Atmospheric Environment 75 (2013) 77–82

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Carbon release from *Sphagnum* peat during thawing in a montane area in China

Xianwei Wang [a], Changchun Song [a,*], Jiaoyue Wang [a,b], Yuqing Miao [a,b], Rong Mao [a], Yanyu Song [a]

[a] Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun 130012, Jilin, China
[b] Graduate University of Chinese Academy of Sciences, Beijing 100039, China

HIGHLIGHTS

- The C released quickly during thawing in the peat and permafrost soils.
- The CO_2 emission was higher during thawing in the sphagnum moss layer.
- The CH_4 emissions showed different trend to the CO_2 emissions during thawing.
- The Q_{10} values of peat and permafrost soil were increased across the freezing point of water.
- The changes of soil substrates and environments during thawing could affect the type of greenhouse gas.

ARTICLE INFO

Article history:
Received 30 September 2012
Received in revised form
12 March 2013
Accepted 19 April 2013

Keywords:
Peatland
Thaw
Methane
Carbon dioxide
Temperature sensitivity
Environment

ABSTRACT

Soil thawing may affect the turnover of soil organic carbon (C) and the release of C to the atmosphere. Little is known about C release during thawing in the Great Hing'an Mountains, China. Through the incubations, we studied the emissions of CO_2 and CH_4 during thawing from the *Sphagnum* moss layer to the permafrost layer under aerobic and anaerobic conditions. Carbon was released quickly during thawing under different conditions. The *Sphagnum* moss layer produced more CO_2 than the other layers. However, there was little CH_4 release during thawing in the *Sphagnum* moss layer and burst of CH_4 emissions in the peat and permafrost soils. These bursts include stored CH_4 in the frozen samples and productions from microbial activity. The temperature sensitivity during thawing decreased across the freezing point in the *Sphagnum* moss layer, did not change greatly in the root layer, and increased greatly in the peat and permafrost layers. Changes in soil substrates and enzyme activities may affect C release during thawing.

1. Introduction

Boreal peatland ecosystems cover about 3% of the earth's surface and store approximately one-third of the total terrestrial C pool (Gorham, 1991; Tarnocai et al., 2009). Peat is partially decomposed plant material that accumulates where plant production exceeds organic matter losses through heterotrophic respiration, leaching or dissolved export, fire combustion or other disturbance-related losses and it represents the balance between CO_2 fixation by net primary production and carbon releases throughout the entire peat column (Turetsky, 2004). *Sphagnum* mosses are usually dominant in the peatland ecosystems and decompose very slowly (Dorrepaal et al., 2005; Wieder and Vitt, 2006). *Sphagnum* mosses and peat soils provide good thermal for the underlying permafrost and contribute to permafrost stability (Turetsky, 2004; Wieder and Vitt, 2006). However, climate models predict that climate change will be most intense at high latitudes (IPCC, 2007). Increased air and soil temperatures could contribute to permafrost thawing in the high latitude ecosystems and expose a large pool of stable C stored in permafrost to microbial decomposition (Davidson and Janssens, 2006; Schuur et al., 2008).

Increases in CO_2 and CH_4 emissions following soil thawing have been shown to affect total annual gas budgets (Papen and Butterbach-Bahl, 1999; Song et al., 2006). Microbial activity essentially stops once the soil is frozen (Schaefer et al., 2011). During thawing, the sudden flush of water and nutrients may induce changes in microbial activity, with organisms shifting rapidly (Schimel and Clein, 1996). The general

* Corresponding author. Tel.: +86 431 8554 2204; fax: +86 431 85542298.
E-mail addresses: songcc@neigae.ac.cn, songcc1981@sohu.com, sunli7912@163.com (C. Song).

1352-2310/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.atmosenv.2013.04.056

mechanisms that explain the increased C emission after thawing include release of C from microbial biomass, death of roots, and changes in soil structure (Matzner and Borken, 2008). However, the mechanisms that control C releases during thawing events are not fully understood (Kim et al., 2012). Future climate change is likely to alter the thawing events. Soil thawing raises the questions about the fate of C cycling in peatland ecosystems.

Peatland environments are generally highly heterogenous, which creates large uncertainties in understanding the resulting effects of dynamic processes such as permafrost thawing (Bäckstrand et al., 2010). Permafrost thawing could also affect the soil moisture and result in different soil environments (Wickland et al., 2006). The organic carbon in the permafrost might be relatively labile since it is not protected from decomposition by physical protection or humification mechanisms (Fan et al., 2008). There are still knowledge gap regarding the extent to which permafrost-protected C is available for microbial metabolism once soils thaw (Warldrop et al., 2010). Laboratory study may reflect the climate effects on permafrost soils under aerobic and anaerobic conditions. The results should help parameterize and validate ecosystem and climate models of C release from permafrost thawing (Lee et al., 2011).

In the Great Hing'an Mountains in China, low temperatures, a short growing season, partial water-saturation, and permafrost limit decomposition of organic matters resulting in an accumulation of organic matter in soils (Wang et al., 2010). However, the permafrost boundary has moved northward with a deeper active layer and the total permafrost area has shrunk remarkably since the 1970s in this montane area (Jin et al., 2007). Such changes may influence the C cycle in local permafrost peatlands. To improve our understanding of the present and future C dynamics in permafrost peatland ecosystems, we collected samples from the continuous permafrost peatlands in the Great Hing'an Mountains, China. The objective of this study was to quantify CH_4 and CO_2 release during thawing under aerobic and anaerobic conditions and to compare the C emissions from the *Sphagnum* moss layer with the permafrost layer during thawing. We hypothesized that the stored CH_4 in the frozen samples would affect the calculation of the CH_4 emission from the microbial production during thawing and that permafrost soils could have high potential decomposability after thawing compared with the active layer.

2. Materials and methods

2.1. Study area

The sampling sites (52°55′–53°10′N, 122°46′–122°16′E) were near the town of Mohe County, which located in the continuous permafrost zone of the Great Hing'an Mountains, northeastern China. Permafrost in this region is an integral part of Eurasian continuous permafrost. The mean annual air temperature is −5.5 °C and the annual precipitation from 1961 to 2000 was 400 mm (Jin et al., 2007). The peatland is poor fen in this region and distributed in the wide valleys, which dominated by *Ledum palustre*, *Vaccinium uliginosum*, *Sphagnum* spp., and *Larix gmelini* Rupr. The thickness of the active layer ranges from 50 to 70 cm above the permafrost layer (Wang et al., 2010; Miao et al., 2012).

2.2. Soil sampling and preparation

We collected samples from *Sphagnum* hummock in December 2010 while the soils were totally frozen. The samples included the *Sphagnum* spp., shrub root, peat, and permafrost soil, which were wrapped in aluminum foil with 10 cm using a band. The 0–10 cm layer was the *Sphagnum* moss layer, which included frozen living *Sphagnum* moss. The 10–20 cm layer was the root layer, which included the shrub roots. The 20–30 and 40–50 cm layers were the peat layer, which could thaw during the summer months. The 80–90 cm layer was the permafrost soil layer, which had frozen over 2 years (Table 1). Then the samples were split along their axis with saw for incubation experiments. Some small pieces (approximately 10 g) of the different layers were taken for analyzing the CH_4 concentration in the frozen samples. The other samples were taken to the Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences and stored at −20 °C. In the laboratory, some samples of each layer were thawed at 4 °C, and then dried for analysis of the soil properties.

CH_4 concentrations in frozen samples were obtained by thawing small frozen subsamples of material in saturated NaCl solution, following the method described by Wagner et al. (2007) (Table 1). We took about 10 g samples in glass jars and sealed them tightly with black rubber stoppers in the field. There were also four blank samples. Then the thawed samples were shaken by hand and CH_4 concentrations were analyzed by gas chromatography (Agilent 7890, Agilent Co., Santa Clara, CA, USA).

2.3. Incubation experiment

In the laboratory, about 40–50 g of frozen samples were placed in 500 ml glass vials and sealed with rubber stoppers. Three vials were incubated under aerobic conditions and three vials were incubated under anaerobic conditions. All vials were incubated in the dark. Anaerobic incubations were conducted by flushing with N_2, for 15–20 min at a time to ensure that O_2 was removed. At each measured time, the samples were also flushed with N_2 for 15–20 min to remove the cumulative gases. During the 48-day incubation, we measured the concentrations of CO_2 and CH_4 emissions from −10 °C to 10 °C. The C emission rates were measured when the soils were at −10 °C (on day 3), and after the soils had been warmed to 0 °C (on day 3). The soils were then incubated at 10 °C for the rest of the incubation period.

At each measurement time, 20 ml of headspace was collected and the CO_2 and CH_4 concentration measured by gas chromatography (Agilent 7890). Once the sampling of a vial was completed, vials under aerobic conditions were flushed with ambient air and resealed for the next measurement.

2.4. Soil characteristics techniques

Soil moisture content was determined gravimetrically by drying the soil at 105 °C for 48 h and measuring the weight changes before and after drying. The C contents were measured with a Multi N/C 2100 Analyzer (containing an HT 1500 Solid Module, Analytik Jena, Germany). Total N concentration was analyzed by the Kjeldahl

Table 1
Substrate quality of the samples used in the incubation study.

Depth (cm)	TOC (g kg^{-1})	TN (g kg^{-1})	C/N ratio	pH	Water content (%)	CH_4 content (μmol g^{-1})
0–10	431.70 ± 40.71	10.80 ± 0.04	36.68 ± 3.96	5.57 ± 0.24	1575.00 ± 275.00	6.40 ± 1.67
10–20	488.63 ± 28.16	19.03 ± 0.04	24.50 ± 0.81	5.30 ± 0.33	992.05 ± 17.05	19.32 ± 4.34
20–30	407.97 ± 4.31	17.11 ± 0.07	22.70 ± 1.78	5.38 ± 0.40	407.97 ± 4.31	29.69 ± 2.65
40–50	234.57 ± 6.62	9.24 ± 0.03	23.25 ± 2.65	5.52 ± 0.20	246.68 ± 5.17	661.73 ± 68.14
80–90	126.23 ± 1.80	5.55 ± 0.01	19.49 ± 0.62	5.74 ± 0.51	103.07 ± 1.01	236.41 ± 6.00

Values are the means ± 1 SE ($n = 3$).