Nitrous oxide and methane emission from a beef cattle feedlot pen in Brazil: chamber measurement and DNDC modeling approaches

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Abstract. Feedlots increasingly used in Brazil as an option for finishing cattle because of the increasing external demand. Large amount of manure in limited areas are an inevitable consequence of feedlots. Manure is a complex of organic matter containing minor minerals that undergoes to a series of reactions from which emissions of nitrous oxide (N$_2$O) and methane (CH$_4$) also occur from feedlot pen. The objective of this study was to provide quantitative information on emission levels of N$_2$O and CH$_4$ from a feedlot pen when used for feeding cattle. In this paper, we report the results of N$_2$O and CH$_4$ emissions measured over 3 months from a 500m$^2$ feedlot pen supporting 21 beef cattle. The feedlot pen consisted of bare soil. N$_2$O and CH$_4$ fluxes from the feedlot pen were initially very low, but subsequently increased. The highest daily fluxes around 52.2 mg N$_2$O-N/500m$^2$.day were obtained. Overall, 0.2 kg N$_2$O-N was emitted from the feedlot pen during the 3-month measurement period. These results suggest that only 0.12% of the excreta N deposited by the beef cattle was emitted as N$_2$O. Similar to N$_2$O fluxes, initial CH$_4$ emissions were very low. Methane fluxes became very high, reaching a peak value of 289 mg CH$_4$-C/500m$^2$.day in the last week of feeding, and no flux measurements were made beyond this period. Overall, 1.1 kg CH$_4$-C was emitted during the 3-month period. This work shows that feedlot pens could be used to mitigate emissions of N$_2$O and CH$_4$ emanating from animal excreta deposition.

Additional keywords: greenhouse gases, beef production, manure management
1. Introduction

Since 2003 Brazil has been one of the largest beef exporter in the world (USDA, 2011). In spite of most of Brazilian beef production comes from grazing systems, beef cattle fed in feedlots has more than doubled in the last 8 years (from 1.96 to 3.05 million heads in 2010), representing now almost 10% of the slaughters in Brazil (Millen et al., 2009; ANUALPEC, 2011). The beef feedlot industry in Brazil has grown in the last decade because of as an option for finishing cattle because of the increasing external demand (Millen et al., 2011).

Large amount of manure in limited areas are an inevitable consequence of feedlots. From a biogeochemical point of view, manure is a complex of organic matter containing minor minerals that, as soon as it is excreted by the animals, undergoes to a series of reactions from which the three GHG gases, methane (CH\textsubscript{4}), nitrous oxide (N\textsubscript{2}O) and carbon dioxide (CO\textsubscript{2}), as well as ammonia (NH\textsubscript{3}), can be produced (Li et al., 2012). Hence, manure management (housing, storage/treatment and field application) impacts those reactions and, consequently, the quantities of direct and indirect N\textsubscript{2}O and CH\textsubscript{4} emissions (Chadwick, et al., 2011).

The most representative manure management practice in Brazilian feedlots consists in the removal of the manure from pens only at the end of the feeding period, with subsequent storage in heaps before being applied to crop and pasture land (Costa Junior, in press). Although, no information about GHG emission from that manure management is available for Brazil, requiring additional information on the subject.

Measurement of N\textsubscript{2}O and CH\textsubscript{4} emissions at field scale is vital for improving the accuracy of the greenhouse gas inventory and for assessing the potential effectiveness of mitigation options. These measurements are also important for developing and verifying the empirical, as well as process-based, modeling approaches that provide emission and
mitigation estimates at farm-scales and beyond (Saggar et al., 2010). In the last 10 years, the prediction of GHG emissions rates using process-based agro-ecosystem models has emerged as a promising route to deal with these issues, primarily at the local scale, and to single out the effect of soil conditions, grazing regimes (Saggar et al. 2007b, 2009), and different manure management systems (Li et al., 2012).

In this paper, we report the results of N2O and CH4 emissions measured from a feedlot pen surface holding 21 typical Brazilian beef cattle between May–August.

2. Methodology

2.1. Site

The field site was a 500 m² beef cattle pen at a commercial Beef Unit of COPLACANA, Piracicaba, São Paulo State, Brazil. Average annual rainfall at this site is about 1243 mm, with driest months being May-August. The mean annual air temperature is about 22.8°C. All data concerning daily rainfall, wind velocity and temperature were taken from an existing automated meteorological station in the experimental site.

Twenty and one Nellore crossbred steers (20 months of age) averaging 252 ± 27 kg (mean ± SD) were moved into a pen in 29 May 2012 and monitored for 78 days period for its pen GHG emissions. The feedlot pen had a bunk length of 25 m, which permitted all steers to consume feed at the same time. Pen floor did not receive any bedding, consisting of bare soil and in the first 2 meters long (from the bunk line) it was concreted. These animals were pasture-grown. Adaptation to finishing diet was done in another pen using a 15 step-up day concentrate in diet. Greenhouse gas collection stopped after 78 days of feeding as steers had reached target finish conditions and were all removed for slaughter. At the same time manure were also removed from the pen, weighted, sampled for chemical analysis and storage as solid in heaps.
2.2. Gas sampling

Static chambers were installed at 16 replicate locations in a Z-shaped transect across the extent of the 500 m² beef cattle pen and at 2 replicate locations in the control (an adjacent pen without animals). The gas measurements were made in 21 occasions, two or three times a week, during the middle of the day in the period above described.

The chambers, 250mm in diameter and 300 mm in height, were inserted about 50 mm into a PVC base (previously installed in the pen floor) on each sampling occasion and took away after sampling in order to avoid chambers damage by the animals and to allow all pen surface be available for manure deposition during the finishing cycle. The PVC bases, 10 mm wide, 250 mm in diameter and 100 mm in height, were put about 100 mm into the soil 1 month before the animal entrance in order to allow chamber insertion without soil disruption. Chamber heights were measured at each placement to calculate the air volume of each chamber.

On each sampling day, the chamber was closed with a lid for 20 minutes, and air above the soil surface was sampled through a tap on the chamber lid, using a 60-ml syringe. A 50-ml air sample was taken from each chamber at 0 min (T0), 10 min (T10) and 20 min (T20). A 25-ml subsample of the 50-ml air samples was injected into an evacuated 12-ml exetainer within 1 h of gas sampling. The gas sample in the exetainer was then stored until GC gas analysis that was undertaken at the same day sampling. Soil temperature (0–10 cm) was also recorded.

2.3. Gas analysis

A SRI gas chromatograph (GC) (Pty Ltd., Hamburg, Germany) was used for simultaneous CH₄ and N₂O gas analysis. Over-pressurised exetainers were manually loaded into a 2-mL sample loop on the GC. A four-port valve diverts the gas stream to the flame ionisation detector (FID) for CH₄ detection and then to an electron capture
detector (ECD) for N\textsubscript{2}O analysis. Further methodology details are given in Hedley et al. (2006). Gas concentrations (at T0, T10 and T20) were used to estimate gas flux at the soil surface for each individual chamber, using the following equation:

\[ F = \rho (V/A) * \left( \Delta c/\Delta t \right) * \left[ \frac{273}{(T+273)} \right] \]

where F is the N\textsubscript{2}O flux (mg m\textsuperscript{-2} h\textsuperscript{-1}); \( \rho \) is the density of N\textsubscript{2}O (kg m\textsuperscript{-3}); V the volume of the chamber (m\textsuperscript{3}); A the base area of the chamber (m\textsuperscript{2}); \( \Delta c/\Delta t \) the average rate of change of concentration with time (ppmv h\textsuperscript{-1}); T is the temperature (8°C) in the chamber.

Mean daily fluxes were calculated as the arithmetic mean value of the 16 chamber fluxes for the pen and 2 chambers for the control on any 1 day, with an uncertainty equal to the standard error of these measurements. The total gas fluxes within each campaign period were calculated by linear interpolation between the measurement days. These mean daily fluxes were summed to produce a 78 day feeding period flux budget for N\textsubscript{2}O and CH\textsubscript{4}.

2.4. Soil moisture and water filled pore space (WFPS) determination

Soil moisture was monitored on each gas-sampling, six soil samples were taken (0–100 mm) for gravimetric soil moisture determination (by drying the samples for 24 h at 105 °C), from sites selected across the width of the pen intersecting the chamber area. The volumetric soil moisture was then calculated by multiplying the gravimetric moisture content by the soil bulk density assessed from four undisturbed soil cores taken at 0–100 mm depth in the start, middle and finished of the campaign. Particle density was assumed to be 2.65 Mg m\textsuperscript{-3}. Total porosity (TP) was calculated for each soil, according to Equation 2:

Total pore space (%)=100*1-(bulk density/particle density)
Water-filled pore space (WFPS) was then calculated as the ratio of the volumetric SWC to the total pore space. The ratio of the volumetric soil moisture content to the total pore space gave the water-filled pore space (WFPS).

2.5. Statistical analyses

We used Microsoft Excel software package for all statistical analyses. Means and standard errors of means were calculated for daily N2O and CH4 fluxes, total C, Total N, soil pH, mineral-N and soil WFPS.

3. Results

3.1 Nitrous oxide and methane fluxes

Fig. 3 shows measured N2O and CH4 fluxes at the soil surface of the beef cattle feedlot pen for the duration of the gas sampling campaign of 78 days. Fig. 1c–f plot WFPS, rainfall, soil temperature and mineral N on the same time series to illustrate relationships of these variables.

Nitrous oxide fluxes from the pen surface were lower during the initial 52 day in late May 2012 when a herd of 21 beef steers started to use the pen (Figure 3). After this time, N2O fluxes increased and the highest fluxes were observed from the last 20 day of the feeding period (from early August). In the highest N2O emissions soil was warm (>20°C) and dry (WFPS < 0.60) (Fig. 1a).

The arithmetic mean values for the 16 replicate chambers on any 1 day ranged between 2.0 and 52.2 mg N2O-N m⁻² day⁻¹, with standard errors of 1.9 and 31.6 mg N2O-N m⁻² day⁻¹. An overall mean value of 19.5 mg N2O-N m⁻² day⁻¹ was estimated, with a standard error of 29.5 N2O-N m⁻² day⁻¹, over the duration of the field campaign. In comparison, the overall mean daily N2O emission from the control site (without animals) was 3.0 ± 1.3 mg N2O-N m⁻² day⁻¹. Using gas flux measurements from the
period of this campaign, the N\textsubscript{2}O emission from this pen is estimated to have been 1.52 g $\pm$ 2.3 g N\textsubscript{2}O-N m\textsuperscript{-2}, compared with 0.2 $\pm$ 0.1 g N\textsubscript{2}O-N m\textsuperscript{-2} for the control site.

Methane fluxes from the soil pen were during the initial 4 weeks of the campaign (late May 2012). After this time, CH\textsubscript{4} fluxes increased and the highest fluxes were observed from late June until late July. These fluxes then declined to low levels where remained until the finish of the feedling cycle in early August 2012. In the highest CH\textsubscript{4} emissions soil was warm (>20\textdegree C) and dry (WFPS < 0.60).

The arithmetic mean values for the 16 replicate chambers on any 1 day ranged between 5.9 and 289.0 mg CH\textsubscript{4}-C m\textsuperscript{-2}, with standard errors of 9.15 and 524.6 mg CH\textsubscript{4}-C m\textsuperscript{-2}. An overall mean value of 109.8 mg CH\textsubscript{4}-C m\textsuperscript{-2} day\textsuperscript{-1} was estimated, with a standard error of 195.9 mg CH\textsubscript{4}-C m\textsuperscript{-2} day\textsuperscript{-1}, over the duration of the field campaign. In comparison the overall mean daily CH\textsubscript{4} emission from the control site (without animals) was 3.0 $\pm$ 1.7 mg CH\textsubscript{4}-C m\textsuperscript{-2} day\textsuperscript{-1}. Using gas flux measurements from the period of this campaign, the CH\textsubscript{4} emission from this pen is estimated to have been 11.4 $\pm$ 20.3 g CH\textsubscript{4}-C m\textsuperscript{-2}, compared with 0.3 $\pm$ 0.2 g CH\textsubscript{4}-C m\textsuperscript{-2} for the control site.

In this study, the spatial variations in measured daily N\textsubscript{2}O and CH\textsubscript{4} fluxes from all the 16 chambers were large with coefficient of variations ranging between 44 and 217%. These spatial variations in N\textsubscript{2}O and CH\textsubscript{4} fluxes presented the typical behavior of emissions from animal systems where excretal inputs are deposited unevenly (Saggar et al., 2010; Giltrap et al., 2011). The coefficient of variation values is similar to those reported for many other New Zealand dairy-grazed pastures studies (Saggar et al., 2004, 2007, 2010; Giltrap et al., 2007, 2008, 2011) and indicates that increasing the number of chambers does not reduce spatial variability in emission estimates from grazed pasture soils but it does give more confidence that the mean value reflects the true flux for the site (Saggar et al., 2010). Saggar et al. (2010) reported that there were no differences
estimating N₂O emissions from grazed pasture using 40 and 20 chamber for a 4.800 m² studying area. Thus, using 16 chambers for 500 m² in our experiment seems to be in a good agreement for estimating CH₄ and N₂O fluxes.

The highest values for N₂O fluxes may be attributed to fresh urine spots and the lowest values were representative of the areas without fresh deposition (Saggar et al., 2010). Although, CH₄ fluxes is a consequence of manure accumulation, that difficult movement of water and gases through the soil and increases anaerobic sites favoring to CH₄ emissions.

3.2. Soil moisture

Soil water content estimated by gravimetric measurement showed that during the gas sampling campaign soil volumetric water content ranged from very dry at 0.10 (v/v) (WFPS 37%) to 0.35 (v/v) (WFPS 71%). The soil was at its driest on the beginning of the field campaign, increasing its moisture after to significant rains (6th and 22th of July) and the stayed stable from 3th July until the finishing of the field campaign in 14th August (WFPS 60%). There were no periods of wetness when the soil was at or above field capacity (WPFS 89%).

4. Discussion

The present study represents the first GHG measurements of a beef cattle feedlot pen in Brazil. We used 16 closed static chambers, over a 78 day period to assess temporal and spatial differences in CH₄ and N₂O fluxes simultaneously at the soil surface. Closed static chambers are a frequently used field method to estimate these trace gas fluxes (Boadi et al., 2004; Saggar et al., 2004, 2007, 2010; Giltrap et al., 2008, 2010, 2011). They have the advantage of being able to assess spatial variability (Kelliher et al., 2002) and such a large number of chambers have been used to provide
data for modelling (Saggar et al., 2004, 2007, 2010) and upscaling (Giltrap et al., 2006) of \( \text{CH}_4 \) and \( \text{N}_2\text{O} \) emissions from animal systems.

Our measurements show that set-stocking 21 beef steers in a 500 m\(^2\) pen for 78 days 0.12 and 0.13\% of excretal N and C inputs (emission factor, EF) were emitted as \( \text{N}_2\text{O}\text{-N} \) and \( \text{CH}_4\text{-C} \), respectively. This value was set assuming the calculated average daily excretal C (1280 g) and N (160 g) per beef cattle. Excretal C and N inputs for a stocking rate of 21 SU pen\(^{-1}\) would therefore be 2096.6 and 262.1 kg C and N pen\(^{-1}\) during the 78 days. As \( \text{N}_2\text{O}\text{-N} \) emissions from the pen site (500m\(^2\)) were 759.6 g \( \text{N}_2\text{O}\text{-N} \) and from the control site 116.5 g \( \text{N}_2\text{O}\text{-N} \), anthropogenic \( \text{N}_2\text{O} \) emissions would be 643.1 g \( \text{N}_2\text{O}\text{-N} \) (pen – control). For \( \text{CH}_4 \), the pen emitted 5712.7 g \( \text{CH}_4\text{-C} \) and from the control site 155.1 g \( \text{CH}_4\text{-C} \), anthropogenic \( \text{CH}_4 \) emissions would be 5557.6 g \( \text{CH}_4\text{-C} \) (paddock – control). It also means an emission of 0.4 and 3.4g of \( \text{N}_2\text{O}\text{-N} \) and \( \text{CH}_4\text{-C} \) per head a day, respectively

The EF obtained for beef cattle in pen is, indeed, much less the EF of 2.0 and 0.5\% of N and C input, respectively, which should be used for Brazil for estimation of direct \( \text{N}_2\text{O} \) and \( \text{CH}_4 \) emission in drylot (IPCC, 2006). Although, this comparison should be analyzed with careful once the manure from the pen under study was removed as soon as the animal reached weighted to be slaughtered, and then, emissions were relocated elsewhere, as far as IPCC emission factor considers an annual basis emission.

In the other hand manure removal at the final of the feeding period represents the most common manure management in beef cattle feedlots pen in Brazil (Costa Junior, et al. in press). Consequently, we believe that these EFs found out here should be useful for further Brazilian greenhouse gas emissions inventories. Although, further research should be carried out in order to increase robustness of our data, verifying the
influence of other animal stocking rates, diets, feedlots facilities and Brazilian regions as well as emission from post use of manure.

5. Conclusions

Nitrous oxide and methane emissions from a 500 m² pen surface holding 21 beef cattle during 78 days on feed were 0.2 kg N₂O-N/day and 1.1 kg CH₄-C, respectively. Emission factor were calculated to be 0.12 and 0.13% of the N and C excreted, respectively.

Once this study represents the first beef cattle feedlot pen surface GHG measurements in Brazil, we suggest that further studies should consider different animal types, stocking rates, diets, and feedlots facilities. Hence, as emissions of N₂O and CH₄ also could occur from the post manure management after pens cleaning, it would be useful those evaluations that still unknown for Brazilian conditions. In addition, this work contributes to validation of computer models and will help to more accurately predict the beef industries contributions to climate change and air quality as well as provides evidence to support N₂O and CH₄ mitigation strategies for beef cattle feedlot manure management.

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References


Smith KA, Dobbie KE. 2001. The impact of sampling frequency and sampling times on chamber-based measurements of N2O emissions from fertilized soils. Global Change Biol. 7:933–945.

Figure 1. Daily mean temperature and rainfall during the field campaign.

Figure 2. Soil water pore filled space during the field campaign.
Figure 3. Methane and nitrous oxide emissions from 500 m² bare soil feedlot pen surface during 78 days holding 21 beef cattle. Vertical bars represent standard deviations (n=18).