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Effect of volume of urine and mass of faeces on N_2O and CH_4 emissions of dairy-cow excreta in a tropical pasture

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Abstract. We aimed to quantify nitrous oxide (N_2O) and methane (CH_4) emissions as a function of the addition of different quantities of bovine faeces and urine on soil under pasture. Two experiments were performed in randomised complete blocks with five replicates. In the first experiment, the emissions of CH_4 and N_2O were evaluated for 14 days after the addition of four amounts of faeces (0.0, 1.2, 1.8 and 2.4 kg of fresh faeces per plot), and in a second experiment, N_2O emissions were evaluated for 43 days after addition of four volumes of urine (0.0, 1.0, 1.5 and 2.0 L). Urine and faeces came from crossbred (Fresian × Gir) dairy cows fed on pasture and concentrates. N_2O emissions from faeces did not alter the emission factor (EF) according to the faeces weight ($P = 0.73$). N_2O-N EF from faeces-N averaged 0.18% (±0.05) of total applied N. The volume of urine applied influenced N_2O losses. The EF decreased linearly ($P = 0.015$) with increasing volumes of urine, being 4.9% (±0.75), 3.36% (±0.7) and 2.43% (±0.46) of N applied emitted as N_2O for the 1.0, 1.5 and 2.0 L volumes of urine respectively. The EF from urine was significantly ($P < 0.0001$) higher than the EF from faeces. There was no change to the CH_4 emissions per kilogram of excreta when the amount of faeces added was varied ($P = 0.87$). However, the CH_4 emitted increased linearly with the amount of faeces ($P = 0.02$). The CH_4 EF was estimated to be 0.95 (±0.38) kg/head.year.

Additional keywords: bovine excrete, N_2O emission factor, Pangola grass.

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Introduction

Globally, livestock account for 14.5% of total greenhouse-gas (GHG) emissions, 44% of which are due to CH_4, mainly from enteric rumen fermentation, while 29% are attributed to N_2O emissions resulting from animal excreta (Gerber *et al.* 2013). In 2012, 78.3% and 57.7% of the overall CH_4 and N_2O emissions of Brazil, respectively, were attributed to livestock activity (MCTI 2014). A very large share of these emissions is attributed to the more than 215 million head of cattle (IBGE 2014) that are distributed over ~200 million ha of pastures. These figures illustrate the overwhelmingly extensive nature of beef and milk production in this country.

To reduce the impact of milk and beef production on Brazil's GHG emissions, there is a need to increase the efficiency of cattle management (Berndt and Tomkins 2013). In Brazil, GHG emissions are reported using an inventory methodology (IPCC 1996), which requires emission factors to be developed for the country or region of study that best captures reliable emission figures and to detect management changes that lead to mitigation of the emissions.

The two main sources of CH_4 in pastoral systems are enteric fermentation and emissions derived from excreta deposition, the latter also being responsible for N_2O emissions from pastures. The direct emission factor (EF_{3PRP}) for N_2O according to the Tier 1 of the IPCC guidelines is 2% (0.02 g N_2O-N/g excreta-N deposited on the soil) irrespective of excreta type.

The IPCC guidelines state that CH_4 emissions from faeces can be estimated using an emission factor of 1 kg of CH_4/head.year. However, several studies have raised concerns about the suitability of such factors. Mazzetto *et al.* (2014) determined emission factors for excreta of 0.02 and 0.05 kg CH_4/head.year (São Paulo, winter and summer, respectively) and 0.06 and 0.10 kg CH_4/head.year (Rondônia, winter and summer, respectively), being significantly lower than the IPCC default value. It is known that CH_4 is produced both in the rumen and in the hindgut (Moss *et al.* 2000) and it is possible that fermentation of carbon products continues after faecal material is deposited on the soil (González-Avalos and Ruiz-Suárez 2001). Saggar *et al.* (2004) reported CH_4 emissions from the faeces of dairy and beef cattle deposited on the soil, with emission factors varying largely and frequently and being very different from that of IPCC (1996), irrespective of the climatic region. In view of such variation, it is fundamental to develop emission factors

for a country or, in several cases, for regions of a country, which is the case of continental countries such as Brazil that has eight different biomes and a variety of cattle-raising systems.

Large variations have also been reported for the N_2O emission factors of urine and faeces of cattle. Emissions of N_2O-N range from 0.1% to 4.0% of the N added as urine, while the corresponding range is 0.1–0.7% of the N in faeces (Lodman *et al*. 1993; Jarvis *et al*. 1995; de Klein *et al*. 2001). In Brazil, urine and faeces of dairy cows applied to a *Brachiaria brizantha* pasture established on a Ferralsol (IUSS 2006) in the Cerrado region induced N_2O-N emissions from urine, corresponding to 1.93% of the N applied during the rainy season and 0.01% during the dry season (Lessa *et al*. 2014). The N_2O-N emissions from dung were equivalent to 0.14% of N applied in the rainy season and 0% in the dry season. Sordi *et al*. (2014) applied bovine excreta to a Cambisol of the Atlantic Forest region in southern Brazil. They measured an average N_2O-N emission equal to 0.26% of urine-N and 0.15% of dung-N. In all these studies, the emission factor for urine was larger than for dung. According to van der Weerden *et al*. (2011), the excreta type can also influence N_2O emissions and the authors suggested disaggregating the IPCC direct N_2O emission factors (EF_{3PRP}) by excreta type.

Apart from local differences associated with climate and soil conditions, there is also the possibility that emission factors for N_2O and CH_4 could be influenced by the amount of excreta deposited on the soil. Hence, the aims of the present study were to quantify CH_4 and N_2O emissions from soil affected by increasing amounts of faeces and urine.

Materials and methods

Two experiments were carried out at the Experimental Station of Embrapa Agrobiology, Seropédica, Rio de Janeiro, Brazil (22°46′S, 43°41′W, 33 m asl). The climate is tropical, with wet rainy summers and dry winters. The average annual temperature is 24°C and the average rainfall is 1500 mm, with the months of July and August being the driest. This region is located in Atlantic Forest Biome. The soil of the experimental area is classified as an Acrisol (FAO classification system, IUSS 2006). In the 0–20 cm depth, there is 23% clay, pH in water is 5.88 and the soil has 0.59% of organic matter. Pangola grass (*Digitaria eriantha*) is the dominant forage species in the pasture that had been established for more than 10 years without liming or fertiliser application, and had not been grazed for the past 2 years as the area was no longer used for fattening cattle.

Fresh faeces and urine were collected from 'Girolanda' cows (cross-bred of Friesland–Holstein of *Bos Taurus* and Gir of *Bos indicus*) of the Dairy Cattle Sector of the Federal Rural University of Rio de Janeiro (UFRRJ). Faeces and urine characteristics are shown in Table 1. The animals were managed on pastures of *Brachiaria decumbens* Stapf and *Panicum maximum* Jacq., being supplemented with brewing residue and concentrate made of corn and soybean (18–22% of crude protein). Faeces and urine were collected during the first 3 h after dawn and were applied in the next hour.

The first experiment was designed to evaluate the effect of increasing amounts of faeces on soil N_2O and CH_4 emissions.

Table 1. Nitrogen concentration of urine, dry matter (DM), carbon (C) and nitrogen (N) concentration and C : N ratio of dung

Excrete	N (g/L)	DM (g/kg)	C (g/kg of DM)	N (g/kg of DM)	C : N
Urine	7.9	–	–	–	–
Faeces	–	150.00	460.00	19.6	23.5

Plots of 1 × 1.5 m were arranged in a randomised complete block design to receive four treatments with five replicates. The treatments were a control and either 1.2, 1.8 or 2.4 kg of fresh faeces, which contained the equivalent of 0, 3.53, 5.29 or 7.06 g N, respectively, taking into account that the total N content in faeces was 19.6 g N/kg dry matter.

For monitoring CH_4 and N_2O fluxes, the bases for static chambers, made of 40 × 60 cm steel frames, were placed in the centre of each plot and inserted into the soil to a depth of 7 cm. For the period of sampling, the top of the chamber with the same basal dimension and of 10 cm height was coupled with the base and this resulted in a chamber height of 12–13 cm. A similar static chamber system was described in detail by Alves *et al*. (2012).

Faeces were placed in the centre of the chamber base with the help of a PVC ring of 0.2 m diameter × 0.05 m height. The required mass of fresh faeces for each treatment was transferred to inside the ring and gently moulded to simulate the contact with the soil, as naturally occurs after animal defecation. Faeces of the 1.2 kg treatment was ~8 cm thick and for the other two treatments (1.8 and 2.4 kg) they were between 11 and 12 cm thick.

The second experiment was set up in another area of the same pasture, with experimental design and plots of the same size. However, the treatments were a control and 1.0, 1.5 or 2.0 L of fresh urine that was carefully added to the centre of each chamber to simulate cattle urination. These volumes of urine were equivalent to 7.9, 11.6 and 15.8 g N/chamber, respectively, for a urine presenting 7.9 g N/L.

The amount of faeces and urine used was defined on the basis of reference values determined from the work of Haynes and Williams (1993), where it was reported that each defecation event produces between 1.5 and 2.7 kg of fresh faeces, and each urination event produces between 1.6 and 2.2 L of urine.

The gas-flux sampling commenced the day following excreta application. The experiment with faeces was sampled for 14 days (6–20 April 2011), while the urine experiment was sampled for 43 days (28 April to 10 June 2011). These gas-sampling periods were set during the study after verifying that gas fluxes from plots receiving urine or faeces and control plots did not differ after these time periods (Muñoz *et al*. 2011).

Gas samples were always taken at between 0900 hours and 1000 hours, as advocated by Alves *et al*. (2012), as this is the time of the day when the fluxes are expected to match the mean flux for the whole 24 h of the day. Evaluation of the linearity of N_2O concentration in the chambers was performed as described by Lessa *et al*. (2014). Since linear behaviour was observed, the chambers were closed for 30 min, with an initial and final sample taken for the quantification of CH_4 and N_2O. The chamber headspace was sampled using polypropylene

syringes of 60 mL, with 30 mL immediately transferred to an evacuated 20 mL chromatography vial. Gas concentrations were determined using a gas chromatograph equipped with a flame ionisation detector for CH_4 and an electron capture detector for N_2O (Autosystem, Perkin-Elmer, Waltham, MA, USA).

Before the analysis of each sample batch, CH_4 standards (1.49, 10 and 100 μmol/mol) and N_2O standards (0.41, 0.81 and 1.20 μmol/mol) together with ambient air (assumed as 310 μmol/mol) were analysed to obtain standard curves for the calculation of gas concentrations in the experimental samples.

Methane and N_2O fluxes were expressed in μg C-CH_4/m^2.h and μg N-N_2O/m^2.h, respectively, using the following equation: gas flux = $(\delta C/\delta t)(M/Vm)V/A$, where $\delta C/\delta t$ is the change in gas concentration in the chamber (μL/L) after the incubation time (h), M is the molecular weight of the gas (μg), Vm is the molecular volume of the gas at the sampling temperature (μL), and V is the volume of the chamber (L) and A the area (m^2). Hourly fluxes were multiplied by 24 to give results on a daily basis.

The cumulative emissions of CH_4 and N_2O during the monitoring period were calculated by summing the daily fluxes. The emissions of CH_4 and N_2O, induced by the application of excreta, were estimated by subtracting the emissions calculated for each excreta treatment from that of the control without excreta.

Samples of urine and faeces were taken to determine their total N content by the Kjeldahl method (Alves *et al.* 1994). The N content of each form of excreta was used to calculate the N_2O emission factor (EF). It was calculated by using the equation $EF = (N\text{-}N_2O_E - N\text{-}N_2O_C)/N_E$, where $N\text{-}N_2O_E$ and $N\text{-}N_2O_C$ are the totals of $N\text{-}N_2O$ emitted from the treatments with excreta addition and from the control, respectively, and N_E is the amount of N applied as excreta.

The temperature inside and outside the chambers and soil temperature at 5 cm depth were measured at the time of gas sampling. The daily precipitation was also measured using a recording rain gauge installed close to the experiment.

To check for normality and homogeneity of data, the tests of Lilliefors and Cochran–Bartllet, respectively, were used. Linear regression analyses were used to assess the effects of excreta rates on the emissions of CH_4 and N_2O. An ANOVA procedure was used to assess treatment effect on N_2O emissions (R version 3.1.2; R core team 2014).

Results and discussion

During the CH_4 from faeces experiment, rainfall events of <5 mm occurred on 3 days (Fig. 1). Air temperature ranged from 22.3°C to 31.1°C. The average soil temperature was 2.5°C lower than the average air temperature during the experimental period (Fig. 1).

High CH_4 fluxes were registered in the first 4 days after faeces placement, and they were significantly different from the slightly negative CH_4 fluxes in the control (Fig. 2). Similar negative fluxes were registered for all treatments during the last few days of monitoring (Fig. 2). The induced CH_4 emissions persisted for 5–6 days after excreta application when the fluxes became similar to the control. Rainfall occurred before the beginning of the CH_4 experiment and the rain showers that occurred in the first 5 days favoured the conditions for CH_4 production in the first days, while the faeces pat was still humid (Holter 1997). The emissions measured in the treatments with 1.2, 1.8 and 2.4 kg of faeces in the first 3 days corresponded to 93%, 85% and 88%, respectively, of the total emissions measured for the 14 days. Considering the fourth day of measurements, the CH_4 emitted reached more than 90% of the total for the three treatments. A similar behaviour has been registered in several other studies (Lodman *et al*. 1993; Jarvis *et al*. 1995; Saggar *et al*. 2003; Sherlock *et al*. 2003). For the treatments with 1.8 kg and 2.4 kg faeces, CH_4 fluxes remained above the control for a longer time, probably due to the greater volume of excreta maintaining a higher humidity in the core of the dung pat.

Saggar *et al*. (2004) argued that with the gradual disappearance of faeces, the soil area previously covered begins to oxidise CH_4. In the present study, the disappearance of faeces was not observed, but after 4–5 days, faeces were drier and started to exhibit a crust formation. This drying process would explain the shift from CH_4 emission to oxidation that occurred over the last days of measurement.

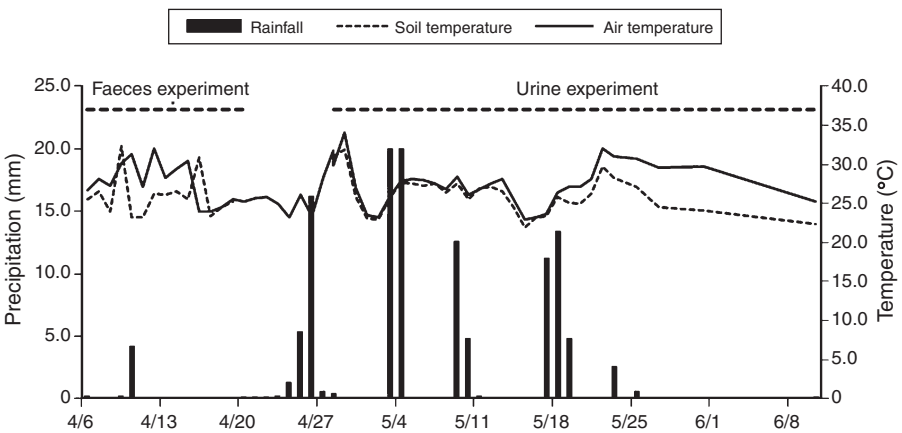

Fig. 1. Rainfall precipitation (mm), soil temperature (0–5 cm depth) and air temperature during the experimental period (4 April to 10 June 2011).

After faeces dry out further, rainfall does not provoke a further stimulus of CH_4 fluxes (Holter 1997).

The low rainfall, along with high soil evaporation during the study period would have contributed to increased soil aeration that would favour soil CH_4 oxidation in the control treatment where no faeces was present (Cardoso *et al*. 2001). Soil compaction (>1.4 Mg/m^3) may have contributed to the positive fluxes of CH_4 occasionally observed in the control treatment (Ruser *et al*. 1998).

The cumulative CH_4 emissions calculated for the control treatment equalled 14.1 (±4.9) mg CH_4/m^2 for the 14 days. When 1.2, 1.8 and 2.4 kg of faeces were added to the soil, the net CH_4 production (with control value subtracted) was 75.3 (±36.8), 105.8 (±50.4) and 92.0 (±43.6) mg CH_4/kg fresh faeces, respectively (Table 2). A significant linear regression was found between the amount of faeces and the respective CH_4 emission, from which a mean CH_4 emission of 108.6 mg CH_4/kg fresh faeces was estimated (Fig. 3). Haynes and Williams (1993) stated that an adult bovine excretes 24 kg of fresh dung per day, which, combined with the CH_4 emission data obtained in the present study, would result in a CH_4 emission of 0.95 ± 0.38 kg CH_4/head.year. This value is close to the IPCC default value (IPCC 1996) of 1 kg CH_4/head.year (Tier 1) and below the range of 1.2–2.6 kg CH_4/head.year estimated for the Brazilian GHG inventory by the use of Tier 2 (Lima *et al*. 2010). The Tier 2 of IPCC estimates the emissions from faeces on the basis of data of consumption, digestibility and volatile solids (IPCC 1996). Mazzetto *et al*. (2014) calculated emissions factors for Nellore dung of 0.02 (winter) and 0.05 (summer) kg CH_4/head.year for São Paulo, and, for Rondônia, the values were 0.06 (winter) and 0.10 (summer) kg CH_4 /head.year, but considering a faecal production of 10 kg/head.day. This would result into a 0.39 kg CH_4/head.year if the same CH_4 emission/kg fresh faeces was used in the current study. Apart from the amount of faeces excreted, the variability in CH_4 emission rates is explained by the animal's diet, the physical form of the

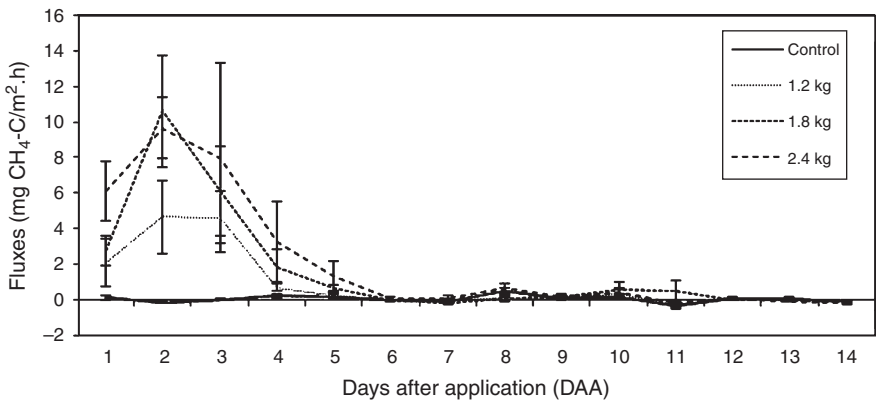

Fig. 2. Daily fluxes of methane (mg CH_4-C/m^2.h) when 1.2, 1.8, 2.4 kg of fresh bovine dung was applied per plot and in control plots during 2 weeks of evaluation. Vertical bars are the standard error of the means (s.e.m.).

Table 2. Cumulative emission of nitrous oxide (N_2O), nitrogen (N) applied per m^2 and emission factor (EF) for 1.0, 1.5 and 2.0 L of urine and 1.2, 1.8 and 2.4 kg of fresh faeces

Cumulative emission of methane (CH_4) for the same treatments and EF per head. The standard error of the mean (s.e.m.) is presented in the parentheses (n = 5)

Excrete	N applied (g/m^2)	N-N_2O accumulated (mg N_2O-N/m^2)	N_2O-N EF (%)	CH_4-C accumulated (mg CH_4-C/m^2)	CH_4-C EF (kg CH_4/head.year)
			Urine		
Control	–	134.2 (±34.0)	–	–	–
1.0	32.9	1745.9 (±245.5)	4.90 (±0.75)	–	–
1.5	49.4	1792.4 (±368.1)	3.36 (±0.70)	–	–
2.0	65.8	1731.5 (±322.6)	2.43 (±0.46)	–	–
Mean	–	–	3.56 (±0.59)		
			Faeces		
Control	–	10.7 (±1.0)	–	10.6 (±8.2)	–
1.2	14.7	32.9 (±10.3)	0.15 (±0.07)	293.0 (±145.4)	–
1.8	22.0	56.5 (±9.4)	0.21 (±0.04)	498.2 (±215.7)	–
2.4	29.4	62.1 (±14.0)	0.18 (±0.05)	661.9 (±309.8)	–
Mean	–	–	0.18 (±0.05)	–	0.95 (±0.38)

dung pat, environmental conditions (air humidity and temperature) and the length of time the dung pat remains intact on the soil (Saggar *et al*. 2004). The CH_4 emission values for faeces from dairy cattle in our experiment and from beef cattle measured in Mazzetto *et al*. (2014) suggested different emissions according to diet and climatic region.

Fluxes of N_2O from faeces started to increase after the third day and remained above those from the control for 5–6 days, varying with the amount of faeces deposited (Fig. 4). The rainfall before the application of the faeces and that registered on the third day probably contributed to increased nitrifier–denitrifier activity that was benefiting from the N substrates applied in the faeces. In the study of local conditions, it was possible to observe the drying of faeces and crusting, which according to Saggar *et al*. (2004) causes a reduction in N_2O fluxes and the cessation of the effect of N added to soil through excreta. This desiccation was observed from the 10th day onward, and, subsequently, matched the fluxes of the control treatment until the last day of monitoring. When considering the cumulative N_2O emissions, more than 90% of the total registered during the 14 days of the study had been emitted by the seventh day.

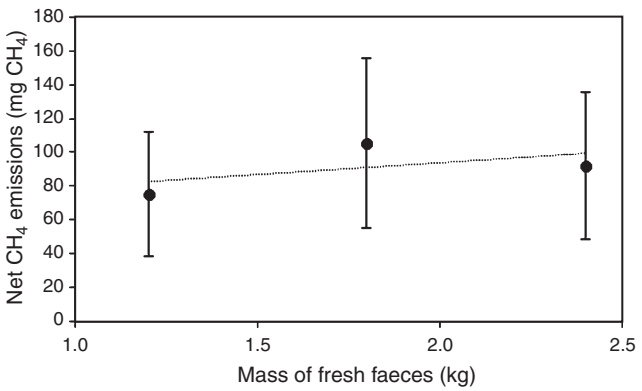

Fig. 3. Net methane emission (mg CH_4) from 1.2, 1.8 and 2.4 kg of bovine dung. Dotted straight line represents the fitted curve (P = 0.026) between CH_4 emission and dung added. (n = 5).

In the control treatment without faeces, 10.7 (±1.0) mg N_2O-N/m^2 were accumulated up to the 14th day of measurement. The presence of faeces accounted for net N_2O emissions of 22.2 (±9.9), 45.7 (±9.2) and 51.9 (±13.8) mg N_2O-N/m^2 for the respective treatments of 1.2, 1.8 and 2.4 kg fresh faeces (Table 2). The linear trend of N_2O emission with the amount of N in the fresh faeces applied resulted in a factor of 2.02 mg N-N_2O/g N fresh faeces (Fig. 5), but the slope was only significant at P = 0.077. A quadratic model was attempted but it was significant only at P = 0.182. The amount of faeces caused little influence on the N_2O emission factor, which agrees with Sordi *et al*. (2014), who showed no clear trend in the N_2O emission factor with varying dung rates.

The IPCC (1996) emission factor for N from urine or faeces directly deposited on pastures (EF_{3FRP}) is 2%; in the present study, we found an average of 0.18%, 10 times less. Lessa *et al*. (2014) conducted a similar investigation in the cerrado region and worked with only 1 kg of fresh faeces of animals supplemented with concentrated soybean and maize, and found that the N_2O EF from faeces after more than 60 days of evaluation was close to 0.14% during the summer and close to zero during the winter (dry season). Sordi *et al*. (2014) evaluated the N_2O emissions from faeces in the Mata Atlantica region in Curitiba and obtained an average EF from faeces of 0.15%, a value similar to the one in the present study. These three studies, undertaken in different Brazilian climatic regions, indicated that direct N_2O emissions from bovine faeces deposited in grassland are much lower than the IPCC (1996) default EF.

In the second experiment, the temperature inside the chamber ranged from 22.9°C to 34.1°C and the soil temperature ranged from 22.0°C to 31.9°C (Fig. 1). During the experiment, the soil temperature was more than 1.1°C lower than the temperature in the chamber. The N_2O fluxes were higher than for the control only after 1 week following urine application, coinciding with two consecutive rainfall events of ~20 mm (Fig. 1). After that, weekly rainfall of 10–12 mm sustained high N_2O fluxes from the areas treated with urine.

Over 3 weeks, N_2O emissions from urine-treated areas were above the levels registered for the control treatment (Fig. 6). In the last week, N_2O fluxes were similar among

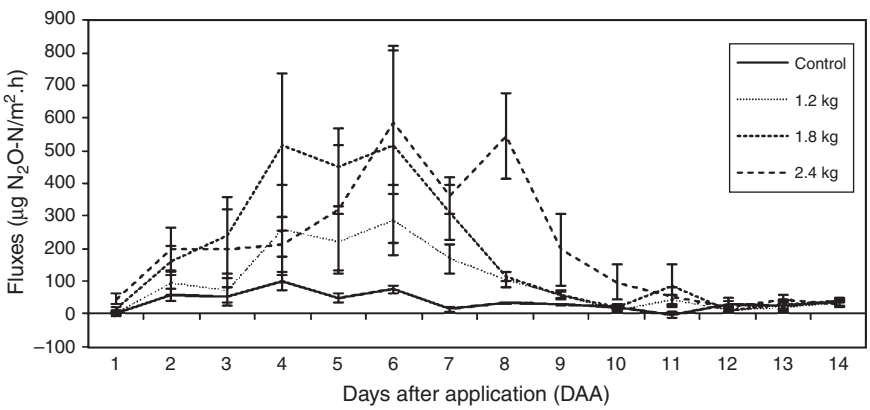

Fig. 4. Daily fluxes of nitrous oxide (µg N_2O-N/m^2.h) when 1.2, 1.8, 2.4 kg of fresh bovine dung was applied per plot and in control plots during 2 weeks of evaluation. Vertical bars are the standard error of means.

treatments, including the control, even after a rainfall of almost 4 mm. The initial lag of N_2O fluxes after urine application can be explained by the fact most of the N in the form of urea and has to be hydrolysed to ammonia before nitrification and denitrification start to give rise to the N_2O fluxes (van Groenigen *et al*. 2005).

More than 95% of the total N_2O emitted from urine was computed in the first half of the monitoring period. Lessa *et al*. (2014) found that 30 days after urine application in a Ferralsol, there was no further difference in N_2O fluxes between the treated soil and the control, without urine. Hence, the induction of N_2O emissions by excreta deposition on soil seems to remain for periods of weeks to a few months and the recommendation of 1 year to a reliable emission accounting (Bouwman 1996) seems overly long.

The N_2O fluxes accumulated in the control totaled 0.13 (±0.03) g N_2O-N/m^2. It was stabilised just a few days before the end of the whole monitoring period, once positive and negative fluxes alternated in the phase (Fig. 6). The last days were without rainfall (Fig. 1), which increased soil aeration and low N_2O fluxes would explain the negative fluxes (Chapuis-Lardy *et al*. 2007); Wu *et al*. (2013) suggested that N_2O production and consumption are regulated by interactions between the O_2 concentration and soil moisture content. Mazzetto *et al*. (2014) also found negatives N_2O fluxes, possibly because of low mineral-N content in soil.

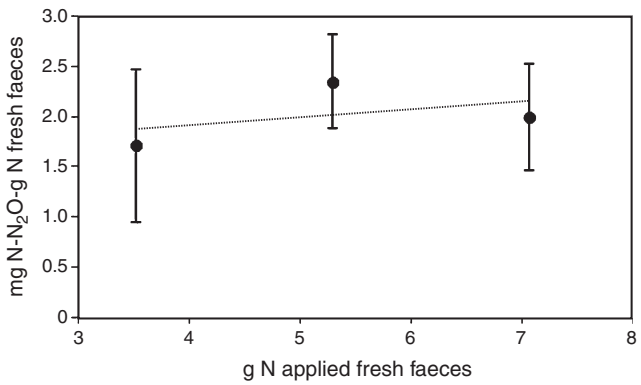

Fig. 5. Variation in nitrous oxide emission factor (mg N-N_2O/g N-fresh faeces applied) with the mass of faeces applied to the pasture. Dotted straight line represents the fitted linear function to data (P = 0.077).

After integrating the N_2O fluxes for the 43 days, we found no relationship between the volume of urine applied and total N_2O emitted, indicating that the increase in urine volume would change the emissions factor of N_2O. The net amount of N_2O from the urine treatments was 1.61 (±0.25), 1.66 (±0.35) and 1.60 (±0.31) g N-N_2O/m^2 (Table 2). We calculated the emission factor for the treatments to be 4.9, 3.36 and 2.43 g N/100 g urine-N, respectively, for 1.0, 1.5 and 2.0 L of urine. The emission factor decreased linearly (P = 0.015) with the increase in urine volume (Fig. 7). Our hypothesis is that the greater the volume of urine deposited in the soil, the more likely it is that preferential flows may occur through the soil and carry the urea-N deeper, reducing the availability of N for N_2O production. Sordi *et al*. (2014) observed that the average EF for urine diminished when the volume of urine increased. They suggested a deeper percolation of urine into the soil and, thus, proportionally less N remained for N_2O production in the topsoil. The EFs measured in the present study were higher than the IPCC (1996) default EF. Lessa *et al*. (2014) found an emission factor of 1.96% for urine during the rainy season in a Ferralsol, and Sordi *et al*. (2014) found 0.32% during wet summer in a Cambisol soil.

Emissions found in the present study, as well as those reported by Lessa *et al*. (2014), Sordi *et al*. (2014) and Mazzetto *et al*. (2014) were from experiments conducted in different soils, namely, Acrisol, Ferralsol, Cambisol and Nitosol, respectively, and in different Brazilian regions, including eastern, central, southern and western regions, respectively, indicating that the urine-N is the major route of N_2O emission from cattle excreta deposited in grasslands. The studies cited above have reinforced the need for a 'breakdown' of the IPCC EFs for each excreta, as proposed by van der Weerden *et al*. (2011). However, different EFs found in the different soils and regions also indicate the necessity to distinguish the EFs by region, considering the importance of livestock in Brazilian and global GHG emissions. The present study has endorsed the fact that CH_4 emissions

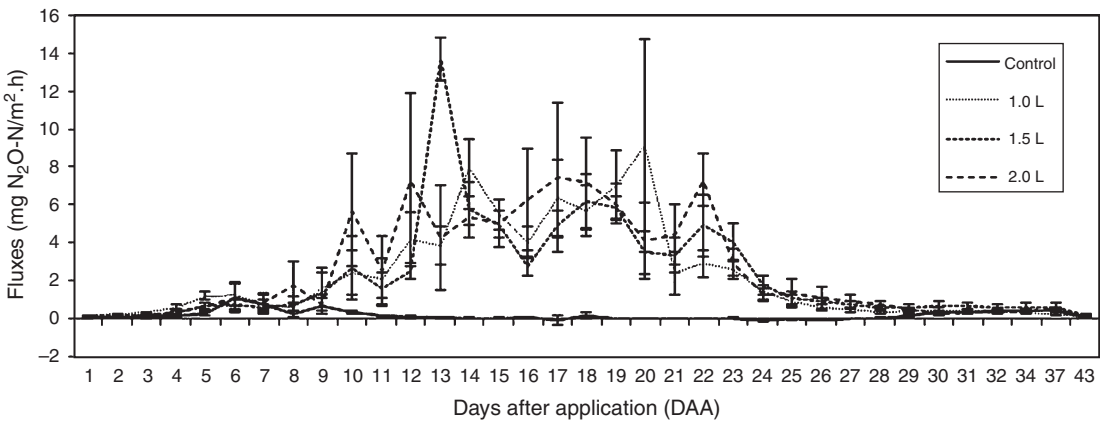

Fig. 6. Daily fluxes of nitrous oxide (mg N_2O-N/m^2.h) when 1.2, 1.8, 2.4 kg of fresh bovine dung was applied per plot and in control plots during 2 weeks of evaluation. Vertical bars are the standard error of means.

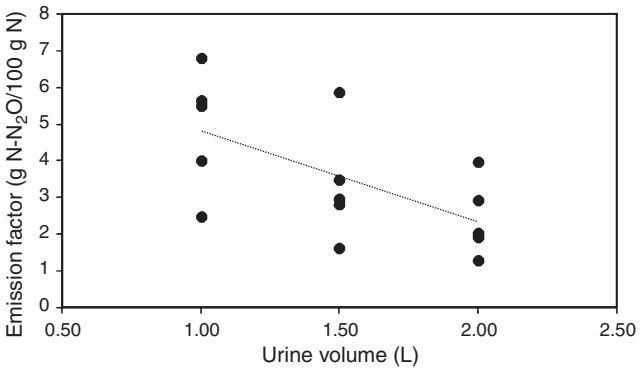

Fig. 7. Variation in nitrous oxide emission factor (g N-N_2O/100 g N applied) with the volume of urine applied to the pasture. Dotted straight line represents the fitted linear function to data ($P = 0.016$)

from dung are the same as the IPCC (1996) default EF, but higher than observed by Mazzetto *et al*. (2014) in the Amazon region.

Conclusions

Methane emission from cow faeces deposited directly on soil of pastures increased proportionately with the amount of faeces applied, at a rate of ~108.6 mg CH_4/kg fresh material. The proportion of the N lost as N_2O from faeces did not change, being 0.18%. In contrast, an influence of an increasing volume of urine on the fraction of the added N that was converted to N_2O was observed, with the fraction that was emitted declining from 4.9% to 2.4% with the increasing volume of urine from 1 to 2.5 L, respectively; in all cases, these values were above the IPCC default EF of 2%.

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