Soil Biology & Biochemistry 37 (2005) 463–473
Soil Biology & Biochemistry
www.elsevier.com/locate/soilbio

Nitrous oxide emission from urine-treated soil as influenced by urine composition and soil physical conditions

Jan Willem van Groenigen*, Peter J. Kuikman, Willy J.M de Groot, Gerard L. Velthof

Soil Science Center, Alterra, Wageningen University and Research Center, Droevendaalsesteeg, P.O. Box 47, Wageningen, 6700 AA, The Netherlands

Received 25 February 2004; received in revised form 11 June 2004; accepted 10 August 2004

Abstract

Urine patches from cattle and sheep on pastures represent considerable, highly localized N applications. Subsequent nitrification and denitrification of the nitrogenous compounds may result in high nitrous oxide (N_2O) emissions. Not much is known about the extent of these emissions, or about possible mitigation options. The aims of this study were to experimentally quantify the effects of urine composition, dung addition, compaction and soil moisture on N_2O emissions from urine patches. For an incubation study at 16 °C, soil was collected from a typic Endoaquoll, and N_2O production was monitored during a 103-day period. Emissions for the whole period averaged 0.3 and 0.9% of the applied urine-N for dry and moist soil, respectively. When compacted or when dung was added, emissions from moist soils increased to 4.9 and 7.9%, respectively. Both addition of dung and soil compaction resulted in a delay of the peak N_2O emission of approximately 10–15 days. No significant effect of amount of urine-N on emission percentages was detected. Changing the volume of urine with equal amounts of urine-N resulted in highly significant effects, peaking with an emission of 2.3% at a water-filled pore space (WFPS) of 78%. When the soil was water-saturated, N_2O production was delayed until evaporation had decreased moisture contents. We concluded that denitrification was the main N_2O forming process in the incubation study. Emission factors for urine reported in the literature do not generally include the potentially considerable effects of compaction or combination with dung. We conclude that realistic emission factors should take into account such an effect, together with estimates for the occurrence of camping areas in pastures. From our results, the best mitigation strategies appear to be increasing the volume of urine through feed additives, and avoiding compaction and promoting more homogeneous application of N through a lower cattle stocking rate. Also, research efforts may be targeted at management practices to avoid camping areas in pastures.

Keywords: Climate change; Mini-review; Urine; Emission factors; Dung; Compaction

1. Introduction

Urine patches and cattle droppings on grasslands represent high, very local additions of nitrogen (N) and readily available carbon (C) that can create optimal conditions for nitrous oxide (N_2O) emissions. Emissions from grazed grassland are generally higher than for ungrazed grassland, and both have normally higher emissions than arable fields or natural ecosystems (Smith et al., 1998). Flessa et al. (1996) estimated the total global N_2O emission from droppings of cattle, buffalo and bison at around 1.18×10^{12} g N_2O-N yr^{-1}, or approximately 16% of the global anthropogenic N_2O flux (IPCC, 2001). In countries that depend economically to a large extent on livestock farming, these fluxes may dominate their greenhouse gas budget. For example, in New Zealand N_2O emissions from urine voided in pastures account for about 52% of the anthropogenic flux (De Klein et al., 2001).

Application of urine on pastures leads to a relatively fast ($\sim$1 d) increase in pH of up to 3 pH units due to hydrolysis of urea to NH_4^+. During this period, a significant portion of NH_4^+ may be lost due to NH_3 volatilization. Bussink and Oenema (1998) concluded from a literature review that these losses may vary between 4 and 44% of applied urine-N. Subsequent nitrification of the remaining NH_4^+ to NO_3^- leads to a decrease in pH over a period of $\sim$2 weeks (Doak, 1952; Haynes and Williams, 1992).

* Corresponding author. Tel.: +31 317 474 784; fax: +31 317 419 000.
E-mail address: janwillem.vanGroenigen@wur.nl (J.W. van Groenigen).

0038-0717/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.soilbio.2004.08.009

Nitrous oxide may be emitted through both nitrification and through subsequent denitrification of the formed NO_3^-. In a literature review, Oenema et al. (1997) estimated that between 0.1 and 3.8% of urine-N is emitted to the atmosphere as N_2O. For dung, this value varied between 0.1 and 0.7% of the applied N. The Intergovernmental Panel on Climate Change (IPCC) identified a default urine-N emission factor of 2.0% (Mosier et al., 1998a; IPCC, 2000). However, there is some concern that studies that work with artificial urine rather than real urine may overestimate emission factors (De Klein et al., 2003). Similar concerns may be formulated for incubation studies vs. field studies.

A number of factors may control the emission factor from urine-N, and may, therefore, be addressed in mitigation strategies. Several studies have mentioned the possible importance of compaction in forming local hot-spots of N_2O emission from pastures (Anger et al., 2003; Carran et al., 1995; Clayton et al., 1994). Compaction may result in higher anaerobicity through lowering gas diffusivity and increasing the water-filled pore space (WFPS) (Ball et al., 1999). The addition of dung, which contains easily available C, may also lead to anaerobicity through increase rates of O_2 consumption. Anaerobic conditions, in turn, may affect both nitrification and the N_2O/N_2 ratio of denitrification. The combined effects of compaction, urine and dung in trampling areas within the field may, therefore, to a large effect control total N_2O emissions from pastures. However, very little experimental data is available to quantify this effect (Oenema et al., 1997).

Also, lowering the N concentration in urine or the total amount of urine-N through different fodder, feed additives or grazing regimes may have a significant effect on N_2O emission factors (Oenema et al., 1997). Decreasing the cattle stocking rate with subsequent application of slurry over the pasture results in better distribution of N in both spatial and temporal terms. For grassland, temporal spreading is especially useful since the rooting system is well developed throughout the year, and mineral N content of the soil can, therefore, be kept relatively low (Dalal et al., 2003; Mosier et al., 1998b). In addition, slurry may be applied in ways that minimize N emissions (Huijsmans et al., 2003).

The aims of this study were to experimentally quantify the effects of urine composition, dung addition, compaction and soil moisture on N_2O emissions from urine patches. For this aim, an incubation study was set up, during which N_2O emissions were quantified for 103 days.

2. Emission factors for urine patches in pastures: a short review

Table 1 summarizes the reported emission factors in the literature for urine patches in pastures and the main experimental parameters. This constitutes an updated and more elaborate version of the tables presented by both Oenema et al. (1997) and Mosier et al. (1998a), since the body of literature on the subject has roughly doubled over the last few years. Only studies where N_2O emissions derived solely from (artificial) urine-N were reported were included. Therefore, confounding factors such as compaction or addition of dung are not included. The body of literature is relatively small and represents a large range in terms of soil type, experimental setup, urine type and duration of the experiment. The median emission factor over all 22 studies is 1.3% (Table 2; for ranges reported in the literature, the average range value is used in calculating the average and median; when only an upper limit is reported, the results are treated as a range between zero and the upper limit). When the results are split out between field and incubation studies and between animal urine and artificial urine, the more realistic conditions result in lower median emission factors of around 0.9% (Table 2).

3. Materials and methods

3.1. Experimental setup

In April 2000, soil from 0 to 20 cm depth was collected from a sandy profile (typic Endoaquoll; 2% clay, 23% silt, 75% sand) for an incubation study. The soil contained 1.9 and 11.1 mg NH_4^+-N and NO_3^--N per kg dry soil, respectively. Total C and N contents were 40.2 and 2.01 g kg^{-1} dry soil, and the pH_{water} was 5.1. The soil was mixed and sieved, and 1 l Mason jars were filled with 500 g of the moist soil. Table 3 lists the different treatments, which were replicated twice.

Artificial urine was created following Doak (1952) using urea (88.6% of total N), hippuric acid (6.2% of total N), creatine (0.8% of total N), allantoin (1.5% of total N), ureic acid (0.4% of total N) and NH_4Cl (2.5% of total N). In addition, all artificial urine contained 14.20 g L^{-1} $KHCO_3$ and 10.50 g L^{-1} KCl, except for three treatments with lower concentrations to study possible inhibitory effects of KCl concentration on microbial processes (Table 3). The standard amount of urine was set at 50 mL kg^{-1} soil, but several treatments deviated from that in order to test the effect of urine volume on N_2O emission (Table 3). Urine was applied superficially.

A total of 50 mL water kg^{-1} soil was added to the treatments labelled dry (Table 3), resulting in combination with the 50 mL urine kg^{-1} soil gift in a volumetric moisture content of 27.3% (46% Water Filled Pore Space, WFPS). Similarly, the treatments labelled ‘moist’ were given 110 mL water kg^{-1} soil, resulting in combination with the urine in a volumetric moisture content of 36.9% (63% WFPS). The lids were loosely placed on top of the jars, allowing exchange with atmosphere. For N_2O measurements, the lids were temporarily closed (see below). The treatments were incubated at 16 °C and 65% relative air moisture content for 103 days.