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Nitrous Oxide Emissions from a Masson Pine Forest Soil in Subtropical Central China

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ABSTRACT

The forest ecosystem plays a pivotal role in contributing greenhouse gases to the atmosphere. In order to characterize the temporal pattern of nitrous oxide (N_2O) emissions and identify the key factors affecting N_2O emissions from a Masson pine forest in a hilly red-soil region in subtropical central China, we measured the N_2O emissions in Jinjing of Hunan Province using the static chamber-gas chromatographic method for 3 years (2010–2012) and analyzed the relationships between the N_2O fluxes and the environmental variables. Our results revealed that the N_2O fluxes over the 3 years varied from −36.0 to 296.7 μg N m^{-2} h^{-1}, averaging 18.4 ± 5.6 μg N m^{-2} h^{-1} ($n = 3$). The average annual N_2O emissions were estimated to be 1.6 ± 0.3 kg N ha^{-1} $year^{-1}$. The N_2O fluxes exhibited clear intra-annual (seasonal) variations as they were higher in summers and lower in winters. Compared with other forest observations in the subtropics, N_2O emissions at our site were relatively high, possibly due to the high local dry/wet N deposition, and were mostly sensitive to variations in precipitation and soil ammonium N content. In this work, a multiple linear regression model was developed to determine the influence of environmental factors on N_2O emissions, in which a category predictor of "Season" was intentionally used to account for the seasonal variation of the N_2O fluxes. Such a model explained almost 40% of the total variation in daily N_2O emissions from the Masson pine forest soil studied ($P < 0.001$).

Key Words: environmental factors, multiple linear regression model, N deposition, season, subtropical forests

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INTRODUCTION

Nitrous oxide (N_2O) is one of the important greenhouse gases, and is almost 300 times more potent in radiative forcing than carbon dioxide (CO_2) over a 100-year time horizon (Rodhe, 1990; Solomon *et al.*, 2007). Atmospheric N_2O concentration has increased linearly to 320 nL L^{-1} (parts per billion) at a rate of approximately 0.26% per year in recent decades (Solomon *et al.*, 2007). N_2O also participates in many photochemical reactions in the atmosphere, and is considered to be the greatest anthropogenic factor influencing stratospheric ozone depletion in the 21st century (Ravishankara *et al.*, 2009).

Approximately 65% of atmospheric N_2O is derived from microbially-mediated nitrification (*i.e.*, the aerobic transformation of ammonium-nitrogen (NH_4^+-N) to nitrate-nitrogen (NO_3^--N) and denitrification (*i.e.*, the anaerobic transformation of NO_3^--N to dinitrogen (N_2)) processes in soils (Smith *et al.*, 2003; Monteny *et al.*, 2006). The availability of soil mineral nitrogen (NH_4^+-N and NO_3^--N), soil temperature, and soil moisture are the primary factors influencing N_2O emissions (Firestone and Davison, 1989; Zheng *et al.*, 2000; Dalal *et al.*, 2003; Zou *et al.*, 2005).

Forests are a major component of the terrestrial ecosystem, covering approximately one third of the global land surface (Li *et al.*, 2000). Forest soils can function as either a source or a sink of atmospheric N_2O and perform a vital function in the processes regulating global climate change (Bowden *et al.*, 2004; Rosenkranz *et al.*, 2006; Billings, 2008). Emissions of N_2O from forest soils have been estimated to be 2.88–7.42 Tg N $year^{-1}$ (Papen and Butterbach-Bahl, 1999; Brumme *et al.*, 2005). Han *et al.* (2012) reported that at the global scale, N_2O emissions account for an average of 0.47 kg N ha^{-1} $year^{-1}$ from forest soils, declining gradually from low latitudes to high latitudes. Annual soil emissions of 0–2 kg N ha^{-1} $year^{-1}$ were also reported from drained pine-dominated forests in eastern and central Finland (Martikainen and de Boer, 1993; Laine *et al.*, 1996). The magnitude of the contribution

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of forest ecosystems to the global sources of N_2O was based on a relatively small number of published datasets (Breuer *et al.*, 2000). Compared to numerous observational data available for greenhouse gas emissions in temperate and tropical forests (Breuer *et al.*, 2000; Hahn *et al.*, 2000; Yan *et al.*, 2008), limited information on N_2O emissions has been reported in subtropical forests (Mo *et al.*, 2006; Su *et al.*, 2012).

The FAO (2001) estimated that subtropical forests contribute 9% of the global forests' N_2O emissions. Masson pine (*Pinus massoniana* Lamb.) is a species of pine that is native to a wide area of central and southern China. It is considered the most important commercial species for fiber and solid wood products. The Masson pine is also a common tree grown for fast-growing plantation forestry in southern China. According to the seventh national forest resources inventory of China, the area of Masson pine plantations in China was 3.36 million ha (Zhang *et al.*, 2012). However, few studies have been carried out to observe N_2O emissions in the Masson pine-growing region in subtropical central China (Su *et al.*, 2012). Therefore, long-term observations of N_2O emissions from Masson pine forests in subtropical China are needed. Such research not only contributes to the understanding of background N_2O emissions from Masson pine forests in the region but also helps to improve the national greenhouse gas inventory for subtropical forests.

In this study, we conducted a 3-year (2010–2012) monitoring experiment of N_2O emissions from a Masson pine forest soil in a typical hilly red-soil region in Hunan Province, China. The objectives of this study were: i) to provide gap-filling information on N_2O emissions from this typical forest region and ii) to establish a regional prediction model to estimate the N_2O fluxes from soils in the Masson pine-growing region in subtropical central China using known environmental factors.

MATERIALS AND METHODS

Site description

The experimental site was located in a typical hilly region of subtropical central China (Jinjing in Changsha County of Hunan Province, China, 28°32′50″ N, 113°19′58″ E, elevation 52 to 445 m). The region has a typical subtropical monsoon climate with a mean precipitation of 1 330 mm and a mean annual air temperature of 17.5 °C (1979–2012). The precipitation at the site has an uneven temporal distribution, mainly concentrated in April, May, and June (Li *et al.*, 2013). The wet season typically lasts from March to September, and the dry season covers from October to February. It also has four distinct seasons of spring (March to May), summer (June to August), autumn (September to November), and winter (December to February). A Masson pine plantation (5–15 years old with approximately 40 000 kg dry matter ha^{-1} of aboveground biomass) was selected to observe soil N_2O fluxes. The selected site was representative of the hilly red-soil region of southern China. For the canopy, the average leaf area index of the Masson pine trees was 2.35 m^2 m^{-2}. Moreover, the soil surface was covered with a thin thatch layer of Masson pine leaf needles. The soil is an acidic red soil (Ultisol, Chinese System Taxonomy), a typical subtropical soil developed from highly weathered granite parental materials. The basic properties of soil at depths of 0-10 and 10-20 cm at the study site are listed in Table I.

Field experimental design

Since January 1, 2010, nine static opaque chambers in total have been installed at three positions (shoulder, backslope, and footslope) with three replicates on a hillslope with a slope of approximately 30° in a Masson pine forest (approximately 100 ha) to measure N_2O emissions from the soil. The static opaque chambers were set at approximately 10-m intervals at each position. The gas sampling was carried out between 9:00 and 11:00 a.m. of local time at approximately one-week intervals from January 2010 to December 2012. Once a year, the stainless steel sampling bases were moved to positions approximately 2–5 m away from their previous positions.

Measurement of N_2O flux

N_2O fluxes from the soil were performed simultaneously using static opaque chambers (made of stainless

TABLE I

Basic properties of soil in the Masson pine forest studied in Jinjing, Changsha County of Hunan Province, China

Depth	Organic C	Total N	Total P	pH	Bulk density	Water content at field capacity	Clay content	Saturated hydraulic conductivity
cm	g C kg^{-1}	g N kg^{-1}	g P kg^{-1}		g cm^{-3}	cm^3 cm^{-3}	g kg^{-1}	cm d^{-1}
0–10	23.20	0.89	0.20	4.29	1.38	0.28	2.49	106.24
10–20	7.42	0.26	0.23	4.46	1.40	0.31	2.67	23.64