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Manatū Ahu Matua

# Development of a framework for estimating nitrous oxide emissions from fertiliser use on different slope pasture classes

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# Executive Summary

Estimates of New Zealand's greenhouse gas (GHG) emissions from the agricultural sector are generated by the Ministry for Primary Industries (MPI), which has developed a mathematical model, called the Agricultural Inventory Model (the Inventory), that calculates the amount of GHG emissions from agricultural activities. Part of the Inventory involves estimating nitrous oxide ($N_2O$) emissions arising from the application of fertiliser nitrogen (N) at the Tier 1 level, using a single EF1 value irrespective of slope. The inventory currently differentiates between urea and other N fertilisers for which the EF1 values are 0.48% and 1% respectively, from trials on flat pastoral land.

In New Zealand, however, a significant proportion of agricultural activity occurs on sloped land. Nitrous oxide emissions from steeper slopes are lower than emissions from flatland (Hoogendoorn et al. 2013; Kelliher et al. 2014; Luo et al. 2013, 2016). Using the New Zealand-developed $N_2O$ emission factors from the dung and urine of ruminant animals (sheep, beef cattle, and deer) deposited across different slope classes, Saggar et al. (2015) generated estimates of direct $N_2O$ emissions from sheep, beef and deer that were 52% lower than the estimates generated using current Inventory emission factors . In the same way therefore, New Zealand's $N_2O$ emissions from fertiliser N applied on slopes could be overestimated in the current Inventory.

The aim of this study was to develop a framework for estimating $N_2O$ emissions from N fertiliser use on pasture on different slope classes that would eventually be incorporated into the Agricultural Inventory Model and help to ensure that New Zealand's emissions estimates are as accurate as possible.

In this study we used data provided by Beef + Lamb New Zealand from their annual survey of beef and sheep farms. These data included the land area classified as low (<12°), medium (12–24°), and high (>24°) slope. The total fertiliser N applied to pastures on New Zealand sheep and beef farms varied between 8% and 25% of the total fertiliser N use in New Zealand during 1990–2013. The $EF_1$ values for urea on medium and high slopes were estimated using the current low slope value of 0.48% from the National Inventory (Ministry for the Environment 2015) reduced by the same proportion as had been measured in urine $EF_1$ values on medium and high slopes. The resulting estimated $EF_1$ values for urea for low, medium and high slope were 0.48%, 0.11% and 0.014%, respectively. Due to lack of data on the type of fertiliser N used it was assumed that all fertiliser N was applied as urea. However, assuming that the relative change in $EF_1$ with slope is the same for all fertiliser N types, this should not affect the relative change in $N_2O$ emissions compared to using a single $EF_1$ value across all slopes. The allocation of fertiliser N to each slope class was calculated for each region and farm type, and then multiplied by the appropriate $EF_1$ for low, medium and high slopes, respectively, to calculate the amount of N directly emitted as $N_2O$.

Using a single $EF_1$ of 0.48% across all slopes resulted in an estimate of direct $N_2O$ emissions of 20.7 Gg $CO_2e$ from fertiliser N applied to sheep and beef farm pastures in 1990 rising to 86.7 Gg in 2013. Accounting for the lower emissions from medium and high slopes produced estimated $N_2O$ emissions of 8.3 Gg in 1990 and 30.5 Gg in 2013. Thus, over the period 1990–2013, the use of revised $EF_1$ values based on slope classes' reduced estimated $N_2O$ emissions from total fertiliser N applied to pastures on sheep and beef farms by between 60% and 65%, compared with using a single flatland $EF_1$ value. In 2013 this was equivalent to a reduction of 0.14% in the total greenhouse gas emissions from the agricultural sector.

# 1 Introduction

It is mandatory for New Zealand to report its annual greenhouse gas (GHG) emissions to the United Nations Framework Convention on Climate Change (UNFCCC) under the UNFCCC and the Kyoto Protocol. 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, enabling the use of country-specific emission factors and fractions rather than default Intergovernmental Panel on Climate Change (IPCC) values.

New Zealand's GHG emissions from the agricultural sector are generated by the Ministry for Primary Industries (MPI), which has developed a mathematical model, called the Agricultural Inventory Model (the Inventory), to calculate the amount of GHG emissions from agricultural activities.

Part of the Inventory involves estimating nitrous oxide (N2O) emissions arising from the application of fertiliser nitrogen (N) at the Tier 1 level, using a single EF1 value irrespective of slope. The inventory currently differentiates between urea and other N fertilisers for which the EF1 values are 0.48% and 1% respectively, from trials on flat pastoral land. In New Zealand, however, a significant portion of agricultural activity occurs on sloped land. As emissions from steeper slopes are likely to be lower than emissions from flatland, New Zealand's $N_2O$ emissions from fertiliser could be overestimated in the Inventory.

As an example, Saggar et al. (2015) recently used New Zealand-developed $N_2O$ emission factors for dung and urine of ruminant animals deposited across different slope classes to estimate $N_2O$ emissions from excreta deposited on New Zealand's sheep, beef and deer farms.  These estimated $N_2O$ emissions were 52% lower than estimates made using the current Inventory emission factor, developed from trials on flat pastoral land. The improved methodology is transparent and complete, and will improve accuracy of emission estimates.

Saggar et al (2015) also estimated that about 8.6 m ha of New Zealand hill land receives about 20% of the fertiliser N applied annually in New Zealand, and approximately 80% of this is applied to medium- and high-slope areas which are likely to have significantly lower $EF_1$ values than flat or low-slope areas. The current New Zealand-specific emission factors for estimating $N_2O$ emissions from fertiliser N ($EF_1$) were developed on flat pastoral land, and are 0.48% for urea-N and 1.00% for all other forms of N fertiliser. By using these emission factors across all land slope classes it is probable that $N_2O$ emissions from fertiliser applied to New Zealand hill country are being over-estimated.

Recognising this, Landcare Research was contracted to undertake a desk study to develop a framework for estimating $N_2O$ emission factors from fertiliser use ($EF_1$) on different slope pasture classes, which would potentially be incorporated into the Agricultural Inventory Model and help ensure that New Zealand's emissions estimates are as accurate as possible.

# 2 Objectives

- To calculate the annual amounts of fertiliser nitrogen (fertiliser N input) applied to different hill slope categories (low (<12°), medium (12–24°), and high >24°) from 1990 to 2013 using the Beef +Lamb NZ Economic Survey data, including documentation of the limitations and uncertainty of these data.
- To develop a scientifically robust and easily implementable methodology for calculating nitrous oxide ($N_2O$) emissions from fertiliser N using values estimated $N_2O$ $EF_1$ on different slope categories, based on the latest flat pastoral land $EF_1$ values used in the Inventory [0.48% for urea-N and 1.00% for all other forms of N fertiliser as obtained from MPI] .
- To provide advice, consistent with IPCC good practice guidance, on how this methodology could be incorporated into MPI's Agricultural Greenhouse Gas Inventory Model.

## 2.1 Expected outcomes

1. A spreadsheet containing values for the amounts of fertiliser N applied to different hill slope categories from 1990 to 2014.

2. A report that describes a valid approach/methodology for calculating $N_2O$ emissions from N fertiliser applied on hill land slopes including advice, consistent with IPCC good practice guidance, on how the methodology could be incorporated into MPI's Agricultural Inventory Model.

# 3 Methodology

## 3.1 Data sources etc.

For this study, we used data provided by Beef + Lamb New Zealand from their annual survey of Sheep and Beef Sheep Farms. The population of commercial farms for the annual survey is drawn from Statistics NZ (SNZ) Agricultural Census/Survey database and are allocated into eight classes (plus non-commercial), five regions, and three slope categories: low (<12º slope), medium (12–24º slope), and high (>24º slope) based on individual farm data characteristics and location that imply Farm Class and their management systems. The farm classes represent different types of farm enterprises that typically have different proportions of low, medium, and high slope land area, and are randomly selected by SNZ from the Sheep and Beef Farm population to bring into Beef + Lamb New Zealand's Sheep and Beef Farm Survey.  Farms entering the Survey have their farm Class verified from the on-farm inspection.

The Sheep and Beef Farm Survey fertiliser "products" for each farm are recorded by their elemental content:

e.g., Urea N 46%, DAP (Di-ammonium phosphate) Sulphur Super N 10.8% and Ammonium Sulphate (AS) N 21%

| | |
|---|---|
| 10 tonnes urea at 46% | =4,600 kg N |
| 10 tonnes DAP S at 10.8% | =1,080 kg N |
| 10 tonnes AS at 21% | =2,100 kg N |
| Total N Fertiliser applied | =7,780 kg N |

Each farm in the Survey is visited once per year in the Survey process.  Fertiliser data are captured from invoices on a standard June ending year basis.  The invoices verify the actual brand and volume from which the elemental kg content is derived.  Farmer input determines the volumes used on pasture and volumes used on crop.  Farmers in the Survey are provided a diary to record this specific information. These data also included the total[1] amount (but not type) of fertiliser N applied to pastures on New Zealand sheep and beef farms. The aim of this study was to quantify emissions from fertiliser applied to sheep, beef and deer pastures. The fertiliser N applied to crops on sheep and beef farms was not included. This could include fodder crops or other commercial crops (e.g. in a mixed farming system).

Data were provided for the years ended 30 June 1990 to 30 June 2014[2] and were broken down by region and farm type. The average distribution of land between the three slope categories was given for each region and farm type based on survey data. Figure 1 displays the five regions and Table 1 shows the five regions and eight farm types used in the annual

[1] Beef + Lamb scaled their survey results so the totals  matched the Statistics New Zealand Agricultural Production survey values

[2] Data for the year ended 30 June 2015 were not available at the time of writing

survey data. The actual land areas by slope class, region and farm type for each year are given in Appendix 1 (Table 5). There was also a small amount of fertiliser N used on ‘non-commercial’ farms in each region. Fertiliser use on non-commercial farms accounted for 2 to5% of the total and was accounted for by assuming non-commercial farms had the mean slope distribution for their region.

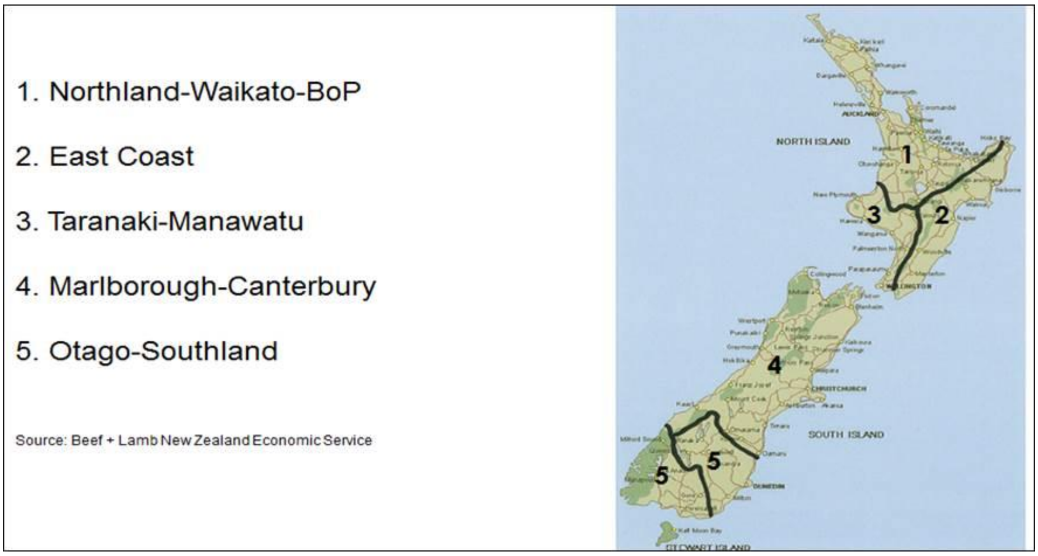


**Figure 1: Five Regions used in Beef+Lamb New Zealand annual survey**

**Table 1: Region and farm type classifications used in Beef+Lamb New Zealand annual survey data**

| Region | Farm Types |
|---|---|
| Northland-Waikato-Bay of Plenty | North Island Hard Hill Country<br>North Island Hill Country<br>North Island Intensive Finishing |
| East Coast | North Island Hard Hill Country<br>North Island Hill Country<br>North Island Intensive Finishing |
| Taranaki-Manawatu | North Island Hard Hill Country<br>North Island Hill Country<br>North Island Intensive Finishing |
| Marlborough-Canterbury | South Island High Country<br>South Island Hill Country<br>South Island Finishing Breeding<br>South Island Mixed Finishing |
| Otago-Southland | South Island High Country<br>South Island Hill Country<br>South Island Finishing Breeding<br>South Island Intensive Finishing |

The total amount of fertiliser N applied to sheep and beef farm pastures was calculated by Beef + Lamb New Zealand, based on the average application rate for each farm type and region, multiplied by the pasture land area. The total amount of N applied to sheep and beef farm pastures is compared to the national amount in the inventory calculation for total N fertiliser use (which includes cropping and dairying) in Table 2. Note that the Beef + Lamb New Zealand data were converted to calendar years by taking the average of consecutive July–June years (e.g. 1990 calendar year is the average of July 1989–June 1990 and July 1990–June 1991 values). This means that 2013 is the last year for which a calendar year value can be determined, as the July 2014–June 2015 data were not available at time of writing.

**Table 2: Total fertiliser N application to sheep and beef farm pastures compared to total fertiliser N use. Data from Beef + Lamb New Zealand and National Inventory Report (Ministry for the Environment, 2014)**

| Year | Fertiliser N applied to sheep and beef farm pastures over each calendar year (tonnes)[3] | Total New Zealand fertiliser N use (MfE) (tonnes) | Sheep and beef pasture fertiliser N as a percentage of national fertiliser N use |
|---|---|---|---|
| 1990 | 9,207 | 59,265 | 16% |
| 1991 | 10,969 | 61,694 | 18% |
| 1992 | 17,642 | 70,122 | 25% |
| 1993 | 24,214 | 104,095 | 23% |
| 1994 | 23,420 | 124,131 | 19% |
| 1995 | 22,187 | 151,263 | 15% |
| 1996 | 23,553 | 153,780 | 15% |
| 1997 | 26,563 | 143,295 | 19% |
| 1998 | 32,112 | 155,467 | 21% |
| 1999 | 33,480 | 166,819 | 20% |
| 2000 | 34,264 | 189,096 | 18% |
| 2001 | 41,122 | 248,000 | 17% |
| 2002 | 55,913 | 309,200 | 18% |
| 2003 | 59,554 | 337,400 | 18% |
| 2004 | 63,084 | 348,000 | 18% |
| 2005 | 66,270 | 350,320 | 19% |
| 2006 | 55,014 | 329,700 | 17% |
| 2007 | 43,384 | 315,920 | 14% |
| 2008 | 29,451 | 328,157 | 9% |
| 2009 | 27,703 | 279,752 | 10% |
| 2010 | 31,922 | 332,981 | 10% |
| 2011 | 28,610 | 360,284 | 8% |
| 2012 | 32,088 | 362,508 | 9% |
| 2013 | 38,576 | 366,600 | 11% |

Appendix 1 contains a complete breakdown of land area by region, year, farm type, and slope class (Table 5) as well as fertiliser application by year, region and farm type (Table 6). This information was supplied by Beef + Lamb New Zealand from their economic survey data.

The data on the quantities of N fertilisers used in New Zealand in 2014 (sourced from Statistics New Zealand and provided by Prof Russ Tillman) (Table 3) demonstrate that

[3] Calendar year amounts were calculated by taking the average of consecutive July-June year values from Table 3.

throughout New Zealand the weight of N applied as urea is over 8 times larger than the amount of N applied as DAP. Thus urea is the dominant N fertiliser used in New Zealand.

**Table 3: Quantities of nitrogen fertilisers used in New Zealand in 2014 (sourced from Statistics New Zealand)**

| Fertiliser | Weight of Fertiliser (tonnes) | Weight of Nitrogen (tonnes) |
|---|---|---|
| Urea | 533,373 | 250,685 |
| Ammonium Sulphate | 59,846 | 12,567 |
| DAP | 166,924 | 30,046 |

Fertiliser form (urea vs ammonium-based vs nitrate-based fertiliser) can also influence the $N_2O$ emissions. For example, Smith et al. (1997) suggested that when soil conditions favour denitrification, nitrate fertilisers produce higher emissions, whereas in dry conditions emissions from urea or ammonium-based fertilisers were higher. Kuikman et al. (2006) analysed $N_2O$ measurements taken across the Netherlands, and concluded that $N_2O$ emissions were greater from nitrate -based fertilisers than from ammonium-based fertiliser and urea due to the former providing a more readily available mineral N pool for denitrification. Smith et al. (2012) reported on a UK-wide series of field experiments comparing N fertiliser forms, where there was evidence of lower emissions from urea. This may have also been partly due to losses of $NH_3$ following rapid urea hydrolysis, which can reduce the net amount of N remaining in the soil as a potential source of $N_2O$ (van der Weerden et al., 2016).

In the absence of any activity data on the form of fertiliser N applied on hill country farms, we have assumed that all N fertiliser was applied to pasture as urea. From the discussions with Fertiliser representatives (Ants Roberts, Ravensdown and Aaron Stafford, Ballance Agri-Nutrients Pers. Comm.), we understand that it is highly likely that DAP is used on fodder crops on the low slopes but also on slopes where farmers are undertaking hill country cropping. However, in some areas in some years DAP will also be the fertiliser of choice to be spread on hill country pastures depending on the price relativity between DAP (sometimes with S added) and super/urea mixes. Very little AS is generally applied to forage crops grown on hill slopes, but this was not included in our sheep and beef pasture fertiliser N estimates. In either case, the relative reduction in $N_2O$ emissions due to accounting for slope should remain the same assuming that all types of N fertiliser have the same relative reduction in $EF_1$ for high and medium slopes.

## 3.2 Emission factor ($EF_1$) values

Kelliher et al. (2014) performed a statistical analysis of New Zealand field trial data of nitrous oxide emissions from pasture. The best estimate for the emission factor for urea fertiliser based 22 field trials in New Zealand was 0.48 ± 0.13 %. A later study by van der Weerden et al. (2016) measured $N_2O$ emissions from urea applications at four sites. The mean emission factors for each site varied from 0.03% to 1.52% with an average of 0.51%. A weighted average of the results from Kelliher et al. (2014) and van der Weerden et al. (2016) gave an $EF_1$ value of 0.48%, the same as the value currently used in the National Inventory.

However, all these trials were conducted on flat land and, based on the results for urine we expect emission factors to decrease with slope. To estimate the reduction in $EF_1$ on medium and high slopes we assumed that the reduction in emission factors for urea with slope would be the same as for urine because the initial chemical form of N in urine is similar to that in urea fertiliser. However, this will need to be verified experimentally, as there have been no field studies on this, either in NZ or overseas. Table 4 shows the emission factors for sheep and beef urine. The low-slope values are those recommended by Saggar et al. (2015) for hill country (which in turn were based on Kelliher et al. 2014). The medium-slope values combine new measurements from Luo et al. (2016) with the recommendations from Saggar et al. (2015). The high-slope values are from the field trials of Luo et al. (2016).

**Table 4: Emission factors for urine on low, medium and high slopes. Values from Saggar et al. (2015) and Luo et al. (2016)**

| N Source | Slope | EF (%) | EF relative to low slope |
|---|---|---|---|
| Beef Urine | Low | 0.99 | 1 |
| | Medium | 0.19 | 0.19 |
| | High | 0.03 | 0.03 |
| Sheep Urine | Low | 0.55 | 1 |
| | Medium | 0.12 | 0.22 |
| | High | 0.005 | 0.009 |

To calculate the $EF_1$ values for urea on medium and high slopes, we took the current, low-slope value of 0.48% from the National Inventory (Ministry for the Environment 2015), and multiplied it by the average of the medium-to-low (0.21) and high-to-low (0.02) slope ratios from Table 4, respectively. Table 5 shows the calculated $EF_1$ values for urea. It is important to note that these $EF_1$ values for urea need to be verified by collecting data from field experiments.

**Table 5: $EF_1$ for urea by slope class**

| Slope class | $EF_1$ (%) |
|---|---|
| Low | 0.48 |
| Medium | 0.098 |
| High | 0.009 |

## 3.3 Calculating $N_2O$ emissions from fertiliser

The method used to calculate $N_2O$ emissions is based on available data on the following components:

$A_{r,f,s}$ – the land area in region *r*, farm type *f*, and slope class *s* (ha)

$N_{fert,r,f}$ – the total amount of N fertiliser applied to pastures in region *r* and farm type *f* (tonnes)

$EF_{1,s}$ – the emission factor for direct emissions from fertiliser N applied to slope *s* (%)

The total amount of direct N2O emissions (N2Ofert,sb tonnes CO2e) for N-fertiliser application to sheep and beef farm pastures is then calculated using the following equation (Eq.1):

$$N_2O_{fert,sb} = \sum_r \sum_f \sum_s N_{fert,r,f} \times \frac{A_{r,f,s}}{A_{r,f,tot}} \times \frac{EF_{1,s}}{100} \times \frac{44}{28} \times 298 \quad (1)$$

where $A_{r,f,tot}$ is the total area in region *r* and farm type *f*; 44/28 is the factor to convert between tonnes $N_2O$-N and tonnes $N_2O$; 298 is the factor to convert tonnes $N_2O$ to tonnes $CO_2$e.

For this study we assumed that all the fertiliser N applied to sheep and beef pasture farms was in the form of urea, as the information on the distinction between the forms of fertiliser N used was not available. Moreover, the New Zealand-specific $EF_1$ values for other forms of N fertilisers have not been determined. This is an important aspect which needs to examine in the future. Note that the choice of the low slope $EF_1$ value (currently 0.48%) does not affect the relative impact of incorporating slope effects on direct $N_2O$ emissions.

The major methodological difference between calculating direct $N_2O$ emissions from fertiliser application and deposition of animal excreta (other than different emission factors) is in the allocation of N to the different slope classes. For animal excreta, Saggar et al. (2015) used a nutrient transfer model to reflect animals' preference to spend more time on lower slopes. However, for fertiliser N we assume that aerial top dressing is the main method of application[4] and, therefore, the allocation of N is directly proportional to the land area in each slope class. However, this may lead to systematic errors as on many farms only part of the total area will have fertiliser applied, and the fertiliser is likely to be preferentially applied to the more productive areas. This is an area where further research is required.

The allocation of fertiliser N to each slope class was calculated for each region and farm type, as shown in Table 1, and was then multiplied by the appropriate emission factors from Table 4 to calculate the amount of N directly emitted as $N_2O$. For the non-commercial farms (accounting for 3-5% of the total area) it was assumed that the land area in each slope class was proportional to the regional average. Explicit formulae for these calculations are given in Appendix 2.

To convert from July-June years used in the Beef+Lamb Sheep and Beef Farm survey data to calendar years as used in the National Inventory, the averages of consecutive years were used. For example, the emissions for calendar year 2000 were the averages of the emissions for the years ended 30 June 2000 and 30 June 2001.

## 3.4 Feasibility of integration into national inventory methodology

The current Inventory reports nitrous oxide ($N_2O$) estimates from applied fertiliser N at the Tier 1 level, using a single $EF_1$ value irrespective of slope. The inventory currently differentiates between urea and other N fertilisers for which the $EF_1$ values are 0.48% and 1% respectively, but does not differentiate between N fertiliser application on different slope classes or farm types.

The proposed framework is similar in structure to that suggested for estimating direct $N_2O$ emissions from hill country by Saggar et al. (2015), the main difference being allocation of N

[4] According to the Beef + Lamb New Zealand data for 2013-14, on average 56% of the fertilised land area was aerially top-dressed. This amount ranges from 3% for Marlborough-Canterbury mixed finishing up to 94% for East Coast hard hill country.

is simply proportional to land area (Section 3.3). Incorporation of this report's methodology into the Inventory would require the inclusion of emission factor ($EF_1$) values for urea by slope class (Table 4), and the following additional activity data:

- land area by slope class, region and farm class (Table 6)
- fertiliser N application by region and farm class (Table7).

The $N_2O$ emissions from fertiliser N would then be calculated according to equation 1 in Section 3.3, and reported at the Tier 1 section of the Inventory. Further work may be needed to confirm that the allocation of N fertiliser according to the relative area in each slope class is reasonable.

# 4 Results

The allocation of fertiliser N across slope classes for New Zealand sheep and beef farms is shown in Figure 1. The total fertiliser N applied to pastures on New Zealand sheep and beef farms varied between 9207 and 66 270 tonnes N (as a percentage of the total fertiliser N use in New Zealand the range was 8% to 25% ), during 1990–2013. As the aim of this study was to quantify emissions from fertiliser applied to sheep, beef and deer pastures the fertiliser N applied to forage crops grown on slopes was not included and only the pasture fertiliser N values were used. Using a single emission factor of 0.48% across all slope classes gave estimates of direct $N_2O$ emissions of 20.7 Gg CO2e in 1990 rising to 86.7 Gg in 2013. Accounting for the lower emissions from higher slopes brought this down to 8.3 Gg CO2e in 1990 (60% reduction) and 30.5 Gg in 2013 (65% reduction over using a single $EF_1$ value) (Figure 2).

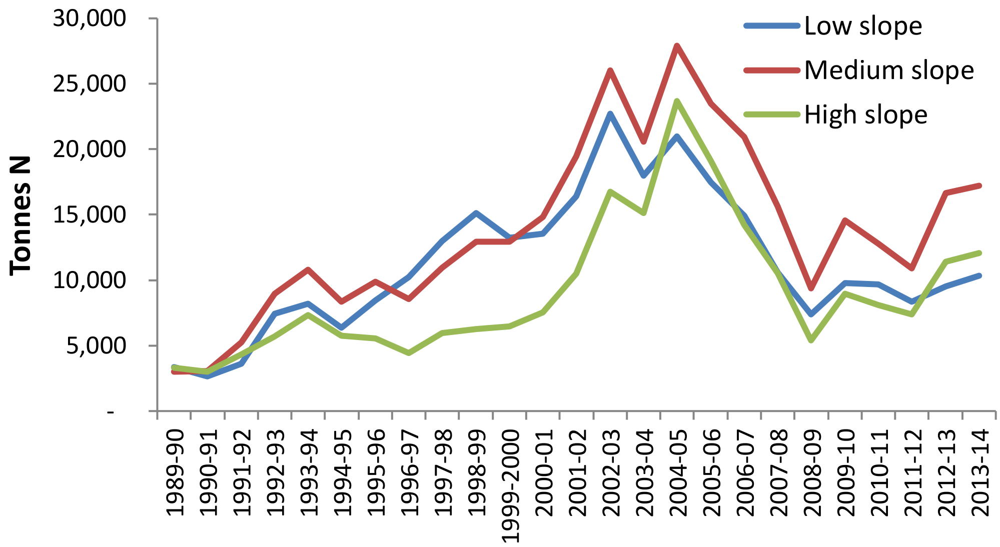


**Figure 2: Allocation of fertiliser N applied to sheep and beef pastures by slope class.**

The highest amount of fertiliser N (66 270 tonnes) applied to sheep and beef grazed pastures in 2005 contributed to the highest estimates of $N_2O$ emissions (149 Gg CO2e using a single $EF_1$ value of 0.48%). However, with the slope-dependent EFs, the estimated $N_2O$ emissions were slightly higher in 2003 (57.1 compared to 55.9 Gg CO2e). This difference in timing occurs because although N fertiliser use on sheep and beef pastures was at its maximum in 2005, there was a higher percentage of the fertiliser N applied to low slopes in 2003.

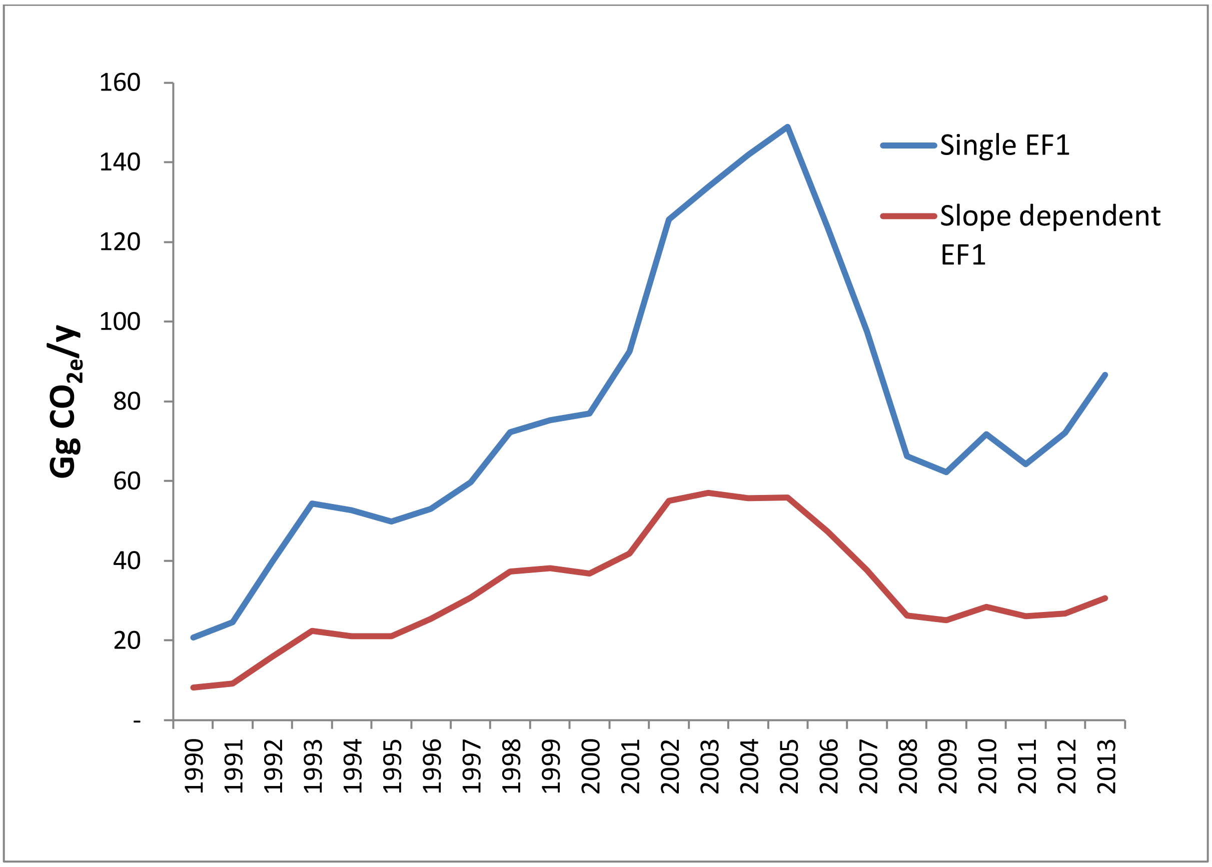


**Figure 3: Direct $N_2O$ emissions for fertiliser applied to pasture on sheep and beef farms using a single emission factor for all slopes (blue line) and using lower emission factors for medium and high slopes (red line).**

# 5 Conclusions

The total fertiliser N applied to pastures on New Zealand sheep and beef farms varied between 9207 and 66 270 tonnes N (as a percentage of the total fertiliser N use in New Zealand the range was 8% to 25% ), during 1990–2013. The proposed framework is similar in structure to that suggested for estimating direct $N_2O$ emissions from hill country by Saggar et al. (2015), the main difference being allocation of fertiliser N is simply proportional to land area. However, this assumption needs to be confirmed.

Calculating direct $N_2O$ emissions from sheep and beef farm pasture using estimated $EF_1$ values of 0.48%, 0.98% and 0.009%, for low, medium, and high slopes, respectively, rather than a single $EF_1$ value of 0.48% indicated the potential for a 60% to 65% reduction in estimated emissions of $N_2O$. Estimates of direct $N_2O$ emissions in 1990 and 2013 were reduced from 20.7 and 86.7 Gg CO2e/y to 8.3 and 30.5Gg CO2e/y, respectively. In 2013 this was equivalent to a reduction of 0.14% in the total greenhouse gas emissions from the agricultural sector.

Incorporation of this report's methodology into the Inventory would require the inclusion of emission factor ($EF_1$) values for urea N by slope class, and the following additional activity data: land area by slope class, region and farm class, and fertiliser N application by region and farm class. The $N_2O$ emissions from fertiliser N would then be calculated according to equation 1 in Section 3.3, and reported at the Tier 1 section of the Inventory.

In the absence of available New Zealand $EF_1$ data on slopes, $EF_1$ values used in this study were estimated from the measured average emission factors for beef and sheep urine applied on slopes. These values need to be confirmed with field measurements of $N_2O$ emissions from fertiliser urea before this work can be incorporated into the inventory.

Further work may be needed to confirm that the allocation of N fertiliser according to the relative area in each slope class is reasonable.

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# Appendix 1 – Selected data from Sheep and Beef Farm Survey data

**Table 6: Land area (ha) in sheep and beef farms by region, farm type, and slope class for years ending 30 June. Data provided by Beef + Lamb New Zealand**

| Region | Farm Type | 1989-90 | 1990-91 | 1991-92 | 1992-93 | 1993-94 | 1994-95 | 1995-96 | 1996-97 | 1997-98 | 1998-99 | 1999-2000 | 2000-01 | 2001-02 | 2002-03 | 2003-04 | 2004-05 | 2005-06 | 2006-07 | 2007-08 | 2008-09 | 2009-10 | 2010-11 | 2011-12 | 2012-13 | 2013-14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Low slope* | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Northland-Waikato-Bay of Plenty | North Island Hard Hill Country | 15,582 | 15,217 | 25,633 | 24,626 | 23,924 | 20,654 | 19,430 | 18,259 | 17,052 | 17,073 | 17,584 | 9,612 | 14,772 | 14,055 | 13,687 | 11,999 | 11,240 | 11,871 | 9,844 | 10,104 | 10,043 | 9,593 | 8,294 | 8,534 | 13,747 |
| | North Island Hill Country | 175,391 | 160,696 | 160,146 | 181,410 | 197,055 | 178,138 | 169,184 | 177,297 | 167,462 | 164,177 | 159,476 | 136,102 | 132,836 | 138,740 | 133,411 | 137,490 | 128,062 | 131,036 | 112,075 | 113,091 | 119,421 | 124,100 | 110,268 | 125,030 | 115,093 |
| | North Island Intensive Finishing | 172,952 | 137,015 | 126,127 | 141,012 | 119,138 | 111,925 | 111,447 | 81,515 | 88,743 | 70,330 | 80,299 | 64,834 | 56,900 | 44,703 | 47,095 | 48,764 | 51,729 | 46,003 | 46,258 | 47,833 | 56,873 | 55,141 | 47,966 | 51,670 | 48,809 |
| East Coast | North Island Hard Hill Country | 31,582 | 33,695 | 28,402 | 30,421 | 29,889 | 27,118 | 21,932 | 17,312 | 19,298 | 18,231 | 19,184 | 19,279 | 20,970 | 22,099 | 19,865 | 25,484 | 25,863 | 28,830 | 27,379 | 26,697 | 22,347 | 30,469 | 30,946 | 34,388 | 34,852 |
| | North Island Hill Country | 50,478 | 45,188 | 46,881 | 55,593 | 54,419 | 60,524 | 60,701 | 66,843 | 66,047 | 58,490 | 59,800 | 60,202 | 64,343 | 67,698 | 66,074 | 63,657 | 62,019 | 61,289 | 60,658 | 54,714 | 64,621 | 60,876 | 51,892 | 45,337 | 47,346 |
| | North Island Intensive Finishing | 124,192 | 114,177 | 117,108 | 127,234 | 124,318 | 125,174 | 125,009 | 116,603 | 111,134 | 101,900 | 104,880 | 96,461 | 93,561 | 89,235 | 85,279 | 76,315 | 83,137 | 94,002 | 89,505 | 91,115 | 95,417 | 81,981 | 87,332 | 82,093 | 76,587 |

| Region | Farm Type | 1989-90 | 1990-91 | 1991-92 | 1992-93 | 1993-94 | 1994-95 | 1995-96 | 1996-97 | 1997-98 | 1998-99 | 1999-2000 | 2000-01 | 2001-02 | 2002-03 | 2003-04 | 2004-05 | 2005-06 | 2006-07 | 2007-08 | 2008-09 | 2009-10 | 2010-11 | 2011-12 | 2012-13 | 2013-14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Taranaki-Manawatu | North Island Hard Hill Country | 12,529 | 13,943 | 15,493 | 10,272 | 11,269 | 16,872 | 16,548 | 16,085 | 15,819 | 15,289 | 13,466 | 16,459 | 14,306 | 13,486 | 13,303 | 14,375 | 15,440 | 16,294 | 16,093 | 14,117 | 15,584 | 15,225 | 13,877 | 11,680 | 12,765 |
| | North Island Hill Country | 47,418 | 47,603 | 49,412 | 50,913 | 57,490 | 48,969 | 43,570 | 39,096 | 37,463 | 35,942 | 38,091 | 41,925 | 42,048 | 42,947 | 47,807 | 44,995 | 43,057 | 47,603 | 47,600 | 49,474 | 47,246 | 46,158 | 45,066 | 44,568 | 48,181 |
| | North Island Intensive Finishing | 118,388 | 99,075 | 94,065 | 96,801 | 90,546 | 83,610 | 75,300 | 69,307 | 66,909 | 61,561 | 52,145 | 48,547 | 45,558 | 42,171 | 37,225 | 32,679 | 32,761 | 37,012 | 42,583 | 37,737 | 32,848 | 32,597 | 31,855 | 32,344 | 31,601 |
| Marlborough-Canterbury | South Island High Country | 106,390 | 142,277 | 141,945 | 184,216 | 210,936 | 195,553 | 202,261 | 205,710 | 201,577 | 184,951 | 149,577 | 155,074 | 148,317 | 193,661 | 161,618 | 126,565 | 106,293 | 82,057 | 85,859 | 82,132 | 123,572 | 98,203 | 106,368 | 77,630 | 73,558 |
| | South Island Hill Country | 213,721 | 172,065 | 207,814 | 202,875 | 224,856 | 226,515 | 211,768 | 221,427 | 216,704 | 223,305 | 212,139 | 201,794 | 208,100 | 89,517 | 271,211 | 119,833 | 175,023 | 148,099 | 143,734 | 126,813 | 64,217 | 55,445 | 78,428 | 78,632 | 78,607 |
| | South Island Finishing Breeding | 556,500 | 650,060 | 646,938 | 733,194 | 670,915 | 664,484 | 740,502 | 763,157 | 699,136 | 687,515 | 681,822 | 667,991 | 666,426 | 652,769 | 532,350 | 508,215 | 409,330 | 406,816 | 374,395 | 364,721 | 364,921 | 366,685 | 357,646 | 298,991 | 297,195 |
| | South Island Mixed Finishing | 381,837 | 193,903 | 193,236 | 268,519 | 254,403 | 235,183 | 276,436 | 274,496 | 290,362 | 286,802 | 251,411 | 235,768 | 226,481 | 232,506 | 242,946 | 231,530 | 176,527 | 190,125 | 184,111 | 182,562 | 191,385 | 191,515 | 208,955 | 199,189 | 200,615 |

| Region | Farm Type | 1989-90 | 1990-91 | 1991-92 | 1992-93 | 1993-94 | 1994-95 | 1995-96 | 1996-97 | 1997-98 | 1998-99 | 1999-2000 | 2000-01 | 2001-02 | 2002-03 | 2003-04 | 2004-05 | 2005-06 | 2006-07 | 2007-08 | 2008-09 | 2009-10 | 2010-11 | 2011-12 | 2012-13 | 2013-14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Otago-Southland | South Island High Country | 68,282 | 61,466 | 41,459 | 42,059 | 47,484 | 45,505 | 42,969 | 46,670 | 47,275 | 44,507 | 39,362 | 38,352 | 43,248 | 43,177 | 47,430 | 45,073 | 49,231 | 69,869 | 72,933 | 65,522 | 69,597 | 65,124 | 67,132 | 69,228 | 64,008 |
| | South Island Hill Country | 122,761 | 172,528 | 189,522 | 178,405 | 212,201 | 190,723 | 195,913 | 193,069 | 117,533 | 117,675 | 116,254 | 102,798 | 94,043 | 93,888 | 78,117 | 97,486 | 90,975 | 97,111 | 92,723 | 96,834 | 105,465 | 119,947 | 103,151 | 99,873 | 102,542 |
| | South Island Finishing Breeding | 193,518 | 177,603 | 177,941 | 203,870 | 156,353 | 126,847 | 132,855 | 164,399 | 152,939 | 137,658 | 153,303 | 160,200 | 141,352 | 104,379 | 94,325 | 82,309 | 95,367 | 108,167 | 89,188 | 95,304 | 109,199 | 111,012 | 99,138 | 100,556 | 85,732 |
| | South Island Intensive Finishing | 381,582 | 362,152 | 356,185 | 378,074 | 321,595 | 284,144 | 294,392 | 312,758 | 282,745 | 265,450 | 240,329 | 256,319 | 383,483 | 365,546 | 329,881 | 306,148 | 308,619 | 309,508 | 294,991 | 287,667 | 275,162 | 274,560 | 269,453 | 227,130 | 238,117 |
| | | | | | | | | | | | | *Medium Slope* | | | | | | | | | | | | | | |
| Northland-Waikato-Bay of Plenty | North Island Hard Hill Country | 70,120 | 65,016 | 132,104 | 131,748 | 151,954 | 111,773 | 106,035 | 105,681 | 101,243 | 85,852 | 89,343 | 45,005 | 63,877 | 57,741 | 58,549 | 57,600 | 52,110 | 55,039 | 53,235 | 54,126 | 58,771 | 53,501 | 52,292 | 42,669 | 69,064 |
| | North Island Hill Country | 717,508 | 705,493 | 703,901 | 659,355 | 706,422 | 674,133 | 609,700 | 637,587 | 610,743 | 663,272 | 660,684 | 618,649 | 576,568 | 535,916 | 528,197 | 533,463 | 512,247 | 504,202 | 517,268 | 499,254 | 520,335 | 482,297 | 460,369 | 470,223 | 477,885 |
| | North Island Intensive Finishing | 212,485 | 201,240 | 183,088 | 209,613 | 190,265 | 190,439 | 215,262 | 158,306 | 154,731 | 133,525 | 122,408 | 105,781 | 116,919 | 88,229 | 87,714 | 89,100 | 85,621 | 93,234 | 91,281 | 87,190 | 87,451 | 70,979 | 76,085 | 74,112 | 65,385 |

| Region | Farm Type | 1989-90 | 1990-91 | 1991-92 | 1992-93 | 1993-94 | 1994-95 | 1995-96 | 1996-97 | 1997-98 | 1998-99 | 1999-2000 | 2000-01 | 2001-02 | 2002-03 | 2003-04 | 2004-05 | 2005-06 | 2006-07 | 2007-08 | 2008-09 | 2009-10 | 2010-11 | 2011-12 | 2012-13 | 2013-14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| East Coast | North Island Hard Hill Country | 150,254 | 180,056 | 159,895 | 169,488 | 160,783 | 158,972 | 149,865 | 126,698 | 118,756 | 88,354 | 96,605 | 84,188 | 80,798 | 98,282 | 108,411 | 115,837 | 112,648 | 127,589 | 141,654 | 142,381 | 142,900 | 149,024 | 148,539 | 159,044 | 160,853 |
| | North Island Hill Country | 345,867 | 331,962 | 350,740 | 367,629 | 368,644 | 364,735 | 364,204 | 381,961 | 348,248 | 356,785 | 340,290 | 322,902 | 326,971 | 319,686 | 288,766 | 303,234 | 284,827 | 278,251 | 262,849 | 261,928 | 241,174 | 236,983 | 261,663 | 270,967 | 274,604 |
| | North Island Intensive Finishing | 255,284 | 226,830 | 231,173 | 219,910 | 222,862 | 184,323 | 198,940 | 197,610 | 204,905 | 189,242 | 176,242 | 191,894 | 188,107 | 178,470 | 169,651 | 158,436 | 162,159 | 170,434 | 163,665 | 155,724 | 159,027 | 157,067 | 161,524 | 149,527 | 152,446 |
| Taranaki-Manawatu | North Island Hard Hill Country | 24,626 | 23,094 | 26,559 | 21,437 | 25,478 | 27,083 | 23,007 | 24,334 | 23,120 | 22,374 | 24,807 | 25,017 | 27,976 | 25,176 | 26,607 | 36,278 | 37,741 | 45,984 | 45,418 | 42,686 | 51,737 | 44,760 | 66,666 | 66,698 | 71,356 |
| | North Island Hill Country | 96,945 | 110,731 | 109,336 | 115,614 | 131,075 | 115,649 | 106,083 | 104,255 | 106,472 | 115,200 | 114,272 | 108,037 | 110,568 | 115,511 | 110,553 | 94,763 | 92,948 | 111,793 | 116,514 | 123,318 | 115,720 | 115,061 | 119,292 | 123,574 | 128,721 |
| | North Island Intensive Finishing | 73,025 | 61,111 | 61,142 | 65,483 | 55,190 | 50,792 | 50,437 | 47,052 | 51,276 | 51,871 | 44,322 | 40,303 | 38,039 | 34,872 | 35,179 | 31,910 | 31,989 | 36,606 | 34,147 | 32,572 | 29,004 | 27,504 | 26,878 | 24,341 | 29,846 |

| Region | Farm Type | 1989-90 | 1990-91 | 1991-92 | 1992-93 | 1993-94 | 1994-95 | 1995-96 | 1996-97 | 1997-98 | 1998-99 | 1999-2000 | 2000-01 | 2001-02 | 2002-03 | 2003-04 | 2004-05 | 2005-06 | 2006-07 | 2007-08 | 2008-09 | 2009-10 | 2010-11 | 2011-12 | 2012-13 | 2013-14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Marlborough-Canterbury | South Island High Country | 77,870 | 94,285 | 92,921 | 100,039 | 101,068 | 93,628 | 93,292 | 90,460 | 58,047 | 57,656 | 194,834 | 211,030 | 201,836 | 231,330 | 299,152 | 58,126 | 221,678 | 264,280 | 275,175 | 272,284 | 294,861 | 246,559 | 275,976 | 265,421 | 263,416 |
| | South Island Hill Country | 182,202 | 147,269 | 166,398 | 182,743 | 208,323 | 197,336 | 207,818 | 212,789 | 208,252 | 190,755 | 185,710 | 150,315 | 158,209 | 177,016 | 131,923 | 152,148 | 134,498 | 162,432 | 142,002 | 156,817 | 193,704 | 141,874 | 160,476 | 164,151 | 171,456 |
| | South Island Finishing Breeding | 398,403 | 458,653 | 444,326 | 468,946 | 474,459 | 440,694 | 485,401 | 498,317 | 518,384 | 471,438 | 453,520 | 446,287 | 426,843 | 430,721 | 393,939 | 355,995 | 302,733 | 333,632 | 337,366 | 362,706 | 355,844 | 327,989 | 355,648 | 350,990 | 308,068 |
| | South Island Mixed Finishing | 46,350 | 39,993 | 41,749 | 59,949 | 67,201 | 62,418 | 38,999 | 46,723 | 40,010 | 44,036 | 46,199 | 56,626 | 64,006 | 64,207 | 38,716 | 44,274 | 41,462 | 37,899 | 32,204 | 32,643 | 29,869 | 32,863 | 38,048 | 39,955 | 42,866 |
| Otago-Southland | South Island High Country | 128,383 | 95,899 | 104,102 | 111,251 | 110,378 | 130,437 | 90,437 | 70,739 | 41,207 | 45,919 | 56,532 | 55,081 | 84,169 | 84,030 | 81,006 | 92,799 | 160,260 | 83,818 | 89,140 | 96,244 | 96,081 | 95,117 | 99,343 | 102,444 | 94,395 |
| | South Island Hill Country | 126,872 | 106,561 | 75,413 | 65,565 | 81,300 | 73,071 | 75,060 | 67,782 | 77,999 | 78,093 | 77,150 | 71,479 | 94,043 | 93,380 | 92,721 | 109,843 | 133,109 | 139,914 | 127,895 | 178,018 | 176,672 | 138,215 | 132,338 | 162,805 | 194,325 |
| | South Island Finishing Breeding | 234,424 | 195,362 | 225,393 | 270,350 | 275,346 | 338,260 | 339,800 | 352,855 | 372,709 | 351,652 | 349,878 | 385,410 | 433,403 | 433,230 | 399,859 | 363,459 | 337,383 | 281,057 | 308,186 | 334,065 | 311,269 | 410,535 | 418,586 | 402,225 | 328,806 |
| | South Island Intensive Finishing | 242,501 | 235,897 | 246,334 | 245,417 | 185,325 | 203,310 | 221,423 | 221,871 | 267,322 | 257,865 | 332,002 | 292,613 | 219,133 | 208,251 | 170,000 | 149,429 | 154,309 | 125,901 | 113,194 | 161,465 | 174,269 | 184,269 | 162,362 | 154,310 | 150,301 |

| Region | Farm Type | 1989-90 | 1990-91 | 1991-92 | 1992-93 | 1993-94 | 1994-95 | 1995-96 | 1996-97 | 1997-98 | 1998-99 | 1999-2000 | 2000-01 | 2001-02 | 2002-03 | 2003-04 | 2004-05 | 2005-06 | 2006-07 | 2007-08 | 2008-09 | 2009-10 | 2010-11 | 2011-12 | 2012-13 | 2013-14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | *High Slope* | | | | | | | | | | | | | |
| Northland-Waikato-Bay of Plenty | North Island Hard Hill Country | 225,235 | 214,414 | 165,623 | 149,601 | 153,247 | 133,035 | 119,359 | 111,768 | 108,703 | 105,852 | 118,332 | 162,541 | 138,134 | 147,771 | 152,077 | 121,371 | 123,974 | 130,943 | 137,827 | 137,842 | 124,982 | 133,568 | 128,025 | 139,030 | 108,996 |
| | North Island Hill Country | 279,031 | 297,875 | 301,672 | 265,138 | 275,133 | 223,547 | 252,179 | 296,632 | 279,103 | 252,831 | 234,331 | 235,087 | 240,237 | 272,039 | 258,653 | 258,482 | 277,921 | 242,131 | 258,634 | 259,281 | 321,299 | 377,941 | 352,857 | 274,523 | 270,218 |
| | North Island Intensive Finishing | 54,357 | 47,099 | 48,823 | 62,884 | 62,236 | 63,480 | 47,327 | 17,721 | 14,790 | 12,231 | 5,876 | 3,412 | 0 | 1,176 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,381 |
| East Coast | North Island Hard Hill Country | 517,755 | 587,552 | 560,684 | 570,391 | 561,710 | 592,871 | 593,978 | 509,939 | 473,540 | 460,001 | 450,137 | 429,935 | 431,126 | 374,519 | 384,830 | 406,007 | 398,292 | 382,153 | 386,870 | 370,785 | 379,891 | 347,353 | 365,159 | 353,551 | 310,447 |
| | North Island Hill Country | 368,302 | 331,962 | 347,267 | 337,143 | 328,268 | 308,990 | 305,060 | 323,075 | 342,244 | 355,323 | 353,105 | 339,321 | 288,890 | 305,896 | 325,474 | 293,975 | 304,352 | 294,186 | 280,689 | 301,509 | 300,025 | 278,292 | 260,559 | 249,880 | 255,666 |
| | North Island Intensive Finishing | 72,445 | 62,416 | 60,835 | 53,407 | 43,966 | 41,266 | 37,637 | 35,594 | 43,991 | 45,911 | 41,087 | 49,256 | 48,258 | 44,617 | 43,547 | 38,987 | 40,334 | 38,655 | 44,326 | 43,901 | 53,009 | 49,035 | 47,143 | 43,246 | 44,494 |

| Region | Farm Type | 1989-90 | 1990-91 | 1991-92 | 1992-93 | 1993-94 | 1994-95 | 1995-96 | 1996-97 | 1997-98 | 1998-99 | 1999-2000 | 2000-01 | 2001-02 | 2002-03 | 2003-04 | 2004-05 | 2005-06 | 2006-07 | 2007-08 | 2008-09 | 2009-10 | 2010-11 | 2011-12 | 2012-13 | 2013-14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Taranaki-Manawatu | North Island Hard Hill Country | 156,829 | 154,686 | 150,946 | 160,777 | 170,998 | 205,565 | 184,860 | 186,422 | 180,496 | 168,924 | 172,228 | 196,190 | 191,065 | 194,811 | 189,270 | 211,852 | 215,810 | 240,421 | 227,806 | 211,078 | 208,820 | 210,099 | 215,383 | 203,168 | 217,668 |
| | North Island Hill Country | 406,747 | 396,354 | 385,830 | 364,875 | 361,032 | 308,398 | 281,311 | 300,736 | 286,884 | 289,382 | 278,754 | 251,549 | 238,267 | 226,579 | 233,804 | 209,977 | 205,716 | 143,528 | 146,353 | 161,716 | 154,750 | 156,536 | 157,730 | 141,807 | 135,193 |
| | North Island Intensive Finishing | 9,958 | 12,963 | 15,991 | 15,185 | 7,761 | 7,033 | 8,525 | 6,994 | 6,878 | 5,700 | 8,864 | 5,496 | 11,058 | 10,137 | 8,590 | 9,611 | 9,635 | 5,288 | 4,419 | 9,533 | 8,387 | 9,508 | 9,291 | 7,002 | 7,023 |
| Marlborough-Canterbury | South Island High Country | 1,116,224 | 1,018,475 | 1,002,446 | 1,024,619 | 1,092,947 | 1,015,042 | 949,110 | 843,344 | 795,003 | 782,324 | 686,780 | 684,510 | 654,688 | 655,416 | 493,747 | 746,285 | 705,809 | 648,452 | 659,885 | 646,480 | 468,353 | 570,752 | 469,285 | 453,858 | 448,412 |
| | South Island Hill Country | 864,113 | 861,075 | 806,847 | 789,046 | 814,276 | 770,917 | 711,164 | 721,599 | 740,792 | 773,619 | 711,413 | 689,117 | 652,529 | 587,584 | 707,829 | 788,342 | 821,669 | 752,440 | 705,394 | 697,470 | 740,602 | 739,265 | 716,711 | 695,061 | 672,722 |
| | South Island Finishing Breeding | 205,526 | 278,081 | 277,259 | 171,203 | 155,682 | 158,374 | 155,895 | 114,996 | 112,544 | 94,942 | 120,322 | 86,378 | 77,107 | 69,557 | 47,912 | 112,936 | 89,541 | 92,556 | 98,741 | 98,737 | 61,728 | 70,020 | 91,909 | 131,853 | 108,730 |
| | South Island Mixed Finishing | 145,672 | 70,290 | 75,148 | 2,498 | 3,600 | 2,229 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,133 | 1,247 | 1,175 | 572 |

| Region | Farm Type | 1989-90 | 1990-91 | 1991-92 | 1992-93 | 1993-94 | 1994-95 | 1995-96 | 1996-97 | 1997-98 | 1998-99 | 1999-2000 | 2000-01 | 2001-02 | 2002-03 | 2003-04 | 2004-05 | 2005-06 | 2006-07 | 2007-08 | 2008-09 | 2009-10 | 2010-11 | 2011-12 | 2012-13 | 2013-14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Otago-Southland | South Island High Country | 1,324,261 | 1,419,006 | 1,331,989 | 1,318,737 | 1,475,789 | 1,339,558 | 1,324,042 | 1,325,691 | 1,331,893 | 1,349,608 | 1,258,353 | 1,226,056 | 1,001,682 | 1,000,029 | 1,113,239 | 1,108,150 | 1,042,271 | 1,117,782 | 1,127,825 | 952,569 | 981,475 | 889,030 | 844,654 | 871,020 | 963,835 |
| | South Island Hill Country | 255,800 | 214,532 | 239,515 | 257,476 | 166,122 | 149,308 | 153,371 | 49,726 | 58,232 | 58,303 | 57,598 | 58,597 | 73,963 | 73,841 | 87,853 | 103,802 | 104,931 | 144,997 | 104,714 | 122,265 | 121,588 | 110,296 | 105,472 | 126,892 | 119,688 |
| | South Island Finishing Breeding | 129,012 | 180,562 | 174,976 | 112,277 | 124,528 | 164,156 | 155,848 | 161,725 | 165,791 | 167,692 | 159,485 | 148,592 | 162,380 | 169,476 | 164,045 | 177,568 | 150,248 | 126,786 | 145,704 | 158,506 | 142,877 | 174,896 | 171,240 | 153,913 | 116,998 |
| | South Island Intensive Finishing | 24,963 | 9,967 | 16,644 | 6,633 | 2,725 | 12,248 | 37,743 | 40,097 | 38,556 | 27,809 | 2,478 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1,843 | 0 | 0 | 0 |

**Table 7: Fertiliser N allocation (tonnes) on sheep & beef pasture by region and farm class for years ended 30 June. Data provided by Beef + Lamb New Zealand**

| Region | Farm Type | 1989-90 | 1990-91 | 1991-92 | 1992-93 | 1993-94 | 1994-95 | 1995-96 | 1996-97 | 1997-98 | 1998-99 | 1999-2000 | 2000-01 | 2001-02 | 2002-03 | 2003-04 | 2004-05 | 2005-06 | 2006-07 | 2007-08 | 2008-09 | 2009-10 | 2010-11 | 2011-12 | 2012-13 | 2013-14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Northland-Waikato-Bay of Plenty | North Island Hard Hill Country | 288 | 275 | 851 | 1,227 | 1,165 | 600 | 444 | 883 | 475 | 536 | 759 | 963 | 794 | 2,058 | 2,356 | 4,048 | 2,934 | 1,651 | 1,681 | 252 | 154 | 369 | 510 | 602 | 1,242 |
| | North Island Hill Country | 795 | 1,186 | 2,965 | 3,504 | 4,810 | 3,122 | 3,501 | 3,087 | 3,639 | 6,571 | 6,537 | 4,914 | 8,747 | 9,221 | 7,872 | 10,704 | 10,115 | 7,084 | 4,591 | 2,495 | 7,132 | 4,821 | 3,850 | 9,495 | 8,735 |
| | North Island Intensive Finishing | 747 | 426 | 619 | 2,276 | 2,675 | 2,335 | 2,125 | 1,176 | 1,355 | 2,345 | 2,549 | 2,137 | 2,264 | 2,405 | 2,827 | 3,313 | 3,269 | 3,983 | 3,327 | 1,994 | 1,890 | 2,113 | 1,160 | 1,410 | 1,431 |
| | Non-commercial | 61 | 47 | 73 | 184 | 247 | 261 | 194 | 143 | 162 | 298 | 336 | 352 | 378 | 554 | 630 | 671 | 686 | 837 | 686 | 437 | 377 | 498 | 266 | 415 | 329 |
| East Coast | North Island Hard Hill Country | 757 | 533 | 539 | 638 | 1,121 | 834 | 451 | 219 | 891 | 917 | 890 | 659 | 2,032 | 3,328 | 1,748 | 5,207 | 3,492 | 2,570 | 1,723 | 888 | 1,464 | 767 | 1,187 | 2,429 | 1,657 |
| | North Island Hill Country | 925 | 705 | 881 | 1,242 | 1,556 | 1,271 | 1,542 | 1,443 | 2,688 | 2,171 | 1,709 | 3,286 | 4,084 | 7,874 | 5,614 | 10,631 | 9,091 | 5,399 | 4,744 | 1,859 | 2,088 | 2,950 | 2,218 | 3,392 | 1,672 |
| | North Island Intensive Finishing | 519 | 612 | 1,072 | 1,250 | 1,962 | 1,519 | 1,215 | 855 | 1,969 | 784 | 1,629 | 2,666 | 3,639 | 4,842 | 3,801 | 4,635 | 2,562 | 3,523 | 2,472 | 1,903 | 2,124 | 610 | 846 | 2,341 | 1,529 |
| | Non-commercial | 92 | 124 | 134 | 163 | 176 | 216 | 185 | 91 | 235 | 117 | 176 | 235 | 358 | 443 | 439 | 487 | 292 | 334 | 364 | 317 | 329 | 88 | 141 | 335 | 225 |

| Region | Farm Type | 1989-90 | 1990-91 | 1991-92 | 1992-93 | 1993-94 | 1994-95 | 1995-96 | 1996-97 | 1997-98 | 1998-99 | 1999-2000 | 2000-01 | 2001-02 | 2002-03 | 2003-04 | 2004-05 | 2005-06 | 2006-07 | 2007-08 | 2008-09 | 2009-10 | 2010-11 | 2011-12 | 2012-13 | 2013-14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Taranaki-Manawatu | North Island Hard Hill Country | 173 | 0 | 223 | 264 | 730 | 493 | 448 | 245 | 168 | 189 | 598 | 294 | 470 | 711 | 1,180 | 1,745 | 1,300 | 935 | 289 | 67 | 403 | 66 | 118 | 182 | 1,308 |
| | North Island Hill Country | 643 | 928 | 1,153 | 1,809 | 2,763 | 2,289 | 1,134 | 704 | 1,579 | 549 | 1,659 | 1,780 | 1,556 | 4,442 | 3,727 | 4,291 | 2,402 | 1,885 | 1,785 | 517 | 1,028 | 1,399 | 1,450 | 2,294 | 1,786 |
| | North Island Intensive Finishing | 331 | 91 | 379 | 383 | 863 | 316 | 495 | 637 | 561 | 627 | 575 | 775 | 798 | 930 | 614 | 1,232 | 735 | 652 | 641 | 280 | 490 | 408 | 430 | 600 | 316 |
| | Non-commercial | 42 | 20 | 59 | 44 | 102 | 57 | 98 | 100 | 66 | 79 | 83 | 105 | 131 | 129 | 131 | 212 | 129 | 108 | 135 | 67 | 136 | 82 | 87 | 133 | 62 |
| Marlborough-Canterbury | South Island High Country | 61 | 83 | 128 | 88 | 106 | 22 | 38 | 76 | 40 | 115 | 69 | 182 | 84 | 60 | 427 | 573 | 318 | 663 | 338 | 235 | 250 | 301 | 156 | 404 | 589 |
| | South Island Hill Country | 241 | 222 | 224 | 235 | 426 | 465 | 482 | 705 | 378 | 1,065 | 436 | 825 | 994 | 735 | 1,814 | 2,026 | 2,119 | 1,915 | 1,088 | 1,129 | 1,584 | 1,356 | 1,391 | 1,202 | 2,555 |
| | South Island Finishing Breeding | 1,263 | 1,432 | 1,054 | 5,229 | 2,598 | 2,739 | 4,623 | 4,896 | 5,836 | 5,551 | 5,259 | 6,317 | 7,404 | 12,328 | 5,887 | 7,349 | 8,934 | 9,458 | 5,547 | 5,043 | 5,810 | 5,330 | 6,209 | 5,212 | 5,615 |
| | South Island Mixed Finishing | 1,980 | 1,094 | 1,312 | 751 | 1,676 | 1,898 | 1,955 | 4,677 | 6,972 | 8,817 | 7,421 | 5,670 | 7,192 | 9,636 | 8,132 | 8,054 | 6,278 | 2,975 | 2,923 | 1,879 | 832 | 1,473 | 1,751 | 2,121 | 2,455 |
| | Non-commercial | 53 | 49 | 37 | 127 | 77 | 95 | 125 | 133 | 145 | 143 | 129 | 200 | 205 | 414 | 224 | 334 | 469 | 410 | 259 | 239 | 235 | 223 | 238 | 251 | 263 |

| Region | Farm Type | 1989-90 | 1990-91 | 1991-92 | 1992-93 | 1993-94 | 1994-95 | 1995-96 | 1996-97 | 1997-98 | 1998-99 | 1999-2000 | 2000-01 | 2001-02 | 2002-03 | 2003-04 | 2004-05 | 2005-06 | 2006-07 | 2007-08 | 2008-09 | 2009-10 | 2010-11 | 2011-12 | 2012-13 | 2013-14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Otago-Southland | South Island High Country | 0 | 0 | 0 | 28 | 0 | 0 | 102 | 56 | 86 | 196 | 58 | 91 | 72 | 123 | 151 | 65 | 26 | 0 | 88 | 30 | 129 | 51 | 83 | 179 | 303 |
| | South Island Hill Country | 0 | 87 | 0 | 23 | 0 | 0 | 54 | 249 | 50 | 323 | 0 | 78 | 1,021 | 636 | 1,158 | 1,205 | 885 | 1,924 | 556 | 419 | 1,338 | 930 | 493 | 547 | 674 |
| | South Island Finishing Breeding | 0 | 147 | 147 | 285 | 278 | 731 | 2,051 | 676 | 267 | 382 | 249 | 695 | 1,976 | 1,890 | 2,571 | 2,143 | 1,891 | 1,517 | 2,193 | 593 | 1,526 | 2,638 | 1,387 | 1,835 | 3,946 |
| | South Island Intensive Finishing | 703 | 669 | 1,335 | 2,327 | 3,001 | 1,210 | 2,529 | 2,157 | 2,317 | 2,541 | 1,495 | 3,644 | 2,060 | 2,646 | 2,210 | 3,479 | 1,937 | 2,098 | 1,207 | 1,493 | 3,854 | 4,041 | 2,606 | 2,083 | 2,714 |
| | Non-commercial | 0 | 12 | 11 | 11 | 10 | 30 | 81 | 25 | 15 | 18 | 15 | 30 | 88 | 76 | 119 | 136 | 137 | 106 | 106 | 27 | 73 | 88 | 46 | 95 | 193 |

# Appendix 2 – Formulae for calculating direct $N_2O$ emissions from Sheep + Beef pasture fertiliser

This method assumes the following data is available:

$A_{r,f,s}$ – the land area in region *r*, farm type *f*, and slope class *s* (ha)

$N_{fert,r,f}$ – the total amount of N fertiliser applied to pastures in region *r* and farm type *f* (tonnes)

$EF_{1,s}$ – the emission factor for direct emissions from fertiliser N applied to slope *s* (%)

The total amount of direct $N_2O$ emissions ($N_2O_{fert,sb}$ tonnes $CO_2$e) for N fertiliser application to sheep and beef farm pastures is calculated according to equation 1:

$$N_2O_{fert,sb} = \sum_r \sum_f \sum_s N_{fert,r,f} \times \frac{A_{r,f,s}}{A_{r,f,tot}} \times \frac{EF_{1,s}}{100} \times \frac{44}{28} \times 298 \qquad (1)$$

where:

$A_{r,f,tot}$ – is the total area in region *r* and farm type *f*

44/28 – is the factor to convert between tonnes $N_2O$-N and tonnes $N_2O$

298 – is the factor to convert tonnes $N_2O$ into tonnes $CO_2$e