Carlson B, Luo J, Wise B. 2016. Nitrous oxide emissions from animal excreta deposited on hill country slopes. In: *Integrated nutrient and water management for sustainable farming.* (Eds L.D. Currie and R. Singh). http://flrc.massey.ac.nz/publications.html. Occasional report No. 29. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 10 pages.

NITROUS OXIDE EMISSIONS FROM ANIMAL EXCRETA DEPOSITED ON HILL COUNTRY SLOPES

Bill Carlson, Jiafa Luo, Bridget Wise

Ruakura Research Centre, AgResearch Limited, Private Bag 3123, Hamilton, New Zealand
Email:bill.carlson@agresearch.co.nz

Abstract
The objective of this study was to conduct field measurements of nitrous oxide (N_2O) 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_2O emissions and the emission factor (EF_3, % of the applied excreta N emitted as N_2O) for animal excreta deposited in the autumn-winter on steep (>25^o) and moderate(12-25^o) slopes. N_2O flux measurements were made using a closed chamber technique.

N_2O fluxes from controls on both medium and steep slopes were less than 0.55 mg N_2O-N m^2 hr^{-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_2O emissions from medium (average 0.035 kg N_2O ha^{-1}) compared to steep slope areas (average 0.021 kg N_2O ha^{-1}), but the difference was not significant (P>0.05). EF_3 values for all excreta types were generally very low and highly variable. There was a trend for higher EF_3 values on the medium slope than on the steep slope, with beef cattle dung on the medium slope having the highest EF_3 value and sheep dung on the steep slope having the lowest EF_3 value. There was no apparent relationship between EF_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_2O 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_2O 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_2O emissions and on excreta nitrogen (N) deposition patterns.

Results from previous studies in hill country indicate that the N_2O emission factor, EF_3, for sheep and cattle urine deposited on low (0 – 12°) slopes is significantly greater than from medium (12 – 25°) slopes and several studies have reported a significantly higher EF_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_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 EF_3 for hill country into EF_3-low slope, EF_3-medium slope and EF_3-steep slope. The EF_3 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 N_2O emission factor (EF_3) 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 Whatawhata Research Centre in the Waikato region in 2015 on steep and medium slopes. As for previous trials assessing EF_3 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 N_2O measurements. Real sheep and cattle excreta were applied for N_2O 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 N_2O emission factors (EF_3) 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.

Soil type	Drainage class	Slope class and average site slopes (mean ± s.e.m.)	Treatment	N load applied (kg/ha)
Kaawa yellow brown earth	Free draining	Medium (16.5° ± 2°)	SU	160
			CU	400
			SD	300
			CD	800
			C	
		Steep (28.5° ± 2°)	SU	120
			CU	300
			SD	300
			CD	800
			C	

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_2O emission measurements were carried out twice a week for the first 4 weeks and thereafter weekly. During weekly phases of N_2O 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_2O fluxes from excreta treatments returned to background (control plot) levels.

A static soil chamber technique was used to measure N_2O emissions using a methodology based on previous studies on N_2O emissions (Luo et al., 2015). Gas samples were analysed for N_2O 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_2O 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 2: Initial soil characteristics and base N_2O flux at each site. MS = medium slope; SS = steep slope; P = phosphorus; OC = organic carbon; TN = total nitrogen; C:N = carbon:nitrogen ratio.

Slope Class	Olsen P (µg ml^{-1})	pH	OC (%)	TN (%)	C:N	Bulk density (g cm^{-3})	Base N_2O flux (mg N m^{-2} hr^{-1})
Medium slope	18	5.5	8.6	0.76	11.3	0.71	0.005
Steep slope	10	5.5	8.2	0.68	12.1	0.73	0.001

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_2O 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_2O fluxes from controls on both medium and steep slopes were low (less than 0.55 mg N_2O-N m^2 hr^{-1}) throughout the measurement period (Figures 1a and 1b). Application of either animal urine or dung increased N_2O 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_2O fluxes were due to application of cattle dung on medium slopes. N_2O fluxes from sheep urine and dung application were generally low and were not much different from the control on most sampling occasions.

Background N_2O emissions

Within a slope class, total background N_2O emissions from the control plots were generally low and exhibited large variation. There was a trend for higher total background N_2O emissions from medium (0.035 kg N_2O-N ha^{-1}) compared to steep slope areas (0.021 kg N_2O-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_2O emission values and therefore the lack of variability.

Total N_2O emissions

Application of either animal urine or dung increased total N_2O emissions, but the magnitudes of the increases were not consistent between excreta types or slope classes. The largest increases in total N_2O emissions were due to applications of beef cattle dung on both medium and steep slopes (Figure 2). The smallest increases in total N_2O emissions were due to sheep dung and sheep urine applications on steep slopes. For all excreta types total N_2O emissions were approximately 5 times higher on moderate slopes than on steep slopes.

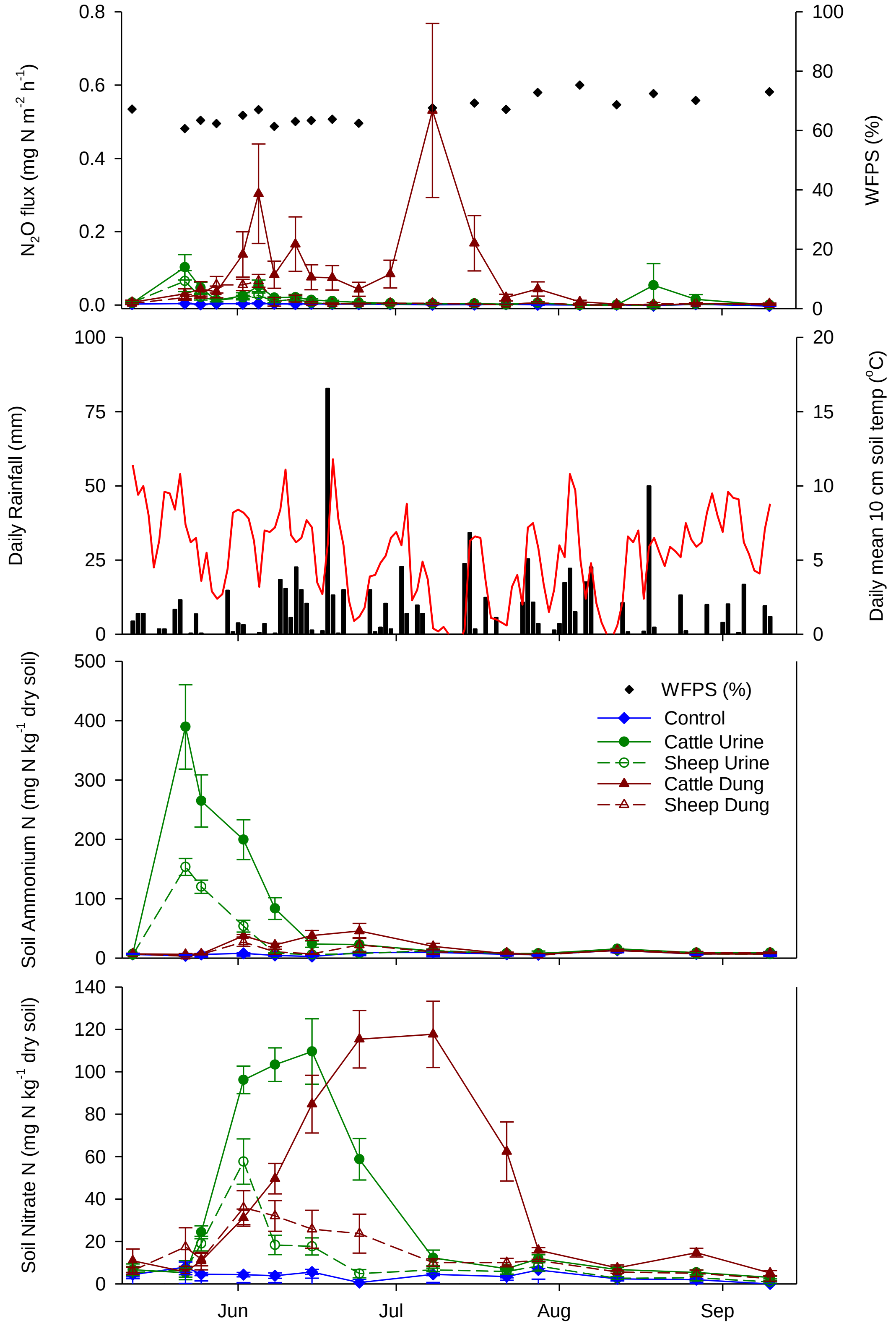

Figure 1a: **Medium slope:** Hourly N_2O fluxes from urine treatments (lines) and WFPS (diamond symbols) at each sampling occasion, daily rainfall (bars) and daily mean 10 cm soil temperature (red lines), and mineral N content following animal excreta application. Data points represent mean values ± standard error of the mean (n = 5 for N_2O flux data and n = 4 for WFPS and soil mineral N data).

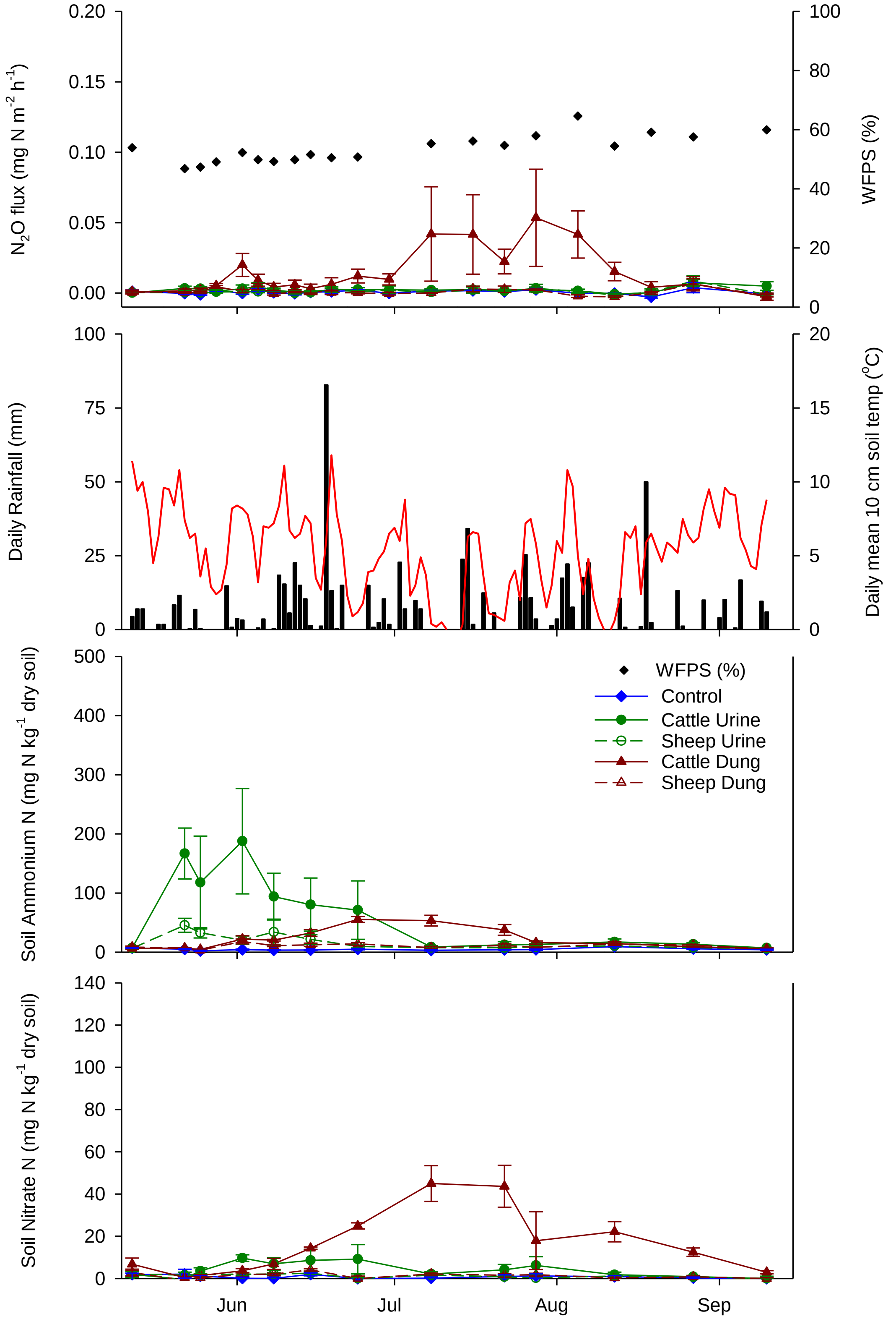

Figure 1b: Steep slope: Hourly N_2O fluxes from urine treatments (lines) and WFPS (diamond symbols) at each sampling occasion, daily rainfall (bars) and daily mean 10 cm soil temperature (red lines), and mineral N content following animal excreta application. Data points represent mean values ± standard error of the mean (n = 5 for N_2O flux data and n = 4 for WFPS and soil mineral N data).

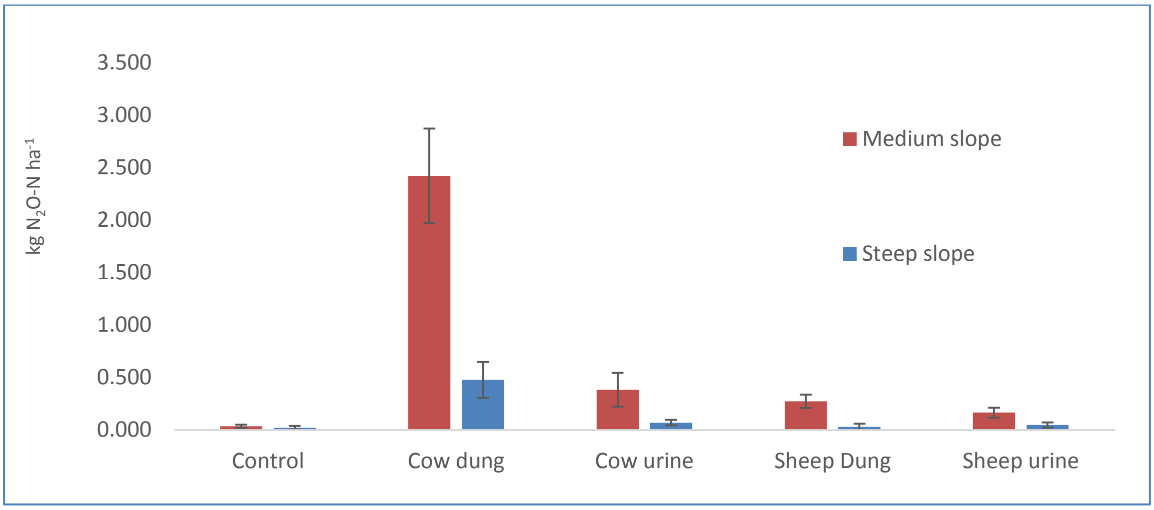

Figure 2: Total emissions from all treatments (kg N_2O-N ha^{-1}). Error bars represent mean ± S.E.M. (n = 5).

Nitrous oxide emission factors - EF_3

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 EF_3 values are 1% and 0.25% for deposited urine and dung, respectively (MfE, 2015). There were relatively large variations in the EF_3 values, as indicated by the standard error of the mean (S.E.M.; Table 3) and no statistically significant difference in urine or dung EF_3 values between the two slope classes. There was a trend for higher EF_3 values on the medium slope than on the steep slope. Beef cattle dung on the medium slope appeared to have a higher EF_3 value than on the steep slope.

Slope class	Treatment	Mean	S.E.M.	Current IPCC Default
Medium	Cattle urine	0.09	0.038	1.00
	Sheep urine	0.08	0.032	1.00
	Cattle dung	0.24	0.047	0.25
	Sheep dung	0.10	0.032	0.25
Steep	Cattle urine	0.02	0.013	1.00
	Sheep urine	0.02	0.023	1.00
	Cattle dung	0.05	0.018	0.25
	Sheep dung	0.00	0.016	0.25

Table 3: EF_3 (%) Values are arithmetic means with standard errors of the means (S.E.M.); n = 5.

Conclusions

N_2O fluxes from the controls on both medium and steep slopes were very low (less than 0.55 mg N_2O-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 N_2O emissions during the 4-6 month (winter/early spring) measurement period were about 0.035 and 0.021 kg N_2O-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 N_2O fluxes. Emission factors were generally very low, with most of the averages being less than 0.1%, and highly variable. The EF_3 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

de Klein CAM, Hoogendoorn C, Manderson A, Saggar S, Giltrap D, Briggs C, Rowarth J (2009) Refinement of the framework for upscaling nitrous oxide emissions from hill country. Report for MAF Policy. Pp 77.

Fraser PM, Cameron KC, Sherlock KC (1994) Lysimeter study of the fate of nitrogen in animal urine returns to irrigated pasture. European Journal of Soil Science 45: 439–447.

Haynes RJ, Williams PH (1993) Nutrient cycling and soil fertility in the grazed pasture ecosystem. Advances in Agronomy 49: 119-199.

Hoogendoorn C, de Klein CAM, Saggar S, Briggs (2008) Determination of factors affecting upscaling of nitrous oxide emissions in hill country. Report Prepared for Ministry of Agriculture & Forestry MAF-POL/CP08 AG-INVENT-22. Pp 45.

Hoogendoorn CJ, Luo J, van der Weerden T, Saggar S, Wise B, Lloyd-West C, Judge A (2013) Evaluation of beef cattle excreta nitrous oxide emission factors – Final report to MPI. Pp 55.

Hoogendoorn, C J, Betteridge K (2011) Nitrogen concentration in the urine of cattle, sheep and deer grazing a common ryegrass/cocksfoot/white clover pasture. New Zealand Journal of Agricultural Research 53: 235-243.

Kelliher F, Cox N, van der Weerden T, de Klein C, Luo J, Cameron K, Di H, Giltrap D, Rys G (2014) Statistical analysis of nitrous oxide emission factors from pastoral agriculture field trials conducted in New Zealand. Environmental Pollution 186: 63-66.

Linn DM, Doran JW (1984) Effect of water-filled pore space on carbon dioxide and nitrous oxide production in tilled and non-tilled soils. Soil Science Society American Journal 48: 1267-1272.

Luo J, Hoogendoorn C, van der Weerden T, de Klein C, Saggar S (2012). Re-assessment of animal excreta nitrous oxide emission factors in grazed hill country – Final Report MAF POL 12210 (IR-D7). Pp 59.

Luo J, Hoogendoorn C, van der Weerden T, Saggar S, de Klein C (2014). N_2O emission factors for animal excreta deposited on hill country steep slopes - Experimental plan and protocol. Report to MPI, Wellington. Pp 16.

Luo J, Hoogendoorn C, Van Der Weerden T, Saggar S, De Klein C, Giltrap D, Rollo M, Rys G (2013) Nitrous oxide emissions from grazed hill land. Agriculture, Ecosystems and Environment 181: 58-68.

Luo J, Sun XZ, Pacheco D, Ledgard SF, Lindsey SB, Hoogendoorn CJ, Wise B, Watkins NL (2015) Nitrous oxide emission factors for urine and dung from sheep fed either fresh forage rape (Brassica napus L.) or fresh perennial ryegrass (Lolium perenne L.). Animal - An International Journal of Animal Bioscience 9, 534-543.

MfE (2015) New Zealand's Greenhouse Gas Inventory 1990-2013. http://www.mfe.govt.nz/climate-change/reporting-greenhouse-gas-emissions/nzs-greenhouse-gas-inventory.

Saggar S, Giltrap DL, Davison R, Gibson R, DeKlein C, Rollo M, Ettema P, Gerald Rys G. (2015) Estimating direct N_2O emissions from sheep, beef, and deer grazed pastures in New Zealand hill country: accounting for the effect of land slope on the N_2O emission factors from urine and dung. Agriculture, Ecosystems and Environment (in press).

van der Weerden TJ, Luo J, de Klein CAM, Hoogendoorn CJ, Littlejohn RP, Rys GJ (2011) Disaggregating nitrous oxide emission factors for ruminant urine and dung deposited onto pastoral soils. Agriculture, Ecosystems and Environment 141: 326-436.