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Quantification of year-round methane and nitrous oxide fluxes in a typical alpine shrub meadow on the Qinghai-Tibetan Plateau

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ABSTRACT

Alpine meadows are the largest grasslands in China. Greenhouse gas exchanges between alpine meadows and the atmosphere are highly uncertain due to the lack of year-round flux measurements. In this study, the methane (CH_4) and nitrous oxide (N_2O) fluxes in an alpine *Potentilla fruticosa* shrub meadow in the Qinghai-Tibetan Plateau were investigated using the static, opaque chamber-gas chromatography method between April 2012 and April 2015. The annual CH_4 uptake (1.33–1.35 kg C ha^{-1} yr^{-1}) and Q_{10} value (1.79) were at the low end of the range for natural grasslands in China, which indicated that global warming at the same extent would result in less of an increase in the CH_4 sink in the Qinghai-Tibetan Plateau, compared to other grassland areas. The N_2O emissions during the spring thaw period showed a tremendous inter-annual variation (0.03 to 0.14 kg N ha^{-1}), which was closely linked to the variation in annual precipitation, especially the precipitation of the previous growing season. The high substrate concentrations and soil moisture during the spring thaw periods together provided the conditions for pulse N_2O emissions. When the pulse N_2O emissions occurred, emissions from the non-growing seasons dominated (67–74%) the annual total emissions. Thus, a proper sampling frequency (daily to weekly measurements) in non-growing seasons was needed for the quantification of annual fluxes. Four gas chromatographic set-ups (the Ar-CH_4, N_2-ascarite, N_2-CO_2, and pure N_2 methods) were adopted for N_2O flux measurements over natural grasslands in China. Using the N_2-CO_2 method, the annual N_2O emissions from the alpine shrub meadow were quantified to be only 0.18–0.27 kg N ha^{-1} yr^{-1} in the present study. Based on measurements using the first three of the four gas chromatographic set-ups, the conclusion that can be drawn is that unfertilized natural grasslands in China function as marginally weak N_2O sources, whereas the pure N_2 method may remarkably overestimate the emissions.

1. Introduction

Grasslands are the dominant ecosystems in China, accounting for approximately 40% of the national land area. As the largest grasslands in China, alpine meadows, with an area of approximately 64 million ha, are widespread on the Qinghai-Tibetan Plateau (Zhang et al., 2010). The Qinghai-Tibetan Plateau is the highest natural geographical unit in the world, with an average altitude of over 4000 m, and a total area of 2.5 million km^2. Alpine meadows are one of the dominant ecosystem types on the Qinghai-Tibetan Plateau, covering 27% of the plateau area (Hu et al., 2010; Wei et al., 2015). The *Kobresia* (*Kobresia humilis*, *Kobresia pygmaea* and *Kobresia capillifolia*) and *Potentilla fruticose* are the typical zonal vegetation of alpine meadows. Alpine meadows support the development of animal husbandry, and are also extremely important for carbon sequestration, water resources and biodiversity. Because of harsh climatic conditions, the alpine meadows are fragile and sensitive to climate change and human activities. Ongoing climate change, intensified activities of subterranean rodents (plateau zokor and pika), and overgrazing result in the degradation of alpine meadows. Degradation of the alpine meadows may have altered ecosystem communities and vegetation productivity, leading to the release of soil carbon and nitrogen (Zhang and Liu, 2003; Li et al., 2014), and intensifying the exchanges of greenhouse gases, such as methane (CH_4) and nitrous oxide (N_2O) (Zhang et al., 2014; Li et al., 2015; Zhao et al., 2017). The accurate quantification of greenhouse gas fluxes in alpine meadows is important to evaluate the effects of global change on ecosystems in the Qinghai-Tibetan Plateau, and their feedbacks to climate change.

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Due to the cold climate in the alpine meadows of the Qinghai-Tibetan Plateau, measurements of the biosphere–atmosphere exchange of CH_4 and N_2O in the non-growing seasons (which last up to seven months per year) were either missing or carried out with very low measurement frequency. Previous intensive flux measurements have exclusively concentrated on the growing seasons (Jiang et al., 2010; Wei et al., 2012, 2015; Zhang et al., 2014; Zhu et al., 2015). Wang et al. (2014) and Wei et al. (2015) simply assumed a ~30% contribution from the non-growing seasons to extrapolate the CH_4 uptake in growing seasons to the annual cumulative uptake. Although Du et al. (2008) and Hu et al. (2010) carried out flux measurements in the non-growing seasons, the extremely low measurement frequencies (once or twice per month) did not allow capturing the short term flux dynamics during periods with freeze-thaw cycles (Holst et al., 2008). Due to the lack of observations in high temporal resolution during the non-growing seasons, large uncertainties may exist in the estimates of annual fluxes in the alpine meadows of the Qinghai-Tibetan Plateau.

Amongst previous measurements of N_2O fluxes with the static chamber method, different gas chromatographic set-ups have been used, yielding conflicting results. Previous measurements of N_2O emissions from natural grasslands in China involved four different gas chromatographic set-ups: (I) the N_2-CO_2 method (Wei et al., 2012, 2014; Chen et al., 2013; Zhang et al., 2014), in which a pure nitrogen gas (N_2) was used as a carrier gas, and a mixed gas of carbon dioxide (CO_2) and N_2 (10% CO_2 in N_2) was introduced directly into the electron capture detector (ECD) cell as a make-up gas; (II) the N_2-ascarite method, in which N_2 was used as the carrier gas while ascarite (coated sodium hydroxide particles) was added to the injection port to remove CO_2 and water from the air samples (Holst et al., 2007, 2008; (III) the Ar-CH_4 method (Pei et al., 2003; Jiang et al., 2010), in which a mixture gas of CH_4 and argon gas (Ar) (with 5–10% CH_4 in pure Ar) was used as a carrier gas; and (IV) the pure N_2 method (Wang et al., 2005; Du et al., 2006, 2008; Lin et al., 2009; Li et al., 2012a, b), in which pure N_2 was used as a carrier gas without any additional make-up gases or treatments for gas samples. For air samples with a stable N_2O concentration but variable CO_2 contents, a comparison study in the laboratory showed reliable and comparable N_2O fluxes among the N_2-ascarite and Ar-CH_4 methods, whilst the pure N_2 method significantly overestimated the N_2O fluxes, with the bias magnitudes increasing with CO_2 concentrations (Zheng et al., 2008). In a field comparison study conducted in croplands, the pure N_2 method was found to significantly overestimate the low ($< 200\ \mu g\ N\ m^{-2}\ h^{-1}$) N_2O fluxes compared to the N_2-ascarite method (Zheng et al., 2008). Unfortunately, many of the N_2O flux measurements in alpine grasslands have been conducted using the pure N_2 method (Du et al., 2008; Lin et al., 2009; Li et al., 2012a, b), which might have resulted in a significant overestimate of the emissions.

Both of these problems seriously hamper the accurate quantification of CH_4 and N_2O fluxes in alpine meadows of the Qinghai-Tibetan Plateau. Thus, there is a necessity to conduct year-round flux measurements in the alpine meadows using any of the N_2-CO_2, N_2-ascarite, and Ar-CH_4 methods, with frequencies high enough to capture the temporal dynamics of fluxes during the spring thaw periods. In this study, the CH_4 and N_2O fluxes in a typical alpine *Potentilla fruticosa* shrub meadow in the eastern Qinghai-Tibetan Plateau were investigated using the static chamber-gas chromatography method (the N_2-CO_2 method), with intensive field observations over 2.5 years. The *Kobresia* meadow and *Potentilla fruticosa* shrub meadow are the dominant types of alpine meadows in the Qinghai-Tibetan Plateau (Li et al., 2006; Yashiro et al., 2010). The former distributes on the sunny slope of the valley and the valley floor, whereas the latter locates in the shady slope of the valley and the floodplain. In spite of a relatively simple plant community, the *Potentilla fruticosa* shrub meadow has very high productivity, and thus becomes a fine pasture traditionally utilized for grazing (Wang et al., 1991). The aims of this study were to (a) characterize the year-round dynamics of the CH_4 and N_2O fluxes and the major drivers for the variations; (b) evaluate the importance of fluxes in the non-growing seasons to the annual totals; (c) accurately quantify the annual fluxes of both gases in the extensively distributed alpine shrub meadow of the Qinghai-Tibetan Plateau; and (d) assess the effects of improper measuring methods on the quantification of annual fluxes in natural grasslands.

2. Materials and methods

2.1. Experimental site

The experimental site (37°38′27.720″N, 101°19′7.572″E; altitude: 3260 m) is located approximately 3 km north of the Haibei Alpine Meadow Ecosystem Research Station in Qinghai province, China. The experimental area (100 ha) extends along a river valley, and the landscape is therefore completely flat. The vegetation is composed of a shrub and herbaceous layer. The shrub coverage varies within 90–98%, with heights ranging from 24 to 64 cm. The shrub layer is dominated by *Potentilla fruticosa*. The plant species of the herbaceous layer mainly include *Kobresia humilis*, *Elymus nutans*, *Ligularia sagitta* (Maxim.) Maettf., *Polygonum viviparum* Linn. and *Anaphalis lactea* Maxim. The rotational grazing system (summer and winter-grazing pastures) has been applied since the 1960s. The *Potentilla fruticosa* shrub meadow has been utilized as a winter-grazing pasture. Therefore, grazing has been forbidden since then between June and August, but Tibetan sheep graze during the daytime from September to May of the following year. The stocking rate is approximately 5.4 sheep unit ha^{-1} during the grazing period, being equal to 4.0 sheep unit $ha^{-1}\ yr^{-1}$. The soil is a Mol-Cryic Cambisol corresponding to a Gelic Cambisol with a pH of 8.3 ± 0.1 (0–10 cm, mean ± standard error) and a bulk density of 0.95 ± 0.07 (0–4 cm). The soil organic carbon, total nitrogen, and texture are listed in Table 1. The research area is subject to a continental monsoon climate, with a long cold winter and a short cool summer (Zhou et al., 2006). The growing season typically begins in early May and ends in late September (Li et al., 2004). Between 1980 and 2012, the annual precipitation amounted to 527.9 mm on average, of which about 80% fell in the growing seasons, while the annual average air temperature was −1.3 °C (Zhang et al., 2014).

2.2. Gas flux measurements

The gas flux measurements were carried out during the period from 21 April 2012 to 21 April 2015, using the static opaque chamber-gas chromatography method (Zhang et al., 2014). Six spatial replicates (at least 30 m away from each other) were randomly selected for flux measurements. A chamber base frame made of stainless steel (length × width × height = 0.5 × 0.5 × 0.15 m) was permanently inserted into the soil at each spatial replicate. Prior to air sampling, a stainless steel chamber (length × width × height = 0.5 × 0.5 × 0.4 m), covered with thermal isolating styrofoam and radiation reflecting tinfoil to prevent dramatic temperature changes in the headspace during chamber closure, was mounted onto the fixed base frame. Rubber strips were used for gas-tight sealing between the base frame and the chamber.

Table 1
The properties of the soil profiles in the experimental alpine shrub meadow.

Soil depth (cm)	SOC ($g\ kg^{-1}$)	TN	Sand (%)	Silt	Clay
0–20	26.7 (0.7)	2.9 (0.04)	39.2 (1.1)	43.8 (1.0)	17.0 (0.5)
20–40	20.8 (2.7)	2.3 (0.1)	38.7 (0.8)	45.5 (0.9)	15.8 (0.4)
40–60	18.8 (1.8)	2.2 (0.2)	37.0 (1.7)	45.4 (1.4)	17.6 (0.5)
60–80	17.9 (1.6)	2.1 (0.2)	30.4 (2.0)	49.0 (1.0)	20.6 (1.1)
80–100	18.1 (1.1)	2.0 (0.1)	30.2 (0.7)	47.2 (0.5)	22.6 (1.0)

SOC: soil organic carbon content; TN: total nitrogen content; Sand, silt and clay: sand (0.02–2 mm), silt (0.002–0.02 mm) and clay (< 0.002 mm) contents. The values in parentheses indicate the standard error of five spatial replicates.