observed a delay and a prolongation of the period with the highest DecR values at all temperatures (Fig. 1).

![Figure 1](image-url)

*Figure 1*. Dynamics of decay rate (DecR, mg C / g substrate / hour) of main peat forming plants at various temperatures (T = 2, 12, 22 °C) and a moisture of 60% of their WHC over 3 months of incubation.

The maximum release of C(CO\(_2\)) associated with a burst of activity of microorganisms-destructors was first recorded at 22°C and 1-2 weeks later at 2°C. At the same time, the extinction of the decomposition activity of the plant substrates was slower at 2°C than at 22°C. For example, maximum values of DecR for *E. vaginatum* were fixed in a day after the start of the experiment at 22°C, and only 7 days later at 2°C. Maximum values of DecR for the mixed sample (60% of *Sph. fuscum* and 40% of *C. calyculata*) at 2 and 12°C were higher than the corresponding values of its individual components (Fig. 1).

The total release of C(CO\(_2\)) over the 3 months of the experiment (C\(_{\text{cum}}\)) was the highest for *C. calyculata* and *E. vaginatum* at 22°C (90-93 mg C / g of substrate) and decreased by a factor of 2 (to 40-46 mg C / g of substrate) at 2°C (Fig. 2A). The samples of *Sph. fuscum* showed the highest resistance to microbial decomposition at all temperatures studied. The C\(_{\text{cum}}\) values for the mixed sample equalled the intermediate value between the losses of C(CO\(_2\)) obtained for its individual
components and also decreased at lower temperatures (Fig. 2A, B). For the 3 months of the experiment, *Sph. fuscum*, *C. calyculata*, and *E. vaginatum* lost 3-5, 10-15, and 9-18% of the initial amount of C, respectively, depending on the temperature.

![Figure 2](image)

**Figure 2.** Total C(CO$_2$) losses from main peat forming plants at various temperatures (T = 2, 12, 22°C) and moisture level of 60% of their WHC: A – mg C / g of substrate; B - % of the initial amount of C in the sample.

According to the two-factor ANOVA, the plant species and temperature significantly affected the variability of the C$_{cum}$ value over the 3 months of the experiment (Table 1). The effect of the plant species on the C$_{cum}$ values was more meaningful than that of the temperature and explained 61% of the total dispersion of the C$_{cum}$ value. The temperature factor was responsible for 31% of the C$_{cum}$ variance.

**Table 1.** Share of dispersion (ɲ, %) explained by the influence of plant species (P), temperature (T), and their combination by total C(CO$_2$) losses for 3 months of experiment.

| Factor | ɲ, % | F   | P      |
|--------|------|-----|--------|
| P      | 61.0 | 450 | < 0.0001 |
| T      | 31.2 | 230 | < 0.0001 |
| P*T    | 4.3  | 32  | < 0.0001 |

Depending on the plant species, the temperature coefficient Q$_{10}$ ranged from 0.97 to 1.30 in the low-temperature range (2-12°C) and was 1.34-2.16 in the temperature range between 12 to 22 °C (Fig. 3). The highest values of Q$_{10}$ were characteristic in both temperature ranges for *C. calyculata* and *E. vaginatum*. In our experiment, the Q$_{10}$ constant was lower than the typical Q$_{10}$ values for the chemical reactions [6].
The temperature sensitivity of the organic substrates decreased during long-term incubation, demonstrating the highest values of $Q_{10}$ in the first month of the experiment [6, 7]. In the late stages of decomposition, the temperature sensitivity of the DecR tends to weaken due to the emergence of adaptation of the microorganism-destructor community to the hydrothermal conditions during the prolonged incubation.

4. Conclusions
The temperature and type of the plant material had a pronounced effect on the dynamics of the DecR of the prevalent peat-forming plants during the incubation experiment. At the initial stages of decomposition, an acceleration of the C(CO$_2$) release from the plant samples was observed. It was recorded first at 22°C and 1-2 weeks later at 2°C. The extinction of the decomposition activity of the plant substrates was slower at 2°C than at 22°C. During the 3 months of the experiment, the Sph. fuscum lost only 3-5% of the initial amount of C, whereas the C-losses from the C. calyculata and E. vaginatum varied from 6 to 18% depending on the temperature. The effect of plant species on the total release of C(CO$_2$) over the 3 months of the experiment was more prominent than the effect of temperature and explained about 61% of the total dispersion of $C_{cum}$.

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