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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

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ABSTRACT

Nearly one-half of New Zealand's ruminant livestock graze on hill country pastures where spatial differences in soil conditions are highly variable and excretal deposition is influenced by pasture production, animal grazing and resting behaviour that impact the nitrous oxide (N_2O) emission factor from excreta (EF_3). New Zealand currently uses country-specific EF_3 values for urine and dung of 0.01 and 0.0025, respectively, to estimate direct N_2O emissions from excreta. These values have largely been developed from trials on flat pastoral land. The use of the same EF_3 for hill pasture with medium and steep slopes has been recognised as a possible source of overestimation of N_2O emissions in New Zealand. The objectives of this study were to develop and describe an approach that takes into account the effects of slope in estimating hill country N_2O emissions from the dung and urine of ruminant animals (sheep, beef cattle, and deer) across different slope classes, and then compare these estimates with current New Zealand inventory estimates. We use New Zealand as a case study to determine the direct N_2O emissions between 1990 and 2012 from sheep, beef cattle and deer excreta using updated estimates of EF_3 for sloping land, the area of land in different slope classes by region and farm type, and a nutrient transfer model to allocate excretal-N to the different slope classes, and compare the changes between these hill pastures-specific and current inventory estimates. Our findings are significant – the proposed new methodology using New Zealand specific EFs calculated from a national series of hill country experiments resulted in 52% lower N_2O estimates relative to using current inventory emission factors, for the period between 1990 and 2012 and reduces New Zealand's total national agricultural N_2O greenhouse inventory estimates by 16%. The improved methodology is transparent, and complete, and has improved accuracy of emission estimates. On this basis, the improved methodology of estimating N_2O emission is recommended for adoption where hill land grasslands are grazed by sheep, beef cattle and deer.

1. Introduction

The Annex I countries [the industrialized member countries of the OECD (Organisation for Economic Co-operation and Development) in 1992, plus countries with economies in transition (the EIT Parties)] that have ratified the United Nations Framework Convention on Climate Change (UNFCCC) have an obligation to report their anthropogenic greenhouse gas (GHG) emissions and removals each year. Reported emissions and removals therefore need to be as accurate as possible. Using the Intergovernmental Panel on Climate Change (IPCC) guidelines for National Greenhouse Gas Inventories and a good practice guidance approach, a pragmatic means of building greenhouse gas inventories can be achieved (IPCC (Intergovernmental Panel on Climate Change), 2006). Countries are encouraged to improve the transparency, accuracy, comparability, consistency, and completeness of their emissions estimates and reporting. This can be achieved by carrying out research and determining country-specific information, thus, enabling the use of country-specific emission factors and fractions rather than IPCC default values (IPCC, 2006).

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In countries such as New Zealand, Australia, Latin and Central America, and China where open grazing is practised, large amounts of animal excreta are directly deposited onto pasture land, and a substantial amount of N is decoupled and recycled. Also the landscape is dominated by hills, including a mosaic of slope classes and aspect categories with different production potentials and variable responses to added nutrients and excretal inputs. While the majority of flat pastures are grazed by dairy cattle, hill country pastures are mainly grazed by sheep and beef cattle.

While we aim to evaluate the globally relevant grazed hill land emissions, we use New Zealand grazed pasture systems as a case study. New Zealand grazed soils also receive an uneven deposition of animal urine and dung, which imposes variable soil fertility (Saggar et al., 1990a,b,b). As a small country with a diverse range of climo-edaphic environments and geography, New Zealand experiences high fluctuations of temperature and moisture from North to South along its 1600 km length and sustain microbially diverse population (Morales et al., 2014). The excretal deposition in hill land pastures with highly variable spatial differences in soil conditions is influenced by pasture production, animal grazing and resting behaviour. This range provides a natural experiment for developing a spatial framework model that disaggregates excretal deposition and N_2O emission factors according to slope class to study the impacts on hill country N_2O emissions at national level.

The New Zealand Agricultural Greenhouse Gas Inventory model ("the Inventory") calculates methane (CH_4) and nitrous oxide (N_2O) emissions using livestock numbers and animal performance data (MfE (Ministry for the Environment), 2012). Using these data and livestock population models based on industry expert opinion, animal dry matter intake, nitrogen excretion, and subsequently, CH_4 and N_2O are estimated.

New Zealand-specific emission factors for estimating N_2O emissions from excreta (EF_3) have been developed (Luo and Kelliher, 2010). These factors, 0.01 for urine and 0.0025 for dung, were developed from trials conducted mainly on flat pastoral land. However, nearly one-half of the national livestock graze hill-country pastures with different production potentials and generally low soil fertility. Pasture production, plant nutrient composition, animal intake, and excretal returns vary with slope class, resulting in more excreta on low slopes (58%) due to stock resting behaviour, compared with 30% for medium and 12% for steep slopes grazed by sheep (Saggar et al., 1990a).

The current estimate of emissions from the excreta of livestock grazing on hill country has been recognised as a possible source of overestimation of N_2O emissions in New Zealand. In 2009, work on developing an improved framework for estimating hill land emissions was undertaken (Hoogendoorn et al., 2008; de Klein et al., 2009). This framework characterised the hill land topography units along with a nutrient transfer model of Saggar et al. (1990a, b); Saggar et al. (1990a,b) and was therefore able to estimate N excretion rates and successfully account for the effect of topography-driven spatial variability on excretal N return and EF_3 in grazed hill land. Field data (de Klein et al., 2010) indicated that on moderate and steep slopes the EF_3 could be a fraction of 0.01 for urine and 0.0025 for dung used on flat pastoral land. Further, the fraction of N in excreta emitted as N_2O decreases as the slope increases (de Klein et al., 2010). A more recent study (Hoogendoorn et al., 2013) detected no significant differences in the EF_3 between low and medium slopes. However, Luo et al. (2013) found that when the results of both trials are combined the EF_3 of low slopes was significantly higher than that from medium slopes. Further, it has been shown that on sloping land there is not much difference between the emission factors of urine from sheep and beef cows (Kelliher et al., 2014).

The present study, therefore, was undertaken to estimate national N_2O emissions from sheep, beef and deer excreta (including the effects of grazed hill-country pastures) using a spatial framework model that disaggregates excretal deposition and N_2O emission factors according to slope class to quantify the impacts on hill country N_2O emissions at national level.

2. Methods and materials

2.1. Overview of a spatial framework for integrating N_2 emissions from hill country

A spatial framework was set up based on different regions and farm types in New Zealand (Table 1). Total N-excretion in hill country, calculated using animal numbers and N excretion data from the National Inventory, was then allocated to each region and farm type based on aggregated New Zealand animal data (Beef + Lamb Economic Farm Survey, 2015). The relative area of the different slope classes (low (<12°), medium (12–24°), or high (>24°)) within each region and farm type was determined from information from the Sheep and Beef Farm Survey. A nutrient transfer model was then used to allocate the excretal-N to each slope class. Nitrous oxide emissions were calculated by multiplying the excretal-N amounts by the appropriate EF_3 for excreta type (dung, urine), animal type and slope category.

Table 1
Average (1990–2012) proportion of land area in flat, rolling and steep slope classes for each farm class (Beef + Lamb Economic Farm Survey).

Farm class	Low slope area <12° (%)	Medium slope area 12–24° (%)	High slope area >24° (%)
Northland-Waikato-Bay of Plenty Hard Hill Country	6.5	34.0	59.5
Northland-Waikato-Bay of Plenty Hill Country	14.5	57.9	27.6
Northland-Waikato-Bay of Plenty Intensive Finishing	34.3	58.0	7.7
East Coast Hard Hill Country	4.1	21.5	74.3
East Coast Hill Country	8.7	45.9	45.5
East Coast Intensive Finishing	30.5	55.6	13.9
Taranaki-Manawatu Hard Hill Country	6.0	14.0	79.9
Taranaki-Manawatu Hill Country	11.2	27.7	61.1
Taranaki-Manawatu Intensive Finishing	52.1	39.4	8.4
Marlborough-Canterbury High Country	13.8	16.7	69.5
Marlborough-Canterbury Hill Country	15.6	15.8	68.5
Marlborough-Canterbury Finishing Breeding	51.5	37.7	10.8
Marlborough-Canterbury Mixed Finishing	81.4	16.2	2.5
Otago-Southland High Country	4.0	6.9	89.1
Otago-Southland Hill Country	36.6	29.7	33.7
Otago-Southland Finishing Breeding	20.5	54.5	25.0
Otago-Southland Intensive Finishing	59.0	39.4	1.7

2.2. Data sources

New Zealand has a total land area of 26.7 Mha and sheep and beef farming is the predominant land-use for hill country. Nearly half the land area (13.5 Mha) is high- or low-producing grassland (MfE (Ministry for the Environment), 2014), of which ~4.68 Mha identified as hill land using the NZLRI method was recommended to describe the hill country (de Klein et al., 2009). A suitable framework should account for year-to-year variations in industry data such as livestock numbers, stock type, land area changes and any material changes in agricultural practices. Data collated by the Beef + Lamb survey were considered as a reliable information source to capture many industry changes. We used data on beef and sheep numbers sourced from Beef + Lamb New Zealand based on the Sheep and Beef Farm Survey and Statistics New Zealand data collected in the Annual Agricultural Production Survey which also includes deer numbers.

Changes in the above variables and other data sets also need to be accounted for in the Inventory back to 1990.

The Sheep and Beef Farm Survey classifies farms into 8 classes (plus non-commercial), 5 regions, and 3 slope categories: low (<12° slope), medium (12–24° slope), and high (>24° slope). The farm classes represent different types of farm enterprises that typically have different proportions of low, medium, and high slope land area. Table 1 shows the farm classes with the (nationally averaged) proportion of low, medium, and high slope land for each class.

When calculating the allocation of dung and urine across slope classes it was assumed that the proportion of low-, medium-, and high-slope land was the same across all farms within the same region and farm class.

The animal numbers from the Sheep and Beef Farm Survey were scaled so that the total animal numbers matched the National Inventory animal numbers. The amount of dung and urine N excreted (N_{ex}) was calculated by multiplying the animal numbers with the N-excretion rates for dung and urine by animal type data supplied by the Ministry for Primary Industries (Table 2; MPI (Ministry for Primary Industries), 2014). It should be noted that the Sheep and Beef Farm Survey data are based on the year starting 1 July, while the N-excretion rates are for calendar years. However, the calendar year excretion data are estimated from the following year's slaughter data. Therefore, we paired the calendar year animal numbers and excretion rates with the region and farm type allocation data from the year ending the following June. Any discrepancy thus induced should be relatively small (in Section 3 we estimate the size of this discrepancy). Table 2 shows the annual values of N excreted in dung and urine per animal derived from these calculations.

Table 3
Proportion of land area by slope class across five hill country farmlets under sheep grazing at Whatawhata (%) (Rowarth, 1987).

Slope class	Farmlet 1	2	3	4	5	Mean area	Standard deviation
(0–10°)	9	13	17	18	26	16.6	6.3
(11–20°)	29	47	36	33	42	37.4	7.2
(21–30°)	33	29	28	25	16	26.2	6.4
(31–40°)	18	9	13	18	11	13.8	4.1
(41°+)	11	2	6	6	5	6.0	3.2

2.3. Nutrient transfer model

The proportion of low-, medium-, and high-slope land within each region and farm class was known from the Sheep and Beef Farm Survey. However, as animals prefer to spend more time on flatter land, the excretal N deposits onto each slope class is not proportional to the area of each slope class. To account successfully for the effect of topography-driven spatial variability of N excretion rates, an approach described in the nutrient transfer model of Saggar et al. (1990a,b); Saggar et al. (1990a,b) was applied. Briefly, the model uses a mass balance approach to explain the accumulation or depletion of nutrients in soils by taking into account of the animal associated nutrient return through variable excretal deposition across the slopes.

Results collated from Rowarth (1987), reported in Saggar et al. (1990b) and de Klein et al. (2009), show the relative proportion of faecal deposition on 5 hill-land-slope classes at Whatawhata

Table 2
Annual N excreted (N_{ex}) in dung and urine by animal type. (Data provided by New Zealand Ministry for Primary Industries – annual national agricultural greenhouse gas inventory).

Year	Non-dairy cattle			Sheep			Deer		
	N_{ex} kg N/animal/y	N_{ex} in urine kg N/animal/y	N_{ex} in faeces kg N/animal/y	N_{ex} kg N/animal/y	N_{ex} in urine kg N/animal/y	N_{ex} in faeces kg N/animal/y	N_{ex} kg N/animal/y	N_{ex} in urine kg N/animal/y	N_{ex} in faeces kg N/animal/y
1990	64.26	42.35	21.91	13.23	8.72	4.51	25.21	17.46	7.75
1991	66.14	43.58	22.55	13.68	9.01	4.66	26.05	18.01	8.04
1992	67.15	44.25	22.90	13.72	9.04	4.68	27.10	18.71	8.39
1993	68.27	44.99	23.28	13.89	9.16	4.74	27.63	19.05	8.59
1994	68.93	45.42	23.50	14.00	9.22	4.77	26.76	18.42	8.34
1995	68.27	44.99	23.28	13.89	9.15	4.74	28.08	19.31	8.77
1996	70.79	46.65	24.14	14.39	9.48	4.91	28.63	19.67	8.95
1997	72.08	47.50	24.58	14.98	9.87	5.11	28.81	19.79	9.01
1998	72.16	47.55	24.61	14.94	9.84	5.09	28.81	19.79	9.02
1999	70.32	46.34	23.98	14.98	9.87	5.11	28.89	19.84	9.06
2000	72.82	47.99	24.83	15.60	10.28	5.32	29.39	20.17	9.22
2001	74.07	48.81	25.26	15.52	10.23	5.29	29.40	20.17	9.23
2002	73.65	48.54	25.12	15.69	10.34	5.35	29.46	20.20	9.26
2003	73.21	48.24	24.96	15.77	10.39	5.38	28.94	19.80	9.14
2004	74.49	49.09	25.40	16.07	10.59	5.48	29.42	20.05	9.37
2005	75.40	49.69	25.71	16.36	10.78	5.58	29.63	20.11	9.52
2006	76.89	50.67	26.22	16.10	10.61	5.49	29.81	20.13	9.68
2007	74.86	49.33	25.53	15.58	10.27	5.31	29.42	19.77	9.65
2008	73.90	48.70	25.20	15.81	10.42	5.39	29.45	19.67	9.77
2009	74.49	49.09	25.40	16.28	10.73	5.55	29.51	19.66	9.84
2010	74.34	48.99	25.35	15.83	10.43	5.40	29.39	19.58	9.81
2011	75.40	49.69	25.71	16.20	10.67	5.52	29.63	19.74	9.88
2012	76.52	50.43	26.09	16.59	10.93	5.66	29.71	19.80	9.91

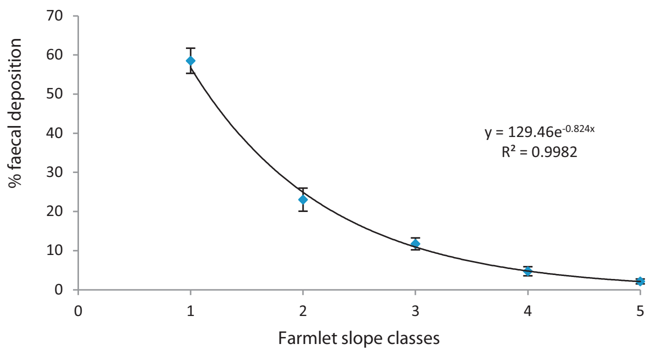

Fig. 1. Relationship between average faecal deposition and slope class across 5 farmlets under sheep grazing at Whatawhata (developed from Rowarth, 1987).

measured across 5 farmlets where the majority of the farmed area was in the 11–20° and 21–30° slope classes, with variable areas under campsites (0–10°) (Table 3).

The proportion of faecal deposition measured on each slope class was fairly constant across the 5 farmlets despite the differences in the proportion of land area in each slope class (Fig. 1). These results suggest that, within the ranges found on the 5 farmlets, the proportion of dung deposited on each slope is not strongly influenced by the size of the land area of each slope class. As the slopes became steeper, the proportion of faecal deposition decreased exponentially (note that while Fig. 1 uses nominal slope classes, the relationship remains exponential if each slope class is replaced by its mid-point). Although no experimental data are available, similar patterns for urine deposition by grazing animals are expected.

The relationship in Fig. 1 was then adapted to account for (i) Sheep and Beef Survey data using 3 slope classes rather than 5, (ii) urine deposition being relatively less influenced by slope class than faecal deposition (because of the animal grazing and resting behaviour), and (iii) some farm classes being outside the range of slope distributions from which the model was developed (e.g. if there is no high slope land then there can be no excretal deposition on high slope land). The following assumptions were made to convert the 5 category (Rowarth, 1987) to the 3 category (Sheep and Beef Farm Survey) system:

1. Low slope area (<12°): All the 0–10° slope class plus 10% of the faecal material from the 11–20° slope class.
2. Medium slope area (12–24°): 90% of the faecal material from 11–20° plus 80% of the 21–30° slope class.
3. High slope area (>24°): the remaining faecal deposition was included in this class.

The allocation of urine across slope classes was not known, but it was assumed that urine deposition was contained within the slope class on which it was excreted, in contrast to dung, which tends to roll down the slope. As the results presented in Fig. 1 include this rolling-down effect for dung, the relative proportion of urine that is deposited during grazing on medium- and high-slope areas was increased slightly compared with dung (Table 4), and urine deposited in the low slope areas was reduced accordingly. The allocation of faecal and urine deposition across slope categories is presented in Table 4. These values are reasonable approximations when the proportional area within each slope class is within the range given in Table 3.

Table 3 shows that the farmlets had between 9 and 26% of the land area in the 0–10° slope class and between 29 and 47% of the land area in the 11–20% slope class. Therefore, 35% was used as a reasonable upper bound of proportion of land in the low-slope category (0–12°) consistent with the measured farmlets. For the lower bound the lowest proportion in the lowest slope class (9%) was used. That is, when the low slope category accounted for 9–35% of the total land area, we applied 61% of faecal depositions to that category. When the proportion of low slope land was outside this range, the faecal and urine N were distributed according to Table 5. For the area of high slope land in the 5 hill country farmlets we assumed that 50% of the land in slope class 21–30° was >24°, giving a range of 24–46% for the percentage of high slope land in the farmlets. We used the approximate urine and dung allocation from Table 4 when the percentage of steep land was 20–40%, with the allocation scaled up or down for higher or lower percentages of steep land (Table 5). After the allocation of urine and dung to the low and high slope areas, the remainder was applied to the medium slope area (12–24° slope).

Table 4
Allocation of faecal and urine depositions across slope categories.

Slope	Mean % faecal deposition	Mean % urine deposition
0–12°	61	55
12–24°	30	31
>24°	9	14

Table 5
Allocation of faecal and urine depositions to low land (0–12° slope) and high land (>24° slope) according to the percentage of low slope and high land available.

Allocation to flat land		
% area of low land	Fraction faecal deposition	Fraction urine deposition
<1%	$30x^*$	$27x^*$
1–5%	0.30	0.27
5–9%	0.45	0.405
9–35%	0.61	0.55
35–85%	$(0.5x^*+0.5)$	$(0.45x^*+0.45)$
>85%	$(0.5x^*+0.5)$	$(0.5x^*+0.50)$
Allocation to steep land		
% area of high land	Fraction faecal deposition	Fraction urine deposition
<1%	$7.5x^*$	$10x^*$
1–20%	0.075	0.10
20–40%	0.10	0.14
40–60%	0.15	0.21
60–85%	0.20	0.28
>85%	$(16x^* - 13)/3$	$4.8x^* - 3.8$

x^*: fractional area of low/high slope land.

2.4. Estimation of direct nitrous oxide emissions

Once the N excreted in urine and dung was allocated to each slope category for each region, farm, and animal type, N_2O emissions were calculated by multiplying the urine-N and dung-N allocations by the appropriate emission factor EF_3 (Table 6). These values are largely based on Kelliher et al. (2014). However, it should

Table 6
EF_3 values by slope class, animal and excreta type (kg N_2O-N/kg excretal-N).

	Beef (and deer)		Sheep	
	Urine	Dung	Urine	Dung
Low	0.0099[a]	0.0021[a]	0.0055[a]	0.0011[a]
Medium	0.0032[a]	0.0006[a]	0.0016[a]	0.0011
High	0.0032	0.0006	0.0016	0.0011

[a] Value from Kelliher et al. (2014).

be noted that Kelliher et al. (2014) used slope >15° as the threshold between low and medium slope, whereas we have used 12°. While this could introduce some error in the national estimate we do not have information on the proportion of land between 12 and 15° slope to quantify this. In addition, no measured EF values were available for high slopes so we have used the same EFs for medium and high slopes. This is a conservative approach based on the measured decrease in EF between low and medium slope. This proposed methodology does not distinguish between flat land soils and low slopes in hill country. Therefore, for sheep urine and dung EFs, we used whichever was the higher of the lowland and low slope values from Kelliher et al. (2014). The EF for sheep dung was not available for medium or high slopes, so the same value was used for all slopes. Finally, in the absence of emission data for deer dung and urine we used the higher beef EFs for deer rather than using lower EFs for sheep.

3. Results

Fig. 2 and Table 7 show the N_2O emissions from sheep, beef and deer excreta from 1990 to 2012 for the current inventory EFs and the revised EFs. Using the current inventory EF values, the emissions in 1990 would have been 13.1 Gg N_2O declining to 10.1 Gg N_2O in 2012 (23% decrease). A major drought between 2006 and 2008 resulted in declining stock numbers, which was the main reason behind this decrease (Fig. 3). Over this period, while there was a slight increase in deer numbers, beef numbers dropped 19% and sheep numbers by 46%. Overall, this resulted in a 23% reduction in excretal N inputs. However, using the methodology and EFs described in Section 2, total emissions were lower. Overall emissions dropped ~1.1 Gg N_2O from 6.0 to 4.9 (18%) between 1990 and 2012. As this methodology had lower EFs for sheep excreta than beef, the percent reduction in N_2O emissions was less than what would be expected from just the reduction in excretal-N. Fig. 2 also shows a hypothetical case where the EFs for the high slopes were half the values in Table 6. This produced only a small decrease in N_2O emissions relative to those calculated using Table 6, as the emissions from high slope areas were only a small fraction of the total (Fig. 4).

Figs. 5, 6 and 7 show that although the land area has decreased, the proportion of land in each slope class and the proportion of excretal N allocated to each slope class have remained fairly stable over this period, so the majority of the change was still due to declining animal numbers. There was a very slight increase in the proportion of excretal N allocated to low slopes (from 55.7% in 1990 to 56.3% in 2012), which slightly offset the effect of declining excretal N inputs. Fig. 4 shows the proportion of N_2O emissions from each slope class. Again, the relative allocation of N_2O emissions between the slope classes remains fairly steady over time, with the majority of emissions deriving from the low slopes due to the higher EFs and excretal N inputs

Using the revised emission factors reduced total N_2O emissions over the period 1990–2012 by 52% compared with the current inventory values (Fig. 2). The use of measured dung and urine EF_3 values of sheep and cattle separately contributed to ~60% of the decrease in estimated N_2O emissions compared to the current inventory (data not shown). The additional effect of different slope EFs had a relatively smaller effect in reducing N_2O emissions estimates from hill land as a large proportion of the sheep, deer and beef excreta was deposited on low slope (57%). Reducing the EFs for high slopes to 50% of the medium slope EF values further reduced the emissions. However, in this case there was only an additional 4% reduction in total emissions between 1990 and 2012 due to the relatively low proportion of excreta allocated to the high-slope land and the already low EF for the medium-slope land.

Certain sources of uncertainty in this new methodology (e.g. uncertainties in EFs, slope class areas, excretal N allocation to slope classes) have not yet been quantified. However, we estimated the likely size of the discrepancy caused by combining calendar year population data and July–June animal and land area distribution data. Fig. 6 shows that the proportion of land in each slope class has been relatively stable, although there have been some small fluctuations, so the potential discrepancy was not expected to be large. The largest change in the relative area in each slope class was between 2003 and 2004. Therefore, we recalculated the total emissions for the calendar year 2004 using three different animal distributions. The first was to use the 2004/05 distributions (the method used in the main part of this study). The other two distributions used were the 2003/04 distribution and a distribution based on the mean of the 2003/04 and 2004/05 distributions ("combined"). The results of these three methods are shown in Table 8. The land area and animal distribution choice made a maximum difference of 0.6% in the total N_2O calculated.

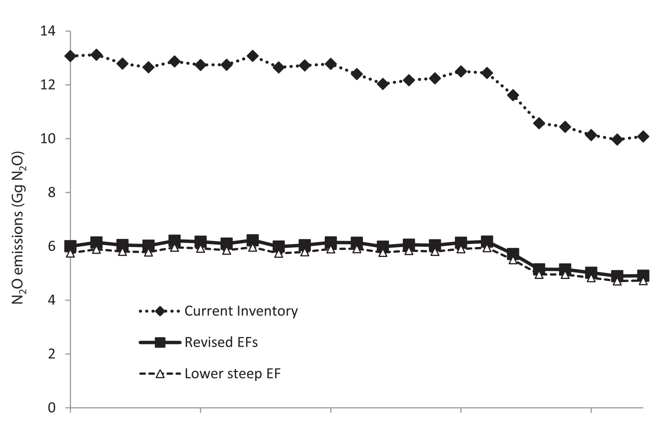

Fig. 2. N_2O emissions from sheep, beef and deer excretal inputs to soil under three different EF scenarios.

Table 7
Direct N_2O emissions from sheep, beef and deer excreta inputs to soil from 1990 to 2012 using current and revised (Table 6) EFs.

Year	N_2O emissions (Gg N_2O/y)	
	Current inventory EFs	Revised EFs
1990	13.07	6.01
1991	13.12	6.14
1992	12.79	6.05
1993	12.65	6.02
1994	12.87	6.21
1995	12.74	6.17
1996	12.75	6.10
1997	13.08	6.23
1998	12.65	5.99
1999	12.72	6.04
2000	12.78	6.15
2001	12.40	6.13
2002	12.03	5.99
2003	12.17	6.06
2004	12.24	6.04
2005	12.50	6.13
2006	12.44	6.18
2007	11.62	5.72
2008	10.57	5.15
2009	10.44	5.14
2010	10.13	5.02
2011	9.97	4.89
2012	10.08	4.91

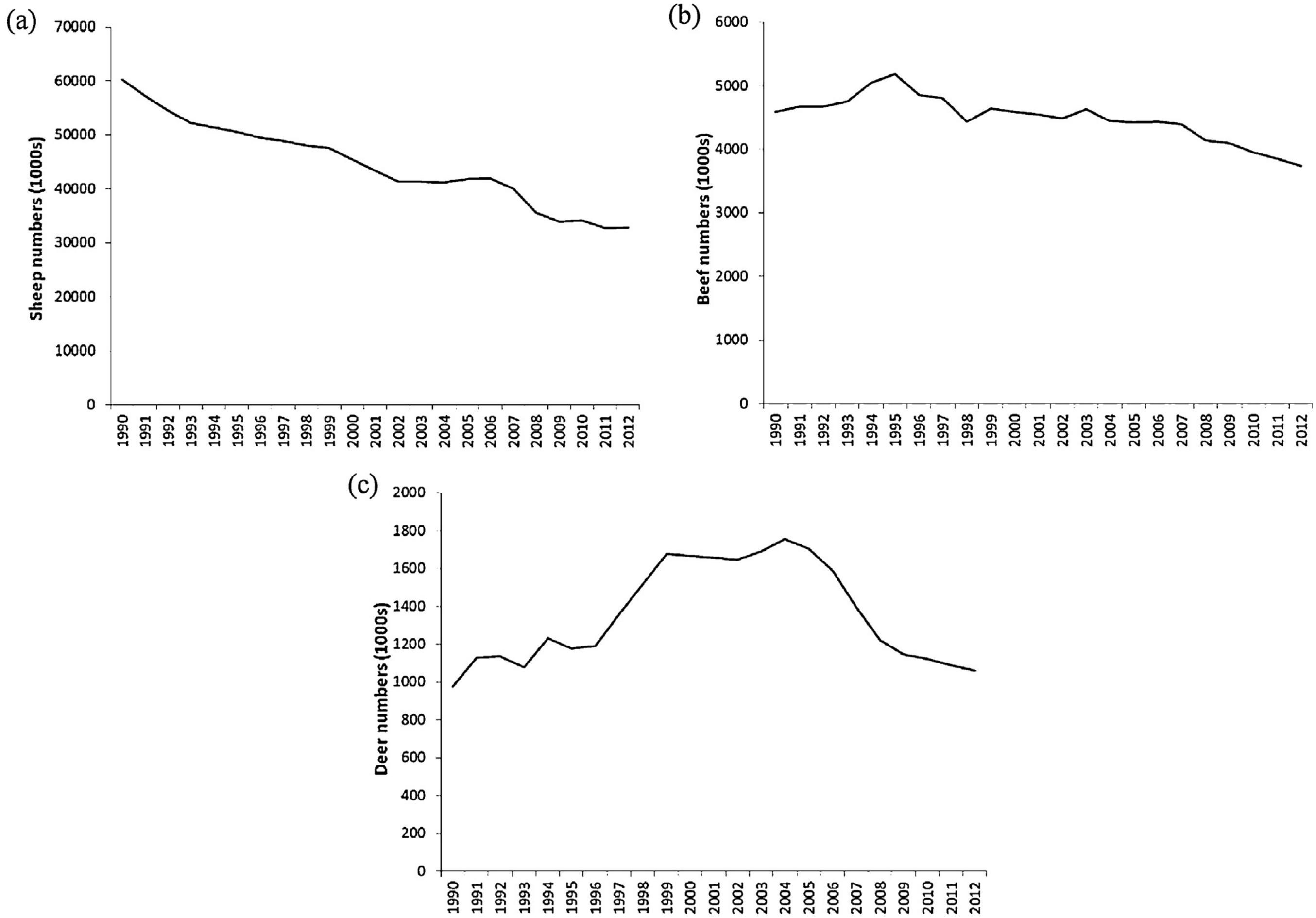

Fig. 3. Total New Zealand (a) beef, (b) deer, and (c) sheep numbers from 1990 to 2012.
Source: National Inventory, 2014

4. General discussion

Hill country is characterized by its steep slopes, differences in aspect, variability in micro-topography, highly spatial differences in soil conditions, and pasture production potentials. The excretal deposition across the slopes and aspects is influenced by pasture production, animal grazing and resting behaviour (Saggar et al., 1990a,b,b). The areas of low slope selected by the grazing animals as resting spots receive relatively more dung and urine deposits compared with medium and high slope areas. Our earlier work (Saggar et al., 1999) suggested that where slope influences plant growth concurrent effects on rhizosphere translocation and deposition affect the nutrient transformations and availability. The C:N and C:P ratios in pasture shoots and roots in the Saggar et al. (1999) study on hill slope effects were further reflections of lower nutrient availability with increasing slope. Lower N_2O

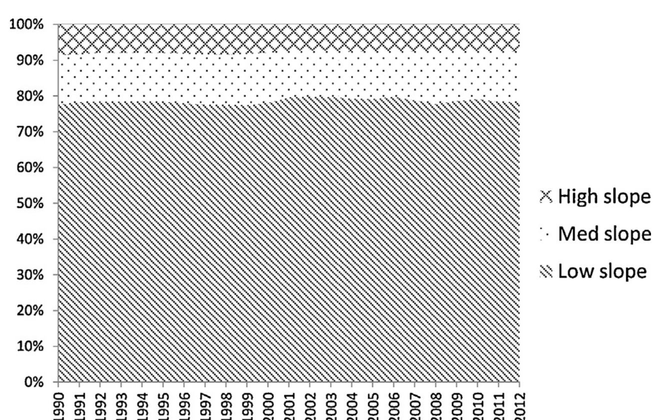

Fig. 4. Proportion of N_2O emissions from each slope category by year, 1990–2012 using emission factors in Table 6.

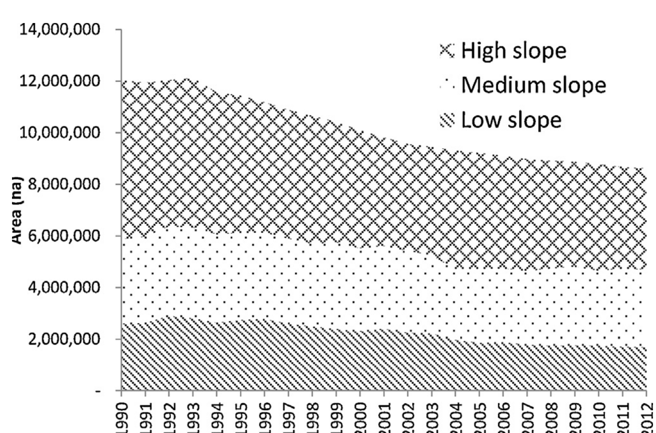

Fig. 5. Sheep, deer and beef land area in each slope category by year, 1990–2012.

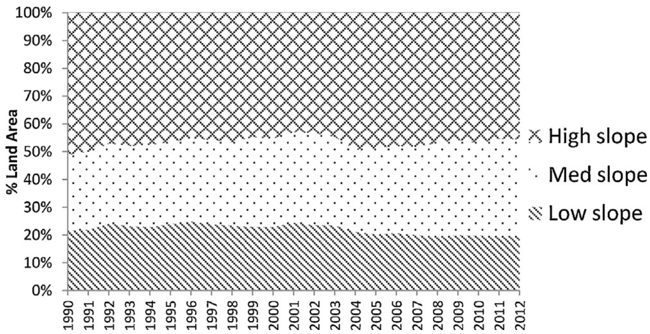

Fig. 6. Proportion of sheep, deer and beef land area in each slope class from 1990 to 2012.

Table 8
N_2O emissions from sheep, beef and deer for calendar year 2004 using 3 different land area/animal distributions.

	N_2O (Gg)
2003/04	6.074
2004/05[a]	6.038
Combined	6.067

[a] Method used for time series results.

emissions and EF on medium slope compared with low slope has recently been reported in a New Zealand study (Hoogendoorn et al., 2013; Luo et al., 2013). This phenomenon is consistent with the hypothesis that under limited fertility and moisture conditions, lower excreta-N inputs across rhizosphere processes respond to a relative shortage of resources and nutrients. Thus, the interacting effects of soil and climatic conditions on excreta-N transformations result in a tight N cycle on medium and high slopes compared with low slope areas; and lower N_2O production on the medium and high slopes compared with low slopes. This pattern of landscape position/slope influence on N_2O emissions based on N enrichment or depletion reported in other international studies (Holt et al., 2007; Vilain et al., 2010; Gu et al., 2011; Schelde et al., 2012) validates this approach to taking account of the effects of slope in estimating hill country N_2O emissions from ruminant animals (sheep, beef cattle, and deer).

The current inventory reports annual animal populations, and N_{ex} estimates based on Tier 2 calculations using different EFs for N excreted in urine and dung. Incorporation of this report's methodology would require the inclusion of the additional activity data for animal numbers and slope areas by farm class and region.

The proposed methodology results in an annual average reduction in the calculated direct N_2O emissions from beef, sheep, and deer excreta between 1990 and 2012 of 51.6%. The majority of this reduction (31%) was due to the lower values for low slope EFs (particularly for sheep) compared with the current values of 0.01 (urine) and 0.0025 (dung). Due to the lack of measured EFs for deer, the higher beef EF values were used. However, it could be argued that the characteristics of deer urination (area/volume) are more similar to sheep than cattle. If the sheep rather than beef EFs were used for deer then the calculated emissions from the proposed methodology would be 2.4% lower (or 52.8% lower than the current inventory).

A number of assumptions have been made regarding the allocation of excretal N to slope classes. These assumptions result in relatively higher allocation of excretal-N to low slope (high EF) classes and thus represent a more conservative approach than just allocating in proportion to area. However, the allocation of N excreted across slopes is an area that could warrant further research and animal tracking methods that now exist to facilitate these studies (e.g. Betteridge et al., 2010; Draganova et al., 2012).

The discrepancy introduced by combining calendar year animal numbers with July–June year data on animal distribution across slope classes was estimated by comparing the effect, for a given calendar year's population data, of using the distribution across slope for the year beginning in July of that year compared with the distribution from the previous year (as well as the mean of the two distributions). The effect was found to be at most ~0.6%. Therefore, this is not a major concern compared with other sources of uncertainty.

The tables for allocating animal excreta across slope classes (Table 5) use discrete categories and therefore have a number of places ("break points") where the % N allocated to a slope class does not change smoothly as the fraction of the total area in the slope class increases; instead there is a sudden step (e.g. this occurs at 5%,

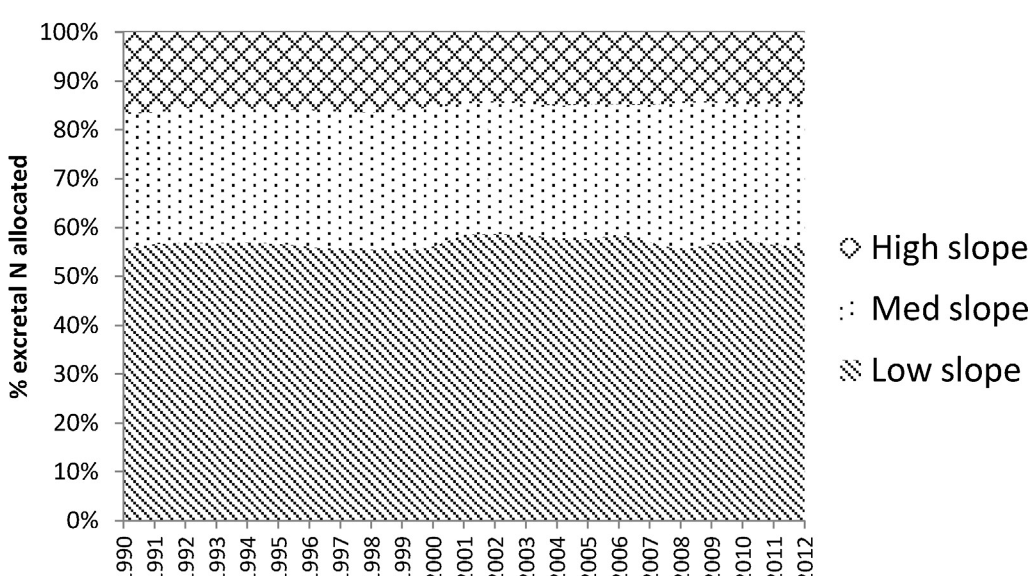

Fig. 7. Proportion of excretal N allocated to each slope category by year, 1990–2012.

9%, and 35% for low slope area). Year-to-year changes in land use mean that the proportion of low-, medium- and high-slope land within a region and farm type can change between years (e.g. a trend to plant trees on steep land could result in a decrease in the relative area of high slope land in sheep, beef, and deer farming). This could result in sudden changes in estimated N_2O emissions between years, if the proportion of land in a given slope class crosses one of the thresholds in Table 5, even for a comparatively small change in relative area in that slope class. However, our method uses 17 distinct regions and farm types. This means that even when the relative land area in a slope class for a particular region and farm type crosses one of these break points, the effect on the total emissions is still fairly small. Fig. 2 does not show any unusual jumps in N_2O emissions even though there are a number of years in which the proportion of land area in the low-slope class crosses a break point for some regions and farm types (as the medium and high slope EFs were the same in this study, break points for the high slope class have no effect on total emissions).

Due to the lack of available New Zealand and international EF1 data, this proposed methodology does not take into account the lower emissions from fertiliser N (emission factor EF_1) from different slopes. In New Zealand only 1.75 mha (19.6%) of hill country land is low slope, with 3.06 M ha (34.5%) medium slope, and 4.06 M ha (45.9%) high slope. Thus, potentially 80% of hill land fertiliser N is received by medium- and high-slope areas, which will result in lower EF_1 compared with flat or low-slope areas. It appears that the current methodology of using the same EF_1 for fertiliser-N applied on hill country contributes to overestimation of N_2O emissions. Thus work has to be undertaken to develop an improved framework for estimating hill land EF_1.

5. Conclusions and recommendations

We calculated the direct N_2O emissions from animal excreta from New Zealand sheep, beef, and deer grazing between 1990 and 2012 using (a) the New Zealand-specific emission factors, 0.01 for urine and 0.0025 for dung developed from trials on flat pastoral land, and (b) the latest emission factors developed from trials on low- and medium-slope hill country, by taking into account the animal type, slope, and disaggregating dung and urine N excretion and N_2O emissions.

Using current inventory EFs developed from trials on flat pastoral land, N_2O emissions decreased by 3 Gg N_2O from 13.1 Gg N_2O in 1990 to 10.1 Gg N_2O in 2012 (i.e. a reduction of 23%). The reduction was largely due to a reduction in animal numbers, particularly sheep. With the proposed new methodology the estimate of emissions decrease between 1990 and 2012 was 1.09 Gg or 18% (from 6.00 Gg N_2O in 1990 to 4.91 Gg N_2O in 2012). On average, the proposed new methodology reduced the estimates of annual N_2O emissions between 1990 and 2012 by 52%, relative to using current Inventory EFs. The use of measured dung and urine EF3 values of sheep and cattle separately contributed to the majority of the decrease in estimated N_2O emissions compared with the current inventory. The uncertainties arising from the proposed methodology have yet to be fully quantified; however, the mismatch in animal population and excreta data (based on calendar years) and the animal and land area distribution data (based on year-ending June 30) has been estimated to cause only up to 0.6% discrepancy in the total N_2O calculation for a given year.

The nutrient transfer model has certain critical thresholds where a small difference in the proportion of farmed land in a slope class can lead to a step change in the proportion of excretal N allocated to that slope class. This may have implications for uncertainty analysis as the model is more sensitive to changes in proportion of land area in a slope class close to certain break point thresholds. However, no sudden changes were observed in the total N_2O emissions time series. This is because with 17 regional farm classes a step change in the N allocation in one regional farm type is still small relative to the total N_2O emissions.

In this study using New Zealand as a case study the direct N_2O emissions between 1990 and 2012 from sheep, beef cattle and deer excreta were determined. This approach involved: (i) updated estimates of EF_3 for sloping land, (ii) the area of land in different slope classes by region and farm type, and (iii) a nutrient transfer model to allocate excretal-N to the different slope classes. The findings are significant – the proposed new methodology using country-specific EFs resulted in 52% lower N_2O estimates relative to using current inventory emission factors. The proposed methodology is transparent, and complete, and has improved accuracy of emission estimates. On this basis, this methodology of estimating N_2O emission is recommended for adoption where hill land grasslands are grazed by sheep, beef cattle and deer. A brief outline for calculating N_2O emission from grazed hill land with the recommended methodology is given below:

For each animal class and region, (i) calculate the total amount of urine, (ii) allocate the urine and dung N to each slope class based on the relative area of each slope class using the nutrient transfer function, (iii) multiply the urine and dung N in each slope class by the corresponding slope-specific EF.

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