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Fluxes of nitrous oxide and nitric oxide from experimental excreta patches in boreal agricultural soil

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Abstract

Nitric oxide (NO) and nitrous oxide (N_2O) emissions were measured from experimental dung and urine patches placed on boreal pasture soil during two growing seasons and one autumn period until soil freezing. N_2O emissions in situ were studied by a static chamber method. NO was measured with a dynamic chamber method using a NO analyser in situ. Mean emissions from the control plots were 47.6 ± 4.5 μg N_2O–N $m^{-2} h^{-1}$ and 12.6 ± 1.6 μg NO–N $m^{-2} h^{-1}$. N_2O and NO emissions from urine plots (132 ± 21.2 μg N_2O–N $m^{-2} h^{-1}$ and 51.9 ± 7.6 μg NO–N $m^{-2} h^{-1}$) were higher than those from dung plots (110.0 ± 20.1 μg N_2O–N $m^{-2} h^{-1}$ and 14.7 ± 2.1 μg NO–N $m^{-2} h^{-1}$). There was a large temporal variation in N_2O and NO emissions. Maximum N_2O emissions were measured a few weeks after dung or urine application, whereas the maximum NO emissions were detected the following year. NO was responsible on average 14% (autumn) and 34% (summer) of total ($NO + N_2O$)–N emissions from the pasture soil. NO emissions increased with increasing soil temperature and with decreasing soil moisture. N_2O emissions increased with increasing soil moisture, but did not correlate with soil temperature. Therefore we propose that N_2O and NO were produced mainly during different microbial processes, i.e., nitrification and denitrification, respectively. The results show that the overall conditions and mechanism especially for emissions of NO are still poorly understood but that there are differences in the mechanisms regulating N_2O and NO production.
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Keywords: Agricultural soil; Dung; NH_3; Nitric oxide; Nitrous oxide; NO_3; Urine; WFPS

1. Introduction

Nitric oxide (NO) and nitrous oxide (N_2O) have important roles in the atmosphere. N_2O is a greenhouse gas with a 296 times larger global warming potential than carbon dioxide over a 100 yr time horizon (IPCC, 2001). The lifetime of N_2O in the atmosphere is 120 yr (IPCC, 2001). NO is not a greenhouse gas but it is a precursor in the formation of tropospheric ozone. NO is an important player in the chemical reactions in the troposphere where it is oxidized to NO_2 (Derwent, 1999). Re-deposition of NO and NO_2 contributes to acidification and eutrophication of ecosystems (Vitousek et al., 1997). The average atmospheric lifetime of NO is short, around 1.5 d and thus large emissions are required to maintain the actual atmospheric mixing ratios (Yamulki et al., 1995).

Soils contribute 70% and 20% to the global emissions of N_2O and NO, respectively (Conrad, 1995). Agricultural soil is the major source of N_2O, accounting for about 35% of the global annual emission (Kroeze et al., 1999; IPCC, 2001). NO originates mainly from fossil fuel combustion (40%) biomass burning (25%) and the remainder from denitrification and nitrification in soils (Bouwman, 1990). There are more data on N_2O than on NO emissions, therefore, the global estimate for NO can be more inaccurate. Annual global N_2O–N and NO–N emissions from fertilized agricultural soils have been estimated to be 2.8 and 1.6 Tg, respectively (Bouwman et al., 2002). However, there are only a few publications on how much NO is emitted from the agricultural soils (Johansson and Granat, 1984; Lång et al., 1995) or other ecosystems,

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e.g., forest soils (Lång et al., 1995; Pilegaard et al., 1999) in northern Europe.

N_2O and NO are produced in soils during microbial denitrification and nitrification (Davidson, 1991; Bouwman, 1990). Several environmental factors regulate the production of these trace gases including soil characteristics (soil drainage, soil texture, content of organic matter, soil pH), crop type, climatic factors and N-input (Bouwman et al., 2002). The emissions of both gases have high spatial, temporal and diurnal variations (Bouwman, 1990; Schindlbacher et al., 2004). Input of organic matter (e.g., dung) to the soil is one crucial regulating factor for these gases. Added organic matter enhances microbial activity, including denitrification, and the associated oxygen consumption may lead to the development of anaerobic microsites. Therefore, pasture soils can be considered as potential sources of NO and N_2O.

The purpose of this study was to investigate NO and N_2O emissions and the importance of NO in the $(NO + N_2O)$–N emissions from a boreal pasture soil. NO and N_2O emissions were measured from experimental manure and urine patches on pasture soil during two growing seasons and one autumn period.

2. Materials and methods

2.1. Study site

The study site is located in eastern Finland (63°09′N, 27°20′E). The soil type according to FAO classification is Dystric Regosol, medium textured. The content of total N is 0.12% and total P is 1.73%. The organic matter content is 5.65% and soil pH (H_2O) is 6.0. The bulk density (BD) of the soil is 1.32 g cm^{-3} and its particle density (PD) is 2.57 g cm^{-3} (depth 0–10 cm). The mean annual temperature (1971–2000) in the region is 2.8 °C and the mean annual precipitation is 609 mm, of which about 50% falls as snow. Snow cover typically appears in mid-November and melts in late April. The coldest month is February (−9.6 °C), and the warmest July (16.7 °C) (Drebs et al., 2002).

The study site (22 m × 7 m) had been used as a dairy pasture for several years. The sward was established with a mixture of timothy (*Phleum pratense* L., 8.4 kg ha^{-1}) and meadow fescue (*Festuca pratensis* Huds., 11.6 kg ha^{-1}) in spring 2000. In the growing seasons 2001 and 2002 the study site was grazed by dairy cows (Holstein-Fresian) at a stocking rate of 4.5 cows ha^{-1}. During the gas measurements in 2003 and 2004 there was no grazing in this field. Grazing was then simulated by cutting the grass (in 2003: 10 June; 26 June; 16 July; 6 August; 25 August and in 2004: 14 June; 6 July; 30 July). On 20 May 2003 the site received a surface fertilization (kg ha^{-1}) of N (88), P (15) and K (25). Fertilization was repeated on 27 June 2003 with N (80) and K (60) and again on 23 July 2003 with N (52), P (8) and K (23). On 25 May 2004 the site received (kg ha^{-1}) N (90) and on 7 July 2004 N (80) and K (60).

2.2. Experimental set-up

For the gas flux measurements, PVC collars (inner diameter 17.6 cm, height 12 cm) were inserted into the soil to a depth of 9 cm. On 26 June 2003, five control, five urine (0.182 l plot^{-1}, equals to 58.31 g N m^{-2}) and five dung (0.460 kg plot^{-1}, equals to 83.62 g N m^{-2}) experimental patches (referred to I urine or I dung) were established inside the collars. Three extra urine and three dung plots were made to permit soil sampling outside the collars. Dung and urine from dairy cattle were collected directly from the cows with plastic buckets. Cows were grazing 25 kg dry matter d^{-1}, and in addition they were fed 6 kg concentrates per day. Total N from dung and urine was analysed by Kjeldahl method (Kemppainen, 1989). Collected urine and dung were pooled and weighted for each dung or urine plot and they were applied on the soil within 2 h. Dung pat for soil sampling was placed over a plastic net (mesh size 1.3 mm × 1.3 mm), which was removed with the dung before soil sampling. On 10 September 2003, new patches (referred to II dung or II urine) were established with three replicates for urine, and three replicates for dung. Three control plots were left without excreta. All plots were fertilized with mineral fertilisers as described above. During the growing season, the grass inside and outside the collars was cut to simulate the normal grazing cycle. In summer 2004, no new experimental patches were applied.

Measurements of NO emissions from control soil and urine- and dung patches started in June 2003, 30 min after the experimental patches were applied. Emissions from these patches were measured thereafter once a week for three months. N_2O emissions in summer 2003 were measured only from control plots. In the autumn 2003, starting from September 10, immediately after application of new patches, the emissions of N_2O and NO were measured from the same PVC collars. Gas measurements from these collars continued until the beginning of November and started again in spring 2004 continuing until the end of August 2004. NO or N_2O emissions were not measured during the winter (from December to April).

2.3. Environmental variables

The volumetric soil moisture was determined using Theta Probe (type ML2, Delta-T-Devices, UK) during each measurement for the calculation of water filled pore space (WFPS):

$$\mathrm{WFPS} = \frac{\text{volumetric soil moisture}}{(1 - (\mathrm{BD}/\mathrm{PD}))} * 100 \quad (1)$$

where BD is soil bulk density and PD is soil particle density.

Air and soil temperatures (depths of 3, 5, 10 and 15 cm) were measured using a YC-260 thermometer and a temperature probe (YCT, Taiwan). Daily precipitation

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