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N_2O emissions from urine-treated tropical soil: Effects of soil moisture and compaction, urine composition, and dung addition

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ABSTRACT

Increasing attention is being paid to the importance of N_2O emissions due to livestock activities in tropical countries. Understanding the key variables driving N_2O emission could help minimize impacts of N_2O release and improve the accuracy of N_2O inventories. We aimed to investigate the effects of soil moisture, soil compaction, urine composition, urine volume, and dung addition on N_2O emissions from a urine-treated tropical Ferralsol under controlled conditions. Manipulated soil conditions (e.g., moisture content, compaction, and dung addition) affected N_2O emissions when varying quantities of urine-N ($p = 0.02$) were applied (urine volumes remained equal) and when varying urine volumes ($p = 0.04$) were applied (quantities of urine-N remained equal). When the amount of urine-N applied was varied, the estimated N_2O emission factor (EF) was 3.14 ± 0.70%, 2.29 ± 1.25%, 3.90 ± 0.64%, 4.73 ± 0.88%, and 6.62 ± 1.10% for moist soil, dry soil, compacted soil, plus dung, and plus dung and compacted soil treatments, respectively. While varying the volume of urine, the estimated N_2O EF was 4.96 ± 1.66%, 4.27 ± 1.42%, 3.99 ± 1.19%, 6.50 ± 0.35%, and 7.37 ± 0.76% for moist, dry soil, compacted soil, plus dung, and plus dung and compacted soils treatments, respectively. The urine-N concentration influenced N_2O emissions ($p = 0.02$) [which decreased linearly ($p = 0.062$)] as well the volume of urine ($p < 0.01$) [which increased linearly ($p < 0.01$)]. The chemical form of the applied urine-N (urea, nitrate, or ammonium) did not affect N_2O emissions and the emissions factor averaged 1.40 ± 0.38%. N_2O production was affected by the KCl concentration in the urine ($p < 0.01$), and the effect was curvilinear. The key driving factor affecting N_2O emissions was soil moisture content. The N_2O response varied when the urine volume differed (in both moist and dry soil conditions), and with the addition of dung.

1. Introduction

Nitrous oxide (N_2O) is the third-largest contributor to the greenhouse gas emissions driving climate change. N_2O emissions come primarily from N fertilization of soil and excretion of urea by animals (WMO, 2015). N_2O emissions from livestock represent approximately 14.5% of the global anthropogenic N_2O flux (Gerber et al., 2013). These fluxes may dominate the greenhouse gas budget in countries where economies depend, to a large extent, on livestock farming. In Brazil, the fraction of the anthropogenic N_2O flux coming from urine and dung voided by livestock in pastures was 37% in 1995 and 57.7% in 2012 (MCTI, 2014). This fraction is expected to continue to increase in the near future.

Urea from urine is rapidly hydrolyzed to yield NH_3 (ammonia) or NH_4^+ (ammonium). Autotrophic nitrifiers oxidize these energy-rich compounds to NO_2^- and subsequently to NO_3^-. Finally, heterotrophic denitrifiers use NO_3^- and NO_2^- as electron acceptors, thereby reducing these oxidized N species to NO, N_2O, and N_2 (Oenema et al., 1997). These reactions occur for both urine and dung patches, although the initial concentration of NH_3/NH_4^+ species is much lower in dung than in urine.

The key factors affecting N_2O emission from N-fertilized soils appear to be water-filled pore space (WFPS), temperature, and mineral N concentration (Dobbie et al., 1999). The main mechanism involved in N_2O emissions varies according to the soil temperature. Nitrification is the predominant process (at approximately 40% WFPS), and when

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WFPS ranges from 50 to 70%, N_2O is mainly produced by denitrification (Dobbie et al., 1999). For grazed grasslands, the high N concentration from animal excretion, chemical form of N compounds, and subsequent N transformations contribute to high N_2O losses (Oenema et al., 1997). Soil temperature and moisture affect N_2O emission from bovine manure patches (Mazzetto et al., 2014). Uchida et al. (2011) attributed higher N_2O fluxes during the rainy season to the warmer and wetter conditions. Soil compaction decreases the total pore volume, especially the number of large pores. This in turn decreases soil aeration, possibly leading to partial anaerobiosis, and to changes in N transformation and N_2O production rates (Oenema et al., 1997). Soil characteristics might also affect N_2O emissions in tropical grassland soils, as found in temperate soils. In this study, we tested the following hypotheses: (1) a greater proportion of the urine-N will be emitted as N_2O from moist soil than from dry soil, and (2) N_2O emissions will be greater from compacted soil than from moist soil.

The level of N_2O emissions from cattle dung and from cattle urine differs. It has been reported that under field conditions, N_2O emissions are much lower from dung patches than from urine patches (e.g., van der Weerden et al., 2011; Lessa et al., 2014; Rochette et al., 2014). In the western Amazon, Mazzetto et al. (2014) evaluated N_2O emissions from dung during wet and dry tropical seasons and concluded that feces cannot be considered an N_2O source under those conditions. None of these studies evaluated N_2O emissions from dung plus urine and how N_2O production might be affected by soil compaction. Therefore, we also investigated the following hypotheses: (3) N_2O emissions will be lower from urine plus dung than from urine alone, and (4) a greater fraction of the excreta-N will be emitted as N_2O from urine plus dung than from the urine-plus-dung and soil compaction treatments.

Lessa et al. (2014) found differences in the N_2O emissions between seasons. They found EFs of 1.93% from urine-N in the rainy season and 0.1% in the dry season, with this variation explained by difference in the soil moisture. The urine-N concentration affected N_2O losses (van Groenigen et al., 2005a, 2005b). The nitrogen concentration in urine varies greatly, depending mainly on the amount of protein in the diet, and ranging from 3.0 to 20.5 g N/L (Dijkstra et al., 2013). Urine-N may interact with other N sources applied to grassland soil as ammonium sulfate and potassium nitrate. Some chemicals present in bovine urine (like KCl) may have an inhibitory effect on N_2O emissions (Agrawal et al., 1985; van Groenigen et al., 2005a). Regarding urine composition, we tested the following hypotheses: (5) N_2O emissions will increase when the urine volume increases, (6) the proportion of the urine-N emitted as N_2O will be greater when urine-N increases, (7) N_2O emissions will differ among nitrogen sources, and (8) N_2O production will be inhibited by increasing KCl concentration in the urine.

Most previous studies on the effects of soil conditions on N_2O emissions from cattle excreta have been conducted on temperate grassland soils (e.g., Oenema et al., 1997; Yamulki and Jarvis, 2002; Rochette et al., 2014). Although Sordi et al. (2013), Lessa et al. (2014), and Mazzetto et al. (2014) represent the few carried out under tropical conditions, no manipulation of either soil conditions or urine characteristics was attempted in these. Different interactions between these variables and N_2O emissions are expected for tropical grassland soils. In addition, there is an increasing need to understand the key variable driving N_2O production from livestock in tropical regions, in order to develop N_2O mitigation strategies and to improve inventories of N_2O emissions.

To this end, we manipulated soil conditions of, and urine application to, a patch of tropical soil under controlled conditions, and then assessed N_2O emissions for 106 d. The objective of this part of the study was to evaluate the effects, on N_2O emissions, of: 1) soil characteristics, 2) the amount of urine-N applied (when the volume of urine applied was constant), 3) the volume of urine applied (when the amount of urine-N was constant), 4) the source of the N in the urine applied, and 5) the concentration of KCl added to the urine.

2. Material and methods

2.1. Location and soil characteristics

The incubation was carried out in the greenhouse facility of the Forragicultura Sector of the São Paulo State University "Júlio de Mesquita Filho" campus in Jaboticabal, São Paulo, Brazil. A 20 cm-deep layer of sandy clay Ferralsol (42% clay, 14% silt, 44% sand) was collected for the incubation study in June 2013, from a grassland in Jaboticabal, Brazil (21°15′22″S, 48°18′08″W; altitude 595 m).

The chemical characteristics of soil were pH 4.9 (in water), 0.18% total N, 2.04% total C, and, for the dry soil (11.0 mg NH_4-N and 4.7 mg NO_3-N) kg^{-1}. The soil was mixed and passed through a 4 mm sieve; then 500 g portions of moist soil were placed in square 1.5 L jars. The dung was from Nellore cattle and was collected immediately after defecation. The animal diet was solely grass (*Brachiaria brizantha* cv. Marandu).

2.2. Experimental design

To determine the effects of, and interactions between, soil characteristics and urine composition on N_2O emissions, four incubations were conducted simultaneously.

a) Incubation 1
A factorial experiment was carried out in a completely randomized design. The first factor was different concentrations of urine-N (125, 250, 500, or 750 mg kg^{-1} dry soil; 5 replicates) applied in equal volumes of urine (50 mL kg^{-1} dry soil) under different soil conditions (moist, dry, compacted, moist plus dung, and moist plus dung plus compaction; 4 replicates). In this incubation, two treatments were included to measure background N_2O: moist and dry soil, without N addition.

b) Incubation 2
A second incubation studied the effect of different volumes of urine (25, 50, 100, or 200 mL kg^{-1} dry soil; 5 replicates) containing equal amounts of urine-N (500 mg kg^{-1} dry soil) on N_2O emissions under the same soil conditions (second factor). The background and experimental design were as above.

c) Incubation 3
In the third incubation, four treatments containing different N sources (500 mg N kg^{-1} dry soil of urea, ammonium sulfate, potassium nitrate, or the background with no N source applied in 100 mL urine^{-1} kg^{-1} dry soil; 4 replicates), were tested using a completely randomized design.

d) Incubation 4
In this incubation the treatments were different concentrations of KCl (0.0, 5.0, 10.0, or 20.0 g L^{-1} urine; 4 replicates) added to the urine then applied in 100 mL urine^{-1} kg^{-1} dry soil, along with a background treatment without added KCl. Each treatment included four replicates in a completely randomized design.

2.3. Treatment preparations

The incubations were conducted under controlled conditions: temperature 25.0 ± 1.0 °C and 80% relative humidity. 500 g of soil was added to each square jar (1.5 L), in which the initial moisture was 8.0 g^{-1} H_2O g^{-1} soil.

a) Urine treatments
Artificial urine was used in order to manipulate its characteristics. The urine was prepared according to Doak (1952) using urea, hippuric acid, creatine, allantoin, ureic acid, and NH_4Cl with total N in