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The impact of excretal returns from yak and Tibetan sheep dung on nitrous oxide emissions in an alpine steppe on the Qinghai-Tibetan Plateau

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ABSTRACT

This study describes the impact of excretal returns derived from livestock dung on nitrous oxide (N_2O) emissions in a grazed alpine grassland ecosystem. N_2O flux, vegetation and soil characteristics were measured in an alpine steppe on the Qinghai-Tibetan Plateau. Measurements were obtained from control (CK) plot and experimental plot to which either yak dung (YD) or Tibetan sheep dung (SD) was added. We found significantly lower surface soil temperature and higher soil moisture in the YD plot than in either the CK or SD plot. The application of YD resulted in significantly less biomass of aboveground vegetation, lower carbon and nitrogen uptake, and significantly higher cumulative N_2O emission in comparison to the CK or SD treatment. N_2O from SD treatment was probably mainly produced via nitrification, while N_2O from YD treatment was primarily produced by denitrification. Emission factors of N_2O for both YD and SD were far lower than the default values proposed by the IPCC and the release of N_2O from YD and SD patches is low.

1. Introduction

Nitrous oxide (N_2O) is one of the most important greenhouse gases contributing to global warming, exhibiting almost 300 times the global warming potential of carbon dioxide (CO_2). Atmospheric concentration of N_2O has increased from a pre-industrial level of 270 ppb to 319 ppb in 2005 (IPCC, 2007). Furthermore, agricultural N_2O emissions, which comprise ~42% of anthropogenic N_2O emissions, are projected to increase by 35–60% by 2030 as a result of the greater use of nitrogen (N) fertilizers and the intensification of animal production (IPCC, 2007; Van Groenigen et al., 2010). Research has shown that N_2O from excreta deposition comprises 85% of the total anthropogenic N_2O emissions in New Zealand (Saggar et al., 2004), and 22% of the total N_2O emission from UK grasslands (Yamulki et al., 1998).

In grassland ecosystems, large amounts of nitrogen (N), equivalent to 75–90% of the N intake of grazing animals, are returned to the soil as excreta. Hence, excreta deposition is considered to be one of the most important sources of N in natural grasslands (Jørgensen and Jensen, 1997; Saarijarvi and Virkajarvi, 2009; van der Weerden et al., 2011). In addition, dung has the potential to increase the availability of other nutrients in the soil, as well as to stimulate soil microbial activity. However, N returns in the dung patches generally beyond short-term plant needs, resulting in the loss of N via leaching and gaseous releases. Dung patches have, therefore, been regarded as active hot spots for N_2O emissions (Flessa et al., 1996; Ma et al., 2006).

N_2O released from soil is primarily produced by two biological processes: nitrification and denitrification (Granli and Bockman, 1994). As a type of organic manure, the addition of dung to soil is thought to create the ideal conditions for denitrification (enhanced oxygen consumption and increased labile organic C and N-substrate concentrations) (Granli and Bockman, 1994; Lovell and Jarvis, 1996). On a grassland site in Germany, Wachendorf et al. (2008) reported that N_2O emission stimulated by the addition of cattle dung was 3.50 kg N ha^{-1}, with an emission factor of 0.33%. A similar rate of dung-derived N_2O emission (1.93 kg N ha^{-1} and an emission factor of 0.28%) was also recorded in eastern Finland on a pasture following the addition of cattle dung. In contrast, much lower effects of cattle dung on N_2O emissions and emission factors have been reported in the other studies (Yamulki et al., 1998; van der Weerden et al., 2011; Hoeft et al., 2012).

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While much is known about the effects of cattle dung deposition on N_2O emissions, fewer studies have examined the effects of sheep dung deposition on N_2O emissions, and far fewer still have compared the effects of cattle and sheep dung deposition in a particular region (Saggar et al., 2004; Hoeft et al., 2012). Sheep dung added to a temperate grassland in Germany resulted in the increment of N_2O emission of 0.10 kg N ha^{-1} and an emission factor of 0.09% (Hoeft et al., 2012). Meanwhile, emission factors for dung deposition recorded in several sheep farms in New Zealand varied from −0.10% to 0.12% (van der Weerden et al., 2011). In addition, the majority of studies to date have been conducted on managed grasslands at low altitudes, with little research undertaken on natural grasslands at high altitudes, which also play an important role in the global terrestrial ecosystem and are extremely sensitive to climate change and human activities (Yamulki et al., 1998; Maljanen et al., 2007; Gao et al., 2009; Lin et al., 2009; Cai et al., 2013a). For this reason, the observations of excreta-derived N_2O emissions from diverse livestock in natural grasslands at high-altitude are urgently needed to obtain more accurate estimates of N_2O budgets on regional scales.

The Qinghai-Tibetan Plateau is the largest grassland ecosystem in the Eurasian continent and spans an area of approximately 2.5 million km^2. The plateau has an average altitude >4000 m above sea level and contains a large proportion (32% of the total area of alpine grassland) of alpine steppe vegetation (Geng et al., 2012). Recently, there has been growing concern over the nutrient dynamics owing to grassland degradation, climate change, and the rapid expansion of livestock grazing, in addition, overgrazing of grasslands has become a major problem for environmental, social and economic issues on the plateau (Arthur et al., 2008; Cai et al., 2013a). Yak and Tibetan sheep are the two dominant livestock species on the Qinghai-Tibetan Plateau, where grazing densities on the total usable grassland (animals km^{-2}) are >1.2 for yaks and >2.8 for Tibetan sheep (Miller, 1990; Lin et al., 2009; Fu et al., 2012). A previous study conducted on an alpine meadow in the northwest of Qinghai-Tibetan Plateau, reported that N_2O emission from yak dung deposition was approximately twice that of a control plot (Lin et al., 2009). Yak dung, having larger dung patches and greater contents of moisture and available N, can result in different soil properties and N dynamics under the patches compared to sheep dung (Hoeft et al., 2012; Cai et al., 2013a). Under laboratory conditions, the cumulative N_2O emission over a 15-day incubation period of alpine steppe soil supplemented with either yak or Tibetan sheep dung was 111 and 28.7 μg N kg $soil^{-1}$, respectively. Both these values were significantly higher than the value obtained from non-treated soil (Cai et al., 2013a). Following this preliminary work, in this study we aim to establish the effects of dung deposition on N_2O emission on alpine steppe in the field, and determine the key differences between the effects of yak and Tibetan sheep dung deposition on N_2O emissions.

2. Materials and methods

2.1. Study site

The experiment was performed at the Xainza Alpine Steppe and Wetland Ecosystem Observation Station in Northern Tibet (N 30°57′, E 88°42′, 4675 m above sea level). This site exhibits a cold and semi-arid plateau monsoon climate, with an average annual temperature of 0 °C and average annual precipitation of 300 mm. Most rain falls from May to September, which is know as the main vegetation period. Frosts occur over a period of up to 279 days, and there is no absolute frost-free season. The alpine steppe vegetation is dominated by *Stipa purpurea* and the soil type is classified as ‘Cryic Aridisols’ according to Chinese soil taxonomy (Gong, 1999). The upper soil layer has a pH value of 8.72 and is comprised of 91% sand, 7% silt and 2% clay. The density of fine soil is 1.52 g cm^{-3}, and contains 0.10% total N, 0.06% total P and 0.88% organic C (Cai et al., 2013a).

2.2. Experimental methods

The experiment was conducted from 3 July to 2 September 2013. In the growing seasons until 2012, the study site was grazed by yak and Tibetan sheep. During the gas measurements in 2013, there was no grazing in this field. The experiment involved adding either yak dung (YD), Tibetan sheep dung (SD) or no dung (control, CK) to nine different plots within the study site (three replicate plots of each treatment). The experiment was in a randomized complete block design and each experimental plot measured 2 × 2 m^2. Fresh dung from yak and Tibetan sheep were manually collected from a randomly selected group of animals (8 animals of each species) located on a camping area adjacent to our study site. Grazing animals were enclosed within the camp at night and fresh dung samples were manually collected into plastic buckets the next morning. The total faeces collected from each type of animal were carefully mixed and stored for nearly 6 h at ambient temperature before the dung samples were applied on the steppe. On a dry matter basis, YD contained 32% organic C and 2.7% total N content, while Tibetan SD contained 29% organic C and 1.7% total N content. Before dung application, grasses were cut to 2 cm height to minimize the differences among experimental plots. The vegetation was not cut during the gas measurement period. On each YD plot, 1200 g of fresh dung (water content: 83.3 ± 0.38%) was placed on the soil surface in a cylindrical shape (approximately 19 cm in diameter and 4 cm high, N-rate: 472 kg N ha^{-1}). On each SD plot, 60 g fresh dung (water content: 61.7 ± 0.08%) was distributed evenly onto the soil surface to form a patch of approximately 20 cm × 11 cm (N-rate: 182 kg N ha^{-1}). Dung pats were similar to the weight and shape of dung patches that occur naturally in fields, which are thereby favorable for evaluating N_2O emissions from the studied region. Adjacent to the nine experimental plots used for emissions sampling, a further nine plots were established to determine changes in soil moisture, soil temperature, the content of inorganic N and the content of microbial biomass C (MBC) and microbial biomass N (MBN) beneath the dung pats. In these additional plots, dung pats (dimensions as above) were placed on nylon nets (mesh size 1.5 mm × 1.5 mm) that were later removed with the dung before soil sampling (Maljanen et al., 2007).

2.3. Measurement of N_2O emission

N_2O emission rates from soil were measured using the static closed chamber technique. The chamber (21 cm in diameter, 30 cm in height) was made of cylindrical polyvinyl chloride (PVC) pipe, with a small silicon-sealed vent for gas sampling and a port for measuring chamber temperature at the top of the chamber. A PVC chamber base (21 cm in diameter, 15 cm in height) was inserted into the soil to a depth of 10 cm at the center of each plot. Following this, dung was applied to the soil surface inside it. To minimize overheating, the extruding part of the chamber was covered with aluminum foil. The whole chamber was made airtight by connecting the chamber top and base with a tight rubber belt (2.7 mm in thickness) (Chen et al., 2008). N_2O measurements were taken two to three times a week between 10:00 and 12:00 am. One each occasion, four 80 mL gas samples were collected with a syringe at six minute intervals after closure of the chamber. Gas samples were immediately injected into 100 mL pre-evacuated gas collecting bags (made in Dalian, China) and delivered to the Institute of Soil Science, Chinese Academy of Sciences, for analysis within three