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Bovine urine and dung deposited on Brazilian savannah pastures contribute differently to direct and indirect soil nitrous oxide emissions

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A B S T R A C T

Cattle ranching is one of the most important agricultural activities in Brazil. The impact of livestock on soil N_2O emissions in Brazil has only been assessed using a Tier 1 approach of the IPCC guidelines, as there are no data available from field studies. Apart from the need for accumulating data for the development of proper direct N_2O emission factors, we tested for possible differences between urine and dung as N_2O sources and the difference in emissions between the dry and wet season. An area of *Brachiaria brizantha* at the Embrapa Rice and Bean Centre in the Cerrado (central savannah) region (Goiás state) was subdivided into plots where fresh cattle urine and dung were monitored for three consecutive periods (two in the rainy and one in the dry season) for N losses, principally N_2O emissions and NH_3 volatilization. ^{15}N-labelled urine N was used in the first monitoring period for an N balance study which indicated that denitrification and NH_3 volatilization were the most important processes for N loss. Percentages of N lost as N_2O and as volatilized NH_3 were greater for urine than for dung. In addition, N losses as N_2O in the rainy season were much greater than during the dry season. Representing the Cerrado region and the extensive pasture systems common in this region, direct emission 0.007 g N_2O–N g^{-1} (0.7%) excreta N, well below the EF_{3PRP} of 0.020 g N g^{-1} (2%) used by IPCC for cattle N in excreta. The fraction of excreta N lost as NH_3 of ~15% was in line with the IPCC guidelines. Disaggregation of emission factors for excreta type is recommended.

1. Introduction

Anthropogenic emissions of greenhouse gases (GHGs) in Brazil are dominated by emissions of enteric methane from cattle, and nitrous oxide derived from the excreta they deposit on pastures. It is estimated that enteric methane contributes 56% of the emissions in the agricultural sector and nitrous oxide 23% (Ministério de Ciência, Tecnologia e Inovação (MCTI), 2013). Together they constitute 28% of the total Brazilian national inventory.

In Brazil, approximately 37% of the 150 million hectares under cultivated pastures are located in the Cerrado area (Bustamante et al., 2012a). These pastures are dominated by *Brachiaria* species and are principally used for extensive beef production systems (Ferraz and Felício, 2010) with approximately 80 million cattle or 40% of the national herd (Instituto Brasileiro de Geografia e Estatística (IBGE), 2013).

The annual amount of N excreted by grazing cattle depends on the protein content of the diet but average values for the dominant pasture systems of Latin America were estimated at 40 and 70 kg N $head^{-1}$ yr^{-1} for beef and dairy cattle, respectively (Intergovernmental Panel on Climate Change (IPCC), 2006). Estimates for Zebu steers grazing on *Brachiaria humidicola* pastures in southern Bahia state (Brazil), varied from 91% to 95% of ingested N, or 30 to 43 kg N $head^{-1}$ yr^{-1} depending on stocking rates (Boddey et al., 2004).

Following IPCC guidelines, a direct N_2O emission factor of 2% is the default for total excreted N on pastures. In addition, factors of 20% and 30% are used to estimate N losses by ammonia volatilization/NOx emissions and N losses by leaching/runoff, respectively. From these N losses the indirect (off-site) soil emissions of N_2O are computed (Intergovernmental Panel on Climate Change (IPCC), 2006). While, in the absence of specific measurements, this methodological approach is of value for estimating

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GHG emissions, the use of default data may lead to large errors in the GHG inventory. For livestock, the available N_2O data used for emission factors comes predominately from a few countries of temperate climate (van Groenigen et al., 2005; Smith et al., 2004) as there is a lack of research in other environments.

Edaphoclimatic conditions in the Cerrado region contrast greatly with most temperate and even sub-tropical regions. In the Cerrado, it is estimated that 61% of the soils are highly weathered Oxisols or Entisols, which are very freely draining (Lopes, 1996). Rainfall is generally between 1200 and 1600 mm and approximately 90% occurs during the warm summer season from October to April (Lopes, 1996). Daytime temperatures at this time of year range from 25 to 35 °C although extremes over 40 °C may occur (Bustamante et al., 2012b). The high rainfall coinciding with high temperatures would likely result in rapid formation of anoxic microsites in the soil, which would favour N_2O emissions (Smith et al., 2003), but rapid drainage and high evapotranspiration rates would suggest that these conditions would be transitory (Skiba and Ball, 2002; Dobbie and Smith, 2003).

The dry season in the Cerrado is extremely severe with often more than 100 days without rain. Thus nitrous oxide emissions from excreta would be expected to be much lower in this period of the year (Yamulki et al., 1998). However, according to Saarijärvi et al. (2006) ammonia volatilization losses, especially from urine, are likely to be higher.

The excreta type could also influence N_2O emissions (van der Weerden et al., 2011). Considering the contrasting characteristics of urine and dung, it is likely that their contributions to N_2O and NH_3 losses differ greatly. In the UK, Yamulki et al. (1998) reported that 1% of cattle urine N and 0.53% of dung N were lost as N_2O and higher emissions from urine than dung were also observed in Germany (Flessa et al., 1996). Large differences in NH_3 volatilization rates between excreta types have been reported, the highest rates registered for urine (Petersen et al., 1998). Cattle ingesting low quality diets excrete a greater proportion of N in dung than cattle ingesting higher quality diets. For cattle grazing unfertilized *Brachiaria* pastures in the Atlantic forest region of Brazil, the ratio of faecal N to urine N was between 0.56 and 1.1 at a site in the South of Bahia (Boddey et al., 2004) and as high as 3 in a hillside site near Juiz de Fora (Minas Gerais) (Xavier et al., 2013).

The vast pasture area in Brazil localized in the Cerrado region is contributing to the large impact of the livestock sector on the nation's GHG emissions, which generates an urgent demand for the development of regional emission factors to improve the evaluation of the impact of different management practices on GHG mitigation strategies.

Therefore, the objective of this study was to quantify ammonia volatilization and N_2O emissions from urine and dung artificially deposited on a pasture area of the Brazilian Cerrado during both the wet and dry seasons with the aim of developing regionally appropriate emission factors.

2. Material and methods

2.1. Site description

The study was carried out on a grass pasture site of the Embrapa Rice and Bean Centre experimental station (16°28′S–49°17′W, 823 m a.s.l.) located in the Municipality of Santo Antonio de Goiás, State of Goiás. The climate is Aw, tropical savannah, megathermic, according to the Köppen's classification (Köppen, 1936). A characteristic of this region is that rainfall is practically absent from June to September. The original vegetation of the region was a forest type with a closed canopy (*Cerradão*) one of the sub-biomes of the Brazilian Cerrados (Bustamante et al., 2012b).

Approximately two decades before this study a *Brachiaria brizantha* cv Marandu pasture was established on a clay loam soil (Ferralsol—FAO classification, Oxisol—US Soil Taxonomy) with a texture of 43% clay and 44% sand in the top 20 cm. Soil samples taken from the area presented the following fertility data: 10.4 g C kg^{-1}, 0.91 g N kg^{-1}, 3.6 mg P kg^{-1}, 90 mg K kg^{-1}, 1.62 cmol Ca^{+2} dm^{-3}, 0.71 cmol Mg^{+2} kg^{-1} and pH 5.7 in water (1:2.5). To comply with the standard low-input grazing in this region neither liming nor basic fertilization were practiced in the area for the study.

Three experiments were set up to study the N losses from cattle excreta, two of them during the rainy season and one in the dry season.

2.2. Preliminary trial on linearity of N_2O emissions

A preliminary study was performed to investigate the response of N_2O emissions in closed static chambers during a period of 50 min. For this trial, five of the static chambers described below (Section 2.6) were positioned on the pasture within a radius of 5 m of each other over an area that had been amended with the equivalent of 60 kg N ha^{-1} as ammonium sulphate. Even though the soil was moist from recent rainfall, the day before sampling 2 L of water were distributed uniformly in each chamber (equivalent to 8 mm of rainfall). The chambers were sealed and gas samples were taken at approximately 09.00 h from each chamber approximately every 10 min up to 50 min after closure, the exact times being noted as the samples were taken. The samples were taken and analysed as described in Section 2.6.

2.3. Experiment 1

The experiment was performed on an area where a grazing simulation had established sward height at 15 cm. Plots of 1.5 × 1.5 m were delimited in the area in order to accommodate the following treatments: (1) a control without excreta; (2) cattle urine addition; and (3) cattle dung addition. The three treatments were applied in a randomized complete block design with six replications (18 plots).

In the centre of each plot, the base of a static chamber of 40 × 60 cm dimension was inserted into the soil to an average depth of 5 cm. The details of the chambers are described in Section 2.6.

Urine and dung were collected fresh from crossbred dairy (Nelore/Friesian) cows during milking at dawn on the day the experiment was set up. The animals were kept in the pasture but supplemented with soybean and corn meal. Approximately 15 kg of fresh dung were well mixed in a container until visually homogeneous. A sample was taken for chemical analysis and the remainder used in the experiment. Dung patches were artificially prepared by pouring the dung (1.6 kg fresh weight, total N 4.2 g) into a 24 cm diameter steel ring of 3 cm height in the centre of the static chamber base. The final dung area was 0.045 m^2, which was close to the average area of 0.047 m^2 $dung^{-1}$ quantified by Braz et al. (2003) after a 10-week period of monitoring a *Brachiaria decumbens* pasture under grazing in Brazil.

One litre of urine labelled with ^{15}N was prepared by mixing 950 mL of fresh urine with 50 mL of urea solution of 17.6 mg N mL^{-1} containing 9.7 atom% ^{15}N in excess. The analysis of samples from fresh and labelled urine revealed N concentrations of 9.8 mg N mL^{-1} and 10.2 mg N mL^{-1}, respectively. The labelled urine ended up with 0.835 atom% ^{15}N excess and 1 L of the final solution (10.2 g N $chamber^{-1}$) was poured onto the soil surface delimited by the walls of the static chamber base taking care to wet the whole area inside the chamber limits. This volume of urine applied was in the range of 0.8 to 1.7 L $event^{-1}$ taken from the inventory data of Whitehead (1995).