Science of the Total Environment 616–617 (2018) 427–434

Contents lists available at ScienceDirect

Science of the Total Environment

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

Effects of warming on N_2O fluxes in a boreal peatland of Permafrost region, Northeast China

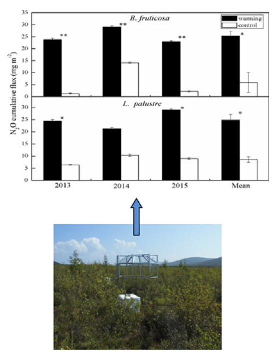
Qian Cui [a,b], Changchun Song [a,*], Xianwei Wang [a], Fuxi Shi [a], Xueyang Yu [a,b], Wenwen Tan [a]

[a] Key Laboratory of Wetland Ecology and Environment, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun 130102, PR China
[b] University of Chinese Academy of Sciences, Beijing 100049, PR China

HIGHLIGHT

- Different vegetation surfaces showed different response on warming.
- Warming increased N_2O fluxes by 147% in boreal peatlands.
- N_2O fluxes were strongly correlated with soil temperature at 5, 10 and 15 cm depth and active layer depth.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 10 August 2017
Received in revised form 23 October 2017
Accepted 24 October 2017
Available online xxxx

Editor: Jay Gan

Keywords:
Warming
N_2O flux
Peatlands
Soil temperature
Active layer depth

ABSTRACT

Climate warming is expected to increasingly influence boreal peatlands and alter their greenhouse gases emissions. However, the effects of warming on N_2O fluxes and the N_2O budgets were ignored in boreal peatlands. Therefore, in a boreal peatland of permafrost zone in Northeast China, a simulated warming experiment was conducted to investigate the effects of warming on N_2O fluxes in *Betula*. *Fruticosa* community (*B. Fruticosa*) and *Ledum. palustre* community (*L. palustre*) during the growing seasons from 2013 to 2015. Results showed that warming treatment increased air temperature at 1.5 m aboveground and soil temperature at 5 cm depth by 0.6 °C and 2 °C, respectively. The average seasonal N_2O fluxes ranged from 6.62 to 9.34 μg m^{-2} h^{-1} in the warming plot and ranged from 0.41 to 4.55 μg m^{-2} h^{-1} in the control plots. Warming treatment increased N_2O fluxes by 147% and transformed the boreal peatlands from a N_2O sink to a source. The primary driving factors for N_2O fluxes were soil temperature and active layer depth, whereas soil moisture showed a weak correlation with N_2O fluxes. The results indicated that warming promoted N_2O fluxes by increasing soil temperature and active layer depth in a boreal peatland of permafrost zone in Northeast China. Moreover, elevated N_2O fluxes persisted in this region will potentially drive a noncarbon feedback to ongoing climate change.

1. Introduction

The permafrost zone contains approximately 50% of global soil organic matter (SOM), storing 1400–1800 Pg of carbon (C) (Tarnocai et al., 2009; Hugelius et al., 2014; Schuur et al., 2015) and 40–60 Pg of nitrogen (N) (Jonasson et al., 1999; Weintraub and Schimel, 2003; Harden

* Correspondence author.
E-mail address: songcc@neigae.ac.cn (C. Song).

https://doi.org/10.1016/j.scitotenv.2017.10.246
0048-9697/

et al., 2012). Rapid warming in northern latitudes would result in permafrost degradation and thaw (Romanovsky et al., 2010), accelerating decomposition of permafrost SOM and stimulating greenhouse gas emissions (Yang et al., 2010; Sierra et al., 2015). While past studies focused on gaseous C dynamics (Schuur et al., 2015), growing evidence suggest that Arctic soils are large N reservoirs and emit high amounts of Nitrous oxide (N_2O) (Repo et al., 2009; Elberling et al., 2010; Marushchak et al., 2011; Voigt et al., 2017a, 2017b). N_2O is a potent greenhouse gas (GHG) that has 310 times radiative forcing of CO_2 over a 100-year time horizon, and also takes part in the depletion of stratospheric ozone (Ravishankara et al., 2009). N_2O generation is regulated by availability of mineral N and is subject to microbial processes of nitrification and denitrification (Bouwman, 1990). Warming may accelerate N mineralization from SOM and leaching of mineral N forms (ammonium and nitrate) may occur. Thus, increased ammonium (NH_4^+) pool could boost nitrification, and hence enhanced (NO_3^-) concentrations through amplified nitrification could accelerate denitrification, and elevate the concentrations of N_2O (Butterbach-Bahl et al., 2013).

Most recently, soils may generate N_2O as a result of high potential nitrification and denitrification rates in boreal ecosystem (Buckeridge and Grogan, 2010; Harms and Jones, 2012; Stewart et al., 2014) and release high N_2O in permafrost peatlands (Repo et al., 2009; Marushchak et al., 2011). Moreover, high N_2O potential has also been found in subarctic peatlands after permafrost thawing (Abbott and Jones, 2015; Voigt et al., 2017b), highlighting the importance of warming to permafrost N_2O fluxes. Previous studies have found that warming promoted N_2O release in a subarctic tundra and an alpine meadow of permafrost region (Voigt et al., 2017a; Chen et al., 2017a), reduced N_2O emission in an alpine meadow (Hu et al., 2010; Shi et al., 2012), however, warming also had no effect on N_2O fluxes in a high Arctic tundra and mountain tundra (Lamb et al., 2011; Zhou et al., 2016). These inconsistent results are mainly due to the various effects of warming on soil moisture, soil SOM content, C/N ratio and plant growth in Arctic soils (Marushchak et al., 2011; Voigt et al., 2017a, 2017b).

The Great Hing'an Mountains of China is characterised by low temperature, a short growing season, partial water-saturation as well as permafrost, leading to an accumulation of organic matter (Wang et al., 2010). Consequently, the permafrost is susceptible to climate change, which permafrost boundary has moved northward by a deepening of the active layer in mountain area (Jin et al., 2007). Generally, permafrost peatlands with large N stocks have negligible N_2O fluxes because of low N minerlization rates (Regina et al., 1996). However, the permafrost degradation will make vast stocks of previously frozen SOM may become available and enhance decomposition of SOM (Hobbie et al., 2000; Schuur et al., 2015). Additionally, experimental warming of both boreal and arctic soils accelerate soil nitrogen pools and cycling (Schimel et al., 2004; Natali et al., 2011; Weedon et al., 2012), likely caused by enhanced rates of nitrogen mineralization or nitrification (Rustad et al., 2001; Keuper et al., 2012). Thus, permafrost thaw and climate warming in this area will in turn enhance nitrogen release from the permafrost and potentially drive a positive feedback to ongoing climate warming (Abbott and Jones, 2015; Macdougall et al., 2016).

To verify the effects of warming on N_2O fluxes in boreal peatlands, we established a warming experiment using opaque chambers in a boreal peatland of permafrost zone in the Great Hing'an Mountains, Northeast China. In this study, we reported the changes in N_2O fluxes and environmental factors in two habitat types following three years of warming during the growing seasons of 2013–2015. The main objectives of this study are to (i) observe temporal variation in N_2O fluxes at different time scales (i.e., daily, monthly, seasonally); (ii) assess the effects of warming on N_2O fluxes; and (iii) investigate the factors that influence N_2O fluxes from permafrost peatlands.

2. Materials and methods

2.1. Study site

The study was conducted in a minerotrophic peatland located in the continuous permafrost zone of the Great Hing'an Mountains, Northeast China (52°94′ N, 122°86′ E, 477 m a.s.l). The study area experiences a cool continental climate with a mean annual temperature of −3.9 °C, a monthly mean temperature ranging from 19.8 °C in July to −31.9 °C in January, and a mean annual precipitation of 452 mm (with 45% of all precipitation occurring between July and August; Miao et al., 2012). The permafrost of this region belongs to an undivided portion of Eurasian continuous permafrost (Jin et al., 2007). The growing season normally starts in early May and lasts until late September. The dominant plant community mainly consists mostly of *Betula fruticosa*, *Ledum palustre*, *Vaccinium uliginosum*, *Sphagnum* spp., *Rhododendron parvifolium*, *Chamaedaphne calyculata*, *Eriophorum vaginatum*, *and Larix gmelini Rupr*. The main microtopographies in the peatland surface are distinguished by hummocks, tussocks and hollows. About 50% of the surface is hummocks covered by moss and some shrubs.

Our study was conducted in two habitat types, a higher shrub community dominated by the deciduous shrub *Betula fruticosa* and *Sphagnum* mosses, and a dwarf shrub community dominated by evergreen shrub *Ledum palustre* and *Sphagnum* mosses. For simplicity's sake, we will refer to these two habitat types as *B. fruticosa* and *L. palustre* hereafter. The height, coverage and above-ground biomass of *B. fruticosa* were 135 ± 14.4 cm, 84 ± 7.1% and 467.1 ± 73.1 g m^{-2}, respectively. The height, coverage and above-ground biomass of *L. palustre* were 50.3 ± 7.1 cm, 44.7 ± 22.8% and 269.6 ± 133.6 g m^{-2}, respectively. The distance between these two habitat types was 200 m and the other focal species were all abundant in both habitat types. These two species were selected because they were abundant at our study site and were widespread in the peatland of the Great Hing'an Mountains (Miao et al., 2012).

2.2. Experimental design

The OTCs were passive warming chambers designed according to the established ITEX protocol in order to obtain quasi-natural transmittance of visible wavelengths and to minimize the transmittance of re-radiated infrared wavelengths (Marion et al., 1997; Aronson and McNulty, 2009). The OTCs had a diameter, height, and open-top diameter of 2.6, 2.3, and 1.3 m, respectively. They consisted of an octagonal galvanized steel structure made with steel tubes, and the warming material was organic glass with a thickness of 6 mm. At 1.8 m height, the vertical beams of the structure were bent inwards to have a truncated pyramid pen-top of 1.3 m diameter and a 60° tilt. A door of 1 m length and 1.8 m height was also installed on one side of each OTC to allow access to the inside, but was kept closed during the experiment. In June 2012, we installed 3 OTCs at each habitat type paired with 3 control plots. At each habitat type, the distance between two adjacent OTCs was around 4 to 5 m, and the distance between an OTC and the adjacent control plot was approximately 3 m.

2.3. N_2O flux measurements

Three replicates of each treatment were randomly selected for N_2O flux measurements. The N_2O fluxes were measured every 7–10 days using the static chamber and gas chromatography during the growing seasons of 2013 to 2015. The static chamber was made by stainless steel and consisted of two parts: a top removable aluminum chamber (50 cm × 50 cm × 50 cm) and a square base collar (50 cm × 50 cm × 20 cm). The chambers were put on the collar during gas sampling and immediately removed after gas samples collected. The chambers were coated with Styrofoam to prevent an increase in the inner air temperature during sampling. The collars