Agriculture, Ecosystems and Environment 188 (2014) 103–110

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Controls of nitrous oxide emission after simulated cattle urine deposition

Khagendra Raj Baral*, Anton G. Thomsen, Jørgen E. Olesen, Søren O. Petersen

Department of Agroecology, Aarhus University, Blichers Allé 20, PO Box 50, DK-8830 Tjele, Denmark

ARTICLE INFO

Article history:
Received 14 December 2013
Received in revised form 25 February 2014
Accepted 27 February 2014
Available online 15 March 2014

Keywords:
Urine
Nitrous oxide
Dicyandiamide
Chamber support
Soil gas sampling

ABSTRACT

Urine deposited during grazing is a significant source of atmospheric nitrous oxide (N_2O). The potential for N_2O emissions from urine patches is high, and a better understanding of controls is needed. This study investigated soil nitrogen (N) dynamics and N_2O emissions from cattle urine, and effects of increasing urinary N to 1000 kg N ha^{-1} or delaying nitrification by amendment of the nitrification inhibitor dicyandiamide (DCD). Soil N_2O concentration profiles and mineral N dynamics were monitored. The study was a randomized block experiment initiated in May 2012, in which urine deposition was simulated in paired field plots to accommodate all measurements. One plot had a pre-installed chamber support for N_2O flux measurements. Volumetric water content (VWC) was determined in the same position in both sub-plots, i.e., with and without chamber supports. Plant growth was monitored using ratio vegetation index (RVI). Compared to unamended urine, emissions of N_2O were significantly higher with urea-amendment, and lower with DCD amendment, also when expressed as proportions of N applied. Soil mineral N dynamics showed that N_2O emissions were closely linked to nitrification activity. There was no close relationship between N_2O emissions and concentration profiles of N_2O in the soil; instead, emissions were significantly ($p < 0.05$) related to N_2O concentrations at 5 cm depth. Chamber supports increased water retention in urine-amended soil, but not in reference soil. Based on patterns of mineral N and VWC it is proposed that nutrient retention and higher salinity in the presence of chamber supports increased water retention. This may have implications for the quantification of N_2O emissions from urine patches.

1. Introduction

Globally, livestock production emits around 1.55 Tg yr^{-1} nitrous oxide (N_2O) to the atmosphere, with a contribution of approximately 40% from urine and dung deposited during grazing (Oenema et al., 1997). This source is likely to increase as the cattle population is projected to grow from 1.5 billion in 2000 to 2.6 billion by 2050 (Rosegrant and Thornton, 2008).

The proportion of nitrogen (N) deposited during grazing that is emitted as N_2O is typically higher than from N inputs to pastures without grazing, and to arable land (Smith et al., 1998; IPCC, 2007). Often more than 70% of N intake is excreted via urine, mainly as urea (Oenema et al., 2005; Wachendorf et al., 2008; Dijkstra et al., 2013), and the concentration in urine patches may reach 1000 kg N ha^{-1} (Haynes and Williams, 1993). Typically urea hydrolysis is complete within 24 h (Petersen et al., 1998), and there is evidence that the high concentrations of ammoniacal N can lead to root scorching and microbial stress (Richards and Wolton, 1975; Lantinga et al., 1987; Monaghan and Barraclough, 1992; Petersen et al., 1998). The elevated soil water content in urine patches, the resulting oxygen demand for degradation of released carbon, and the stimulation of N transformation processes, are all factors which may contribute to higher N_2O emissions (Monaghan and Barraclough, 1993; Petersen et al., 2004a; van Groenigen et al., 2005).

Transformations of ammoniacal N via nitrification and denitrification will proceed as long as mineral N is available in the soil. During this period there is a potential for N_2O production via NH_3 oxidation, heterotrophic denitrification, or nitrifier-denitrification (Wrage et al., 2001). The relative importance of these processes for N_2O emissions is not well known. Manipulation experiments can help elucidate the importance of factors controlling N_2O emissions, e.g., urinary N composition (Oenema et al., 2005; Dijkstra et al., 2013) or nitrification activity (Di and Cameron, 2005; Kelly et al., 2008; Singh et al., 2009). Cattle urine deposition is readily simulated under field conditions where N_2O fluxes from individual urine patches can then be measured using static flux chambers (Anger et al., 2003; Bol et al., 2004; de Klein et al., 2011; Taghizadeh-Toosi et al., 2011; Ball et al., 2012). Most studies of emissions from

* Corresponding author. Tel.: +45 87154762.
E-mail address: khagendra.baral@agrsci.dk (K.R. Baral).

http://dx.doi.org/10.1016/j.agee.2014.02.029
0167-8809/

urine-affected soil have used permanent chamber supports to minimize soil disturbance during flux measurements, the assumption being that the restriction of horizontal water movements by a permanently installed support does not alter soil moisture conditions as this will influence the potential for N_2O emissions (van Groenigen et al., 2005; Lu et al., 2006; van der Weerden et al., 2012).

We conducted a field experiment simulating cattle urine deposition on a pasture dominated by ryegrass. The objectives of the study were: (a) to investigate effects of urea-N concentration and de novo NH_3 oxidation for soil N dynamics in urine patches and associated N_2O emissions; (b) to examine the distribution of N_2O production in the soil profile; and (c) to evaluate the effect of N_2O flux chamber supports on soil moisture dynamics in urine patches. We hypothesized that elevated urea in cattle urine would stimulate N_2O fluxes, and that blockage of nitrification activity would reduce N_2O emissions directly or indirectly. Chamber supports were not expected to influence soil moisture conditions.

2. Materials and methods

2.1. Site information

The study was conducted on a pasture at Research Centre Foulum, Tjele, Denmark (55°52′ N, 9°34′ E) during spring–summer 2012. The soil is classified as a Typic Hapludult and contains 77% sand, 15% silt and 8% clay. The soil pH_{H_2O} was 5.1 and electrical conductivity was 33 μS cm^{-1}. The vegetation was a mixture of ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.), but dominated by ryegrass at the time of the experiment. The field, which had not been grazed or fertilized since the previous year, was cut to 5 cm height 1 week before the study was initiated.

2.2. Urine materials

Urine was manually collected from milking Holstein-Friesian dairy cattle in the morning two days before field application. The cattle were fed a diet with grass-clover, maize silage, grass-clover silage and barley as main ingredients. It was stored in air-tight plastic containers at 2 °C to avoid hydrolysis. Sub-samples of the cattle urine were removed to determine the urea concentration (14.6 g N L^{-1}) by a colorimetric method (Mulvaney and Bremner, 1979). A urine volume of 2.5 L per simulated patch was selected (Petersen et al., 1998), corresponding to a loading rate with unamended urine of 608 kg urea-N ha^{-1}. One portion of urine was amended with 7 g N L^{-1} urea (AR grade, Merck) to give a urea-N loading of approximately 1000 kg ha^{-1} assuming 90% of urinary N was urea (Konstantinides et al., 1991; Petersen et al., 1998). Another portion was amended with dicyandiamide (DCD) corresponding to an application rate of 10 kg ha^{-1} (Zaman and Blennerhassett, 2010; Di and Cameron, 2012). The experiment was initiated on 23 April 2012 by application of urine, using a watering can with a cross bar, according to the experimental design described below.

2.3. Experimental design

The manipulation experiment was designed as a randomized block design with four treatments in three replicate blocks separated by 2 m. The treatments included; (i) an unamended control (*CTL*), (ii) unamended cattle urine (*U*), (iii) cattle urine amended with urea (*UU*), and (iv) urine amended with dicyandiamide (*UD*). To accommodate all measurements, each field plot consisted of paired identical patches (each 0.6 m × 1 m) that were separated by 40 cm. Each pair was equipped as indicated in Fig. 1.

One week before urine application, metal supports for flux chambers (35 cm × 25 cm × 15 cm) with a 20-mm flange at the top were inserted to 12–13 cm depth in one patch of each pair. Two-rod 20-cm TDR probes (Thomsen, 2006) for determination of volumetric water content (VWC) were installed inside each support frame for flux chambers, and in the corresponding position of patches without frames.

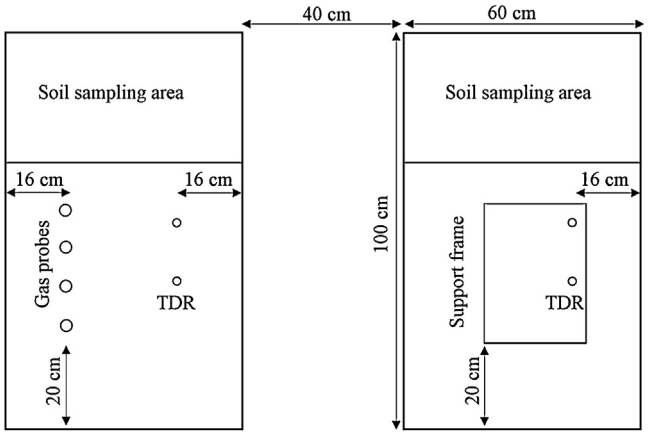

Fig. 1. Layout of a field plot comprising two urine patches. The left figure shows a pair of permanently installed TDR probes to measure volumetric soil water content outside the flux chamber supporting frame and soil gas probes to collect the subsoil gas samples. The right figure shows a pair of permanently installed TDR probes to measure volumetric water content inside the frame and the frame to support a N_2O flux chamber.

Diffusion probes for soil gas sampling (Petersen, submitted for publication) were installed at several depths one day before urine application. Only three sets of probes (5, 10, 20 and 50 cm sampling depth) were available at the time of the experiment; these were installed in treatments *CTL*, *U* and *UD* of one selected block. The gas sampling probes (o.d., 16 mm) contain a 10-mL diffusion cell connected to the surrounding soil via a silicone membrane of 3 mm diam. at the sampling depth. The diffusion chamber is equipped with two 1/16″ stainless steel tubes with luer fittings for flushing the diffusion cell at sampling. For installation, holes of similar diameter were made with an auger to near the sampling depth, and probes were then inserted to final position with a wooden hammer.

2.4. Field measurements

Manual measurements of soil VWC took place 0.13, 1, 2, 6, 9, 15, 21 and 28 days after urine application using a TDR100 instrument (Campbell Scientific, Logan, UT, USA) and a robust Allegro (DOS) field computer (Juniper Systems, Logan, UT, USA) using ManTDR software (Thomsen, 2006).

Concurrently with measurements of soil water content, N_2O fluxes were measured using static chambers (35 cm × 25 cm × 25 cm) insulated by 12 mm Thermaflex with a reflecting surface (12 mm thickness) to avoid temperature changes during deployment (Bol et al., 2004). The chambers were vented via a PVC tube (24 cm length, 7.5 mm internal diam.) extending to an opening beneath the Thermaflex cover, and equipped with a rubber septum for gas sampling. Both chamber bases and flux chambers had a 10 mm wide and 4 mm thick rubber seal; a brick weighing approximately 3 kg were placed on top of each chamber during measurements to ensure a tight seal. Gas samples were taken with a 10-mL syringe five times during *c.* 1 h, the first sample at time zero and subsequent samples at 15-min intervals. Ten-mL gas samples were transferred to 6-mL Exetainers (Labco, High Wycombe, UK).

To determine soil NH_4^+ and NO_3^-, pH, EC and gravimetric water content, six soil cores (20 cm depth, 20 mm diam.) were taken randomly outside the area used for flux measurements, avoiding