NITROUS OXIDE EMISSIONS FROM ANIMAL EXCRETA DEPOSITED ON HILL COUNTRY SLOPES

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Abstract
The objective of this study was to conduct field measurements of nitrous oxide (N\textsubscript{2}O) emissions caused by deposition of sheep and beef cattle dung and urine on hill country pasture. This work was carried out on a free-draining volcanic soil at the Whatawhata Research Farm in the Waikato region as part of a series of nationwide field trials conducted in 2015. This research provides field data to determine background N\textsubscript{2}O emissions and the emission factor (EF\textsubscript{3}, % of the applied excreta N emitted as N\textsubscript{2}O) for animal excreta deposited in the autumn-winter on steep (>25\textdegree) and moderate (12-25\textdegree) slopes. N\textsubscript{2}O flux measurements were made using a closed chamber technique.

N\textsubscript{2}O fluxes from controls on both medium and steep slopes were less than 0.55 mg N\textsubscript{2}O-N m\textsuperscript{-2} hr\textsuperscript{-1} through the four month (winter/early spring) measurement period. Greater variability in background emissions was exhibited on the steep slopes than on the medium slopes. There was a slight trend for higher total background N\textsubscript{2}O emissions from medium (average 0.035 kg N\textsubscript{2}O ha\textsuperscript{-1}) compared to steep slope areas (average 0.021 kg N\textsubscript{2}O ha\textsuperscript{-1}), but the difference was not significant (P>0.05). EF\textsubscript{3} values for all excreta types were generally very low and highly variable. There was a trend for higher EF\textsubscript{3} values on the medium slope than on the steep slope, with beef cattle dung on the medium slope having the highest EF\textsubscript{3} value and sheep dung on the steep slope having the lowest EF\textsubscript{3} value. There was no apparent relationship between EF\textsubscript{3} and soil properties, including soil Olsen P, moisture and mineral nitrogen levels.

Introduction
In grazed hill country, there is great spatial variation in soil chemical and physical characteristics and in excreta deposition patterns due to animal behaviour, all of which are known drivers of N\textsubscript{2}O production and emissions. In the Ministry of Agriculture and Forestry (MAF)-funded studies conducted in 2008-09, a framework was developed and later refined to enable up-scaled calculations of N\textsubscript{2}O emissions in hill country (Hoogendoorn et al., 2008; de Klein et al., 2009). This framework considered the impact of topography in hill country on both the drivers of N\textsubscript{2}O emissions and on excreta nitrogen (N) deposition patterns.

Results from previous studies in hill country indicate that the N\textsubscript{2}O emission factor, EF\textsubscript{3}, for sheep and cattle urine deposited on low (0 – 12\textdegree) slopes is significantly greater than from medium (12 – 25\textdegree) slopes and several studies have reported a significantly higher EF\textsubscript{3} from cow urine deposited on relatively flat low-land sites compared to low slope/camp areas of grazed hill country (van der Weerden et al., 2011; Luo et al., 2012; 2013; Kelliher et al., 2014; Saggar et al., 2015). A previous Ministry for Primary Industries (MPI)-funded trial also suggested that EF\textsubscript{3} values for animal dung on the medium slope were lower than those on the low slope (Hoogendoorn et al., 2013).
It is possible that emissions from excreta on steep (>25°) slopes in hill country may be even lower. There is a need for robust data to provide evidence for consideration of a national-level disaggregation for EF₃ for hill country into EF₃-low slope, EF₃-medium slope and EF₃-steep slope. The EF₃ values generated in this initial study will help to provide direction for further research for refining New Zealand’s agricultural greenhouse gas inventory (MfE, 2015).

The objective of this study was to determine the autumn-winter N₂O emission factor (EF₃) for sheep urine, beef cattle urine, sheep dung and beef cattle dung, as affected by slope class (steep vs. medium).

Materials and Methods

Site Description and Preparation
This work was carried out on a free-draining volcanic soil at the Whatawahata Research Centre in the Waikato region in 2015 on steep and medium slopes. As for previous trials assessing EF₃ from sheep urine and dung in hill country (Luo et al., 2012; 2013), the trial site was located in hill country that had a history of moderately intensive management (stocking rate of 12-14 stock units ha⁻¹ yr⁻¹). Grazing animals were excluded from the field trial sites for at least three months before the commencement of the trials. Approximately two weeks before the trial began field plots were established on both slope class areas. Excreta treatments were assigned to the plots in a randomised block design with 5 replicates of each treatment. There were 4 excreta treatments: sheep urine (SU), beef cattle urine (CU), sheep dung (SD), beef cattle dung (CD) and a control (C) on the medium and steep slope areas. Plot size was 1.5 x 1.5 m for all treatments, and there was an additional buffer area of at least 0.5 m between adjacent plots. At four of the five blocks in each slope class, separate areas (about 1.0 x 1.5 m) within each plot were used for destructive soil sampling. These plots received the same treatments as for N₂O measurements. Real sheep and cattle excreta were applied for N₂O measurements; and artificial sheep and beef urine (Fraser et al., 1994) and real sheep and beef dung were applied to the separate soil sampling areas within plots.

Table 1. Study plan for determining autumn/winter N₂O emission factors (EF₃) for cattle and sheep excreta applied to medium and steep sloped areas of grazed hill country. CU = beef cattle urine, CD = beef cattle dung, SU = sheep urine, SD = sheep dung and C = control.
**Treatment application**
Sheep urine was collected from cull ewes at a local abattoir. All these sheep had been fed a diet of low quality pasture, similar to the quality found on hill country farms. Beef cattle urine was collected from beef heifers grazing hill country pasture at the Whatawhata Research Centre farm.

Freshly deposited sheep and beef cattle dung were collected from nearby paddocks. The dung was thoroughly mixed and stored in containers at 4°C until application day. On the application days, all applied urine and dung were again sampled for analysis of total N concentration to determine actual N loading rates.

**Excreta N rates**
Due to wide variations in urine-N concentration within days, between days and between individual sheep and cattle, a standard urine N concentration of 6 g N L\(^{-1}\) was adopted for both livestock types (Haynes and Williams, 1993). The total N concentration of the sheep urine collected was 15.7 g N L\(^{-1}\), while the total N concentration of the beef cattle urine collected was 6.9 N L\(^{-1}\). Water was added to decrease the concentrations to the standard value of 6 g N L\(^{-1}\).

The urine was applied at 10 L m\(^{-2}\) for beef cattle and 4 L m\(^{-2}\) for sheep to represent the average volume of urine voided in a single urination event, resulting in N loadings equivalent to 600 and 240 kg N ha\(^{-1}\). Previous studies with sheep urine on hill country have had N loadings of ~240 kg N ha\(^{-1}\) (Luo et al., 2013; Hoogendoorn et al. 2011). Urine N loadings onto medium and steep land were adjusted for runoff, where 33% and 50% runoff was assumed (Luo et al., 2014), resulting in reduced specific N loading rates (see Table 1). On both the medium slope and the steep slope areas, beef cattle and sheep dung were applied at a rate of about 800 kg N ha\(^{-1}\) and 300 kg N ha\(^{-1}\), respectively (Table 1).

**Treatment application**
Treatments were applied on 20 May 2015. Urine was applied slowly and evenly to the entire area for both the gas and soil sampling sub-plots. Appropriately sized containers with perforated lids were used to apply the urine to the gas sampling plots and small garden sprinkling cans were used to apply the urine to the soil sampling sub-plots. To ensure that the urine was applied evenly on the plots, the total amount to be applied to each gas/soil sub-plot was divided equally into quarters, and each quarter applied evenly to the entire area. The same procedure was used for both the medium and steep slope plots. Great care and patience were taken to apply urine to the plots in order to prevent urine runoff. Dung was applied evenly to the gas sampling plots and to the soil sampling plots.

**Nitrous oxide measurements and calculations**
Following the treatment applications, N\(_2\)O emission measurements were carried out twice a week for the first 4 weeks and thereafter weekly. During weekly phases of N\(_2\)O flux measurement, additional sampling occurred as soon as practicable following rainfall events of greater than 10 mm of rain in 24 hr. Gas sampling continued for four months, when N\(_2\)O fluxes from excreta treatments returned to background (control plot) levels.
A static soil chamber technique was used to measure N$_2$O emissions using a methodology based on previous studies on N$_2$O emissions (Luo et al., 2015). Gas samples were analysed for N$_2$O concentration using a gas chromatograph fitted with an electron capture detector. The hourly emissions were integrated over time, for each chamber, to estimate the total emission over the measurement period. From these results EF$_3$ values were calculated. Differences in EF$_3$ between treatments were analysed using the statistical software package GenStat® for Windows® 13th edition.

Soil and climate parameters
At four of the five blocks in each slope class, separate areas within each plot were used for destructive soil sampling. These plots received the same treatments as for N$_2$O measurements (Table 1), except that artificial sheep and beef urine replaced real sheep and beef urine. Soil samples were taken to a depth of 75 mm at every gas sampling event. Soil moisture was determined on each occasion and soil ammonium-N (NH$_4^+$-N) and nitrate-N (NO$_3^-$-N) were determined on each alternate occasion (2M KCl extraction followed by analysis using a Skalar SAN$^{++}$ segmented flow analyser).

Water-filled pore space (WFPS) was calculated by dividing volumetric water content by total porosity (Linn and Doran, 1984).

Daily rainfall and ambient air and soil temperatures were recorded for the entire trial period, beginning at least 1 week before treatment application, at a permanent meteorological site approximately one kilometre from the trial site.

Results

Soil and climatic conditions
Soils in medium slope areas generally had higher concentrations of phosphorus (Olsen P), organic carbon (OC) and N, but lower carbon:nitrogen ratios compared to those in the steep sloped areas (Table 2). Soil bulk densities were similar for both slope classes.

<table>
<thead>
<tr>
<th>Slope Class</th>
<th>Olsen P (µg ml$^{-1}$)</th>
<th>pH</th>
<th>OC (%)</th>
<th>TN (%)</th>
<th>C:N</th>
<th>Bulk density (g cm$^{-3}$)</th>
<th>Base N$_2$O flux (mg N m$^{-2}$ hr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium slope</td>
<td>18</td>
<td>5.5</td>
<td>8.6</td>
<td>0.76</td>
<td>11.3</td>
<td>0.71</td>
<td>0.005</td>
</tr>
<tr>
<td>Steep slope</td>
<td>10</td>
<td>5.5</td>
<td>8.2</td>
<td>0.68</td>
<td>12.1</td>
<td>0.73</td>
<td>0.001</td>
</tr>
</tbody>
</table>

The total amount of rainfall during the first six weeks post excreta application was 171 mm. The mean daily air temperature during the first six weeks post excreta application was 11.8°C. During the entire trial period the mean daily air temperature was 11.1 °C.
Soil mineral N concentrations

Soil mineral N concentrations are presented in Figures 1a and 1b. Concentrations of NH$_4^+$-N and NO$_3^-$-N in the control treatments were generally low for both slope areas throughout the sampling period. On the excreta treated plots concentrations of NH$_4^+$-N in the soil peaked within several days after urine application. The peak NO$_3^-$-N concentrations were generally much less than the peak NH$_4^+$-N concentrations. Nitrification only appeared to account for only a small part of the decline in soil NH$_4^+$-N concentrations.

Dung-treated soils at both medium and steep slope sites showed some increase in NH$_4^+$-N concentrations after application (Figures 1a and 1b). NO$_3^-$-N concentrations in the cattle dung treated soil on both medium and steep slopes peaked within two months post excreta application. However, sheep dung treated soil showed no peaks in NO$_3^-$-N concentrations on both slope class sites.

Nitrous oxide fluxes

Background N$_2$O fluxes, measured on one occasion before the excreta treatments were applied, were generally low (between 0 and 0.005 mg N m$^{-2}$ hr$^{-1}$) and were similar across the two slopes.

N$_2$O fluxes from controls on both medium and steep slopes were low (less than 0.55 mg N$_2$O-N m$^{-2}$ hr$^{-1}$) throughout the measurement period (Figures 1a and 1b). Application of either animal urine or dung increased N$_2$O fluxes, but the patterns and magnitudes of the increases were not consistent between excreta types and slope classes. Changes in the fluxes were not significantly correlated to changes in soil moisture levels, mineral nitrogen (N) concentrations or temperature. The largest increases in N$_2$O fluxes were due to application of cattle dung on medium slopes. N$_2$O fluxes from sheep urine and dung application were generally low and were not much different from the control on most sampling occasions.

Background N$_2$O emissions

Within a slope class, total background N$_2$O emissions from the control plots were generally low and exhibited large variation. There was a trend for higher total background N$_2$O emissions from medium (0.035 kg N$_2$O-N ha$^{-1}$) compared to steep slope areas (0.021 kg N$_2$O-N ha$^{-1}$), but this trend was not statistically significant (P>0.05). None of the basic soil chemical properties (Olsen P, TN, OC and C:N ratio) measured at the start of the trials (Table 2) were able to account for the slope class variation in observed background emissions. One of the reasons for this could be related to the low overall N$_2$O emission values and therefore the lack of variability.

Total N$_2$O emissions

Application of either animal urine or dung increased total N$_2$O emissions, but the magnitudes of the increases were not consistent between excreta types or slope classes. The largest increases in total N$_2$O emissions were due to applications of beef cattle dung on both medium and steep slopes (Figure 2). The smallest increases in total N$_2$O emissions were due to sheep dung and sheep urine applications on steep slopes. For all excreta types total N$_2$O emissions were approximately 5 times higher on moderate slopes than on steep slopes.
Figure 1a: Medium slope: Hourly $\text{N}_2\text{O}$ fluxes from urine treatments (lines) and WFPS (diamond symbols) at each sampling occasion, daily rainfall (bars) and daily mean 10 cm soil temperature (red lines), and mineral N content following animal excreta application. Data points represent mean values ± standard error of the mean (n = 5 for $\text{N}_2\text{O}$ flux data and n = 4 for WFPS and soil mineral N data).
Figure 1b: Steep slope: Hourly N₂O fluxes from urine treatments (lines) and WFPS (diamond symbols) at each sampling occasion, daily rainfall (bars) and daily mean 10 cm soil temperature (red lines), and mineral N content following animal excreta application. Data points represent mean values ± standard error of the mean (n = 5 for N₂O flux data and n = 4 for WFPS and soil mineral N data).
Figure 2: Total emissions from all treatments (kg N₂O-N ha⁻¹). Error bars represent mean ± S.E.M. (n = 5).

Nitrous oxide emission factors - EF₃

Nitrous oxide emission factors were calculated for each of the excreta types. These are presented in Table 3. Emission factors were generally very low, with most of the averages being less than 0.1%. The NZ default EF₃ values are 1% and 0.25% for deposited urine and dung, respectively (MfE, 2015). There were relatively large variations in the EF₃ values, as indicated by the standard error of the mean (S.E.M.; Table 3) and no statistically significant difference in urine or dung EF₃ values between the two slope classes. There was a trend for higher EF₃ values on the medium slope than on the steep slope. Beef cattle dung on the medium slope appeared to have a higher EF₃ value than on the steep slope.

<table>
<thead>
<tr>
<th>Slope class</th>
<th>Treatment</th>
<th>Mean</th>
<th>S.E.M.</th>
<th>Current IPCC Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>Cattle urine</td>
<td>0.09</td>
<td>0.038</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Sheep urine</td>
<td>0.08</td>
<td>0.032</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Cattle dung</td>
<td>0.24</td>
<td>0.047</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Sheep dung</td>
<td>0.10</td>
<td>0.032</td>
<td>0.25</td>
</tr>
<tr>
<td>Steep</td>
<td>Cattle urine</td>
<td>0.02</td>
<td>0.013</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Sheep urine</td>
<td>0.02</td>
<td>0.023</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>Cattle dung</td>
<td>0.05</td>
<td>0.018</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>Sheep dung</td>
<td>0.00</td>
<td>0.016</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Table 3: EF₃ (%) Values are arithmetic means with standard errors of the means (S.E.M.); n = 5.
Conclusions

N₂O fluxes from the controls on both medium and steep slopes were very low (less than 0.55 mg N₂O-N m⁻² hr⁻¹) throughout the 4-6 month (winter/early spring) measurement period. The low fluxes may reflect low soil fertility status in the soils of these hill land sites, compared with flat land soils. Average background N₂O emissions during the 4-6 month (winter/early spring) measurement period were about 0.035 and 0.021 kg N₂O-N ha⁻¹ for the medium and steep slopes, respectively, and these emissions were not significantly different from each other. Application of either animal urine or animal dung appear to increase N₂O fluxes. Emission factors were generally very low, with most of the averages being less than 0.1%, and highly variable. The EF₃ values generated in this initial study will help to provide direction for further research for refining New Zealand’s agricultural greenhouse gas inventory.

Acknowledgements

This study was funded by MPI. We acknowledge the extensive input by technical staff at AgResearch Ruakura (Stuart Lindsey, Martin Kear, Emma Bagley and Moira Dexter).

References


