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Temperature sensitivity of soil carbon mineralization and nitrous oxide emission in different ecosystems along a mountain wetland-forest ecotone in the continuous permafrost of Northeast China

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ABSTRACT

Soil organic matter decomposition under global warming has a potential to alter soil carbon and nitrogen storages in permafrost. The objectives of this study were to investigate the temperature sensitivity of greenhouse gas emissions from soil samples along a mountain wetland-forest ecotone in the continuous permafrost and determine its influencing mechanisms. The CO_2, N_2O and carbon, nitrogen substrates were measured at 5, 15 and 25 °C. The relation between greenhouse gas emission rates and temperature depended on substrate quality in the three ecosystems. Soil DOC, MBC, NH_4^+ and NO_3^- concentrations determined the higher CO_2 and N_2O emission rates in the thicket peatland and the surface soil layer. During the incubation period, the degrees of soil carbon and nitrogen losses in the thicket peatland were 0.6–4.7% and 1.0–14.3 (1000 × %), approximately 1.6 and 1.2 times higher than those in the forest and fen, respectively. The highest degrees of soil carbon and nitrogen losses in the thicket peatland indicated that more greenhouse gases would emit from soils when permafrost degradation induced the succession from wetlands or forest to the wetland-forest ecotone. Although the gas emission rates presented significant differences in the three ecosystems, the Q_{10} values with 2.0 to 2.2 for CO_2 and 2.4 to 3.0 for N_2O, did not change significantly, indicating that the temperature sensitivity of gas emissions would not fluctuate much in the ecosystems along the mountain wetland-forest ecotone. However, the higher Q_{10} values in the deeper soil layer in our study indicated that the decomposition of soil C and N in the deeper active layer of the permafrost region is more impressionable to global warming. As laboratory results could not actually reflect the situation in the field, more field work about temperature sensitivity of soil organic matter decomposition in different ecosystems should be encouraged in the future.

1. Introduction

Northern high latitude region is known as a high potential contribution to climate change due to its large C stocks approximately 750 Pg C in the upper 3 m (McGuire et al., 2009; Schuur et al., 2008). The substantial stocks of C in this region are due to wet and cold physical conditions that are not conducive to the decomposition of soil organic matter (Grosse et al., 2011). Meanwhile, northern high latitude region is considered as the particularly sensitive area to climate change (Serreze et al., 2000). The largest temperature increases in recent decades occurred in the northern hemisphere land areas of 40–70°N (Serreze et al., 2000), and the climate change models predict that peatlands in the northern latitudes will be subjected to higher temperatures with longer growing seasons (IPCC, 2007). It is assumed that 25% of the estimated stocks of C in northern peatlands and permafrost would be subjected to loss due to global warming in the 21st century, and this potential loss would be two to three times larger than simulated C loss from the mineral soil (Davidson and Janssens, 2006). Moreover, through field and incubation studies, the more sensitive decomposition rate with temperature at lower temperature range indicated that the sensitivity of organic matter decomposition to climate changes may be latitude-dependent, with the response to global warming being greater at high latitudes (e.g., Bagherzadeh et al., 2008; Kato et al., 2005; Niklińska and Klimek, 2007; Peng et al., 2009; Schindlbacher et al., 2010; Wang et al., 2010). Thus, the study of the potential decomposition rate of soil organic matter in high latitude region has been a focus on the debate regarding the potential impacts of climate change on the global C cycle (Hobbie et al., 2000; Sjögersten and Wookey, 2002; Wang et al., 2010).

Abbreviations: SOC, soil organic carbon; DOC, dissolved organic carbon; MBC, microbial biomass carbon; TN, total nitrogen; C/N, the ratio of C and N; NH_4^+, ammonium; NO_3^-, nitrate; Q_{10}, the change of the gas emission rate as a consequence when temperature increases by 10 °C.

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Ecotone is a transitional area between two different ecosystems, and contains elements of both bordering communities as well as organisms which are characteristic and restricted to the ecotone (Graves, 2011). Ecotone has been regarded as a sensitive area and attracts particular interest due to its ecological importance and sensitive response to the environmental variables (Schimel et al., 1990; Stottlemyer et al., 2001). Recently, the wetland-forest ecotone in the permafrost region is becoming a hot study topic (Stine et al., 2011). Permafrost degradation induced by human activities and climate changes can alter the water-heat process of soils, which results in changes in species composition and gives rise to community succession (Jorgenson et al., 2001; Yang et al., 2010). Generally, in the lowland ecosystems, the loss of ice-rich permafrost would result in the gradual expansion of aquatic plants or hygrophytes (Osterkamp et al., 2000); On the contrary, in the upland ecosystems, permafrost thaw might cause the replacement of hygrophilous community by xeromorphic community or shrub (Guo et al., 2007). Meanwhile, some studies have shown that vegetation types strongly affected soil greenhouse gas emissions (e.g., Inglett et al., 2012; Schaufler et al., 2010; Ward et al., 2013). Thus, the changed dominant community is bound to affect soil greenhouse gas emissions. So far, the studies on greenhouse gas emissions at the permafrost ecotone have primarily focused on forest-tundra ecotone and taiga-tundra ecotone (e.g., Flessa et al., 2008; Rodionow et al., 2005; Sjögersten and Wookey, 2002; Stottlemyer et al., 2001). However, the literatures on the greenhouse gas from wetland-forest ecotone are greatly lacking (Stine et al., 2011), and only Hartshorn et al. (2002) detected the soil respiration rate at the peatland-forest ecotone in Southeastern Alaska. To the best of our knowledge, there have been no published papers on the temperature sensitivity of soil organic matter decomposition along a mountain wetland-forest ecotone in the continuous permafrost region.

The Great Hing'an Mountains, Northeast China is located in the southern margin of the permafrost region of the Eurasian continent (Zhou et al., 2000). The climate in this region has become dryer and warmer over recent decades (Sun et al., 2005), and the global circulation model predicted that the temperature in the Great Hing'an Mountains would rise by 2–4 °C over the next 100 years (Liu et al., 2011). Accordingly, the shrinkage of wetland area in this region tends to increase, and about 30% of the wetland area will disappear by 2050 (Liu et al., 2011). By now, the degraded wetlands in the gentle slope of the Great Hing'an Mountains have gradually been invaded by shrub and pioneer species of *Betula Platyphylla*. As time increases, the vegetation of *B. Platyphylla* will be replaced by *Larix gmelini*, and finally wetland will degrade as forest ecosystem (Sun et al., 2010; Zhao et al., 2012). The degradation of wetland in the Great Hing'an Mountains will inevitably affect the greenhouse gas emissions. To understand how soil C and N cycling in wetland-forest ecotone would be important in predicting responses of ecosystems in permafrost region to climate change. Our aim in the current study was therefore to investigate the roles of temperature and soil substrate quality in controlling soil C mineralization and N_2O emission in the ecosystems along the mountain wetland-forest ecotone in continuous permafrost region of Northeast China.

2. Materials and methods

2.1. Site description and sampling

The study area is located at the northwest slope of the Great Hing' an Mountains of Northeastern China (52°44′N, 122°39′E). It is in the continuous permafrost zone. The climate of this area is cool continental, with a 30-year (1980–2009) mean annual temperature of −3.9 °C and mean annual precipitation of 452 mm, 203 mm with rainy season in July and August (Wang et al., 2013). During the growing season (May–September) of 2010 and 2011, the monthly mean air temperature varied from 5.3 to 20.3 °C, and the extreme daily temperature reached to 39.4 °C (Miao et al., 2012). We selected three research sites approximately 400 m apart along one hillslope with the slope of six degrees. These three research sites include the major transitions in plant communities along a transect from fen at the base (515 m asl) to thicket peatland in the mid (558 m asl) and then forest at the summit (590 m asl). The dominant species in fen is sedges *Eriophorum vaginatum*, interspersed with *Ledum palustre*, *Chamaedaphne calyculata* and *Sphagnum*. Thicket peatland is dominated by *B. platyphylla*, interspersed with *L. palustre*, *C. calyculata*, *Betula ovalifolia*, *Sphagnum* and undersized *Larix gmelini*. In the forest, *L. gmelini* is the dominant vegetation, interspersed with *B. platyphylla*.

On 24 August 2012, from each research site, three squares of 100 m^2 were randomly selected. In each square, after removal of surface litter and aboveground vegetation, five soil cores of 0–20 cm depth were sampled using a grid sampling method. We cut the soil cores from the surface part with each segment for 10 cm long and then mixed the soils from the same layer into a composite sample. The soil samples were sealed in plastic bags with headspace removed, and immediately transported to Sanjiang Experimental Station of Wetland Ecology, Chinese Academy of Sciences. After the removal of visible root material by hand picking, each soil sample was homogenized sufficiently, and slightly air dried at room temperature to the extent that can be sieved with a 4 mm mesh without sticking together for the following incubation experiment. Part of the samples were air-dried, crushed and sieved to 0.25 mm for soil organic carbon (SOC) and total nitrogen (TN) analyses. Soil dissolved organic carbon (DOC), microbial biomass carbon (MBC), and inorganic N (NH_4^+ and NO_3^-) were directly measured using the wet soil after sieving. Soil physicochemical properties are shown in Table 1.

2.2. Chemical analyses and incubation experiment

Based on the field temperature in growing season, three temperatures gradients with 5, 15 and 25 °C were selected. The maximum water holding capacity (MWHC) was measured by the method of Rey et al. (2005). Each soil sample in triplicates (equivalent of 10 g dry weight) was incubated at 70% MWHC in 500 ml airtight glass jars at 5, 15 and 25 °C (±1 °C), respectively. At each incubation temperature, three empty jars randomly distributed among the others as blank. Soil CO_2 and N_2O emission rates were measured at increasing time intervals on day 1, 3, 5, 7, 9, 12, 15, 28 and 35. For each gas sampling, the soil jars

Table 1
The main properties of soil organic layer in three ecosystems along a mountain wetland-forest ecotone in continuous permafrost of Northeast China.

Site	Soil layer (cm)	SOC (%)	TN (%)	C/N	pH
Forest	0–10	30.6 ± 1.2^c	1.6 ± 0.0^c	19.2 ± 0.7^b	3.9 ± 0.1^c
	10–20	19.7 ± 0.5^e	1.1 ± 0.0^e	17.5 ± 1.0^c	4.0 ± 0.1^{bc}
Thicket peatland	0–10	41.8 ± 1.3^a	1.9 ± 0.1^a	21.6 ± 1.1^a	4.1 ± 0.1^b
	10–20	29.3 ± 1.5^c	1.5 ± 0.1^c	19.6 ± 1.4^b	4.1 ± 0.1^{ab}
Fen	0–10	33.9 ± 0.8^b	1.6 ± 0.1^b	19.4 ± 0.4^b	4.3 ± 0.2^a
	10–20	22.4 ± 0.8^d	1.4 ± 0.1^d	16.6 ± 0.6^c	4.1 ± 0.2^{ab}

Values are means and standard deviation (n = 3). SOC, soil organic carbon; TN, total nitrogen; C/N, the ratio of C and N; pH, the ratio of water to soil was 1:5. Different lowercase letters of a, b, c, d and e in the same column are significantly different by LSD test ($P < 0.05$).