Accounting for the utilization of a N_2O mitigation tool in the IPCC inventory methodology for agricultural soils.

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Abstract

In this study we review recent studies where dycandiamide was used as a nitrification inhibitor to reduce both N_2O emissions from urine patches and nitrate leaching from pasture systems, and which led to the development of a commercial product for use on farmland. On average, emissions of N_2O and nitrate leaching were reduced by 72% and 61% respectively. This study then demonstrates how a mitigation tool can be accounted for in the Intergovernmental Panel on Climate Change's inventory methodology when constructing an inventory of New Zealand's agricultural soil N_2O emissions. The current New Zealand specific emission factors for EF1 (0.01), $EF3_{PRP}$ (0.01) and $Frac_{LEACH}$ (0.07) are amended to values of 0.0058, 0.0058 and 0.0455. Examples are also given, based on OVERSEER™ models, of the implications of farm management scenarios on N_2O inventories and total greenhouse

gas production when using a N_2O mitigation tool; CO_2 equivalents kg^{-1} milk solid decreased from 14.2 to as little as 11.7, depending on the management scenario modelled.

Introduction

Agricultural greenhouse gas (GHG) emissions make a significant contribution to New Zealand's GHG inventory. New Zealand's emissions of N_2O, from agriculture, are calculated using the approach of the Intergovernmental Panel on Climate Change (IPCC). Emissions from this sector totalled 36,867 Gg CO_2 equivalents in 2004, which is 14.8% higher than the 1990 level. This increase was partially attributable to a 24.3% increase in N_2O emissions from the agricultural soils category. The emissions of N_2O comprise 33.4% of New Zealand's total agricultural emissions (Ministry for the Environment 2006).

These N_2O emissions are dominated by nitrogen (N) excreta deposited during grazing and from fertiliser. The IPCC guidelines divide agricultural N_2O emissions into three categories: direct emissions from agricultural land, emissions from animal waste systems, and indirect emissions associated with nitrogen (N) that is removed in biomass, volatilized, leached, or exported from the agricultural land (Mosier et al. 1998).

Direct emissions from agricultural land associated with fertiliser are a function of the amount of N fertiliser used multiplied by the emission factor EF1 (New Zealand specific default value 0.01 kg N_2O-N/kg fertiliser N). Similarly the direct emissions from N excreted by grazing animals are a function of the total amount of N excreted multiplied by an emission factor ($EF3_{PR\&P}$, New Zealand specific default value 0.01 kg N_2O-N/kg excreted N).

The main source of indirect N_2O emissions is associated with the leaching of N and is a function of the total N inputs (fertiliser N and excreta N) and the fraction of the total N inputs that leach, FRACLEACH (New Zealand specific default value 0.07 (Thomas et al. 2005)). This mass of leached N is multiplied by a further emission factor, EF5, (IPCC default value 0.025 kg N_2O-N/kg N leached) to calculate the total amount of N_2O associated with N leaching and runoff.

Nitrous oxide is produced in the soil via microbial processes such as nitrification (the conversion of ammonium (NH_4^+) to nitrate (NO_3^-)) and denitrification (the reduction of NO_3^- to dinitrogen). The nitrification process is conducted by soil microorganisms such as *Nitrosomonas sp.* and *Nitrobacter sp.*, which derive their energy from the oxidation of NH_4^+ to NO_3^-. The resulting NO_3^- is also susceptible to leaching from the soil during periods of drainage. Treating the soil with a nitrification inhibitor to reduce the nitrification rate therefore has the potential to reduce both the direct emissions of N_2O and indirect emissions of N_2O associated with NO_3^- leaching.

Recent work at our centre has shown that the application of a fine particle spray of nitrification inhibitor (dicyandiamide; DCD) to grazed pasture soil can significantly reduce the emissions of N_2O from urine patches and fertiliser (i.e. reduce the emission factors EF1 and $EF3_{PR\&P}$), and in addition reduce the amount of NO_3-N leached and thus the value of FRACLEACH; at the same time dry matter (DM) production increases occur in the grazed pasture Di and Cameron (2002; 2003; 2004a; 2004b; 2004c; 2005; 2006). No enhancement of ammonia volatilization has been recorded during DCD use under fertiliser or urine treatments (Di and Cameron 2004c). Furthermore, DCD does not leave persistent residues in the soil, decomposing completely in the soil (Amberger 1989; Mc Carty and Bremner 1989).

The DCD was applied in solution or as a fine particle spray (FPS) directly onto the soil, or freshly grazed pasture, after urine deposition to enable the inhibitor to treat the maximum number of nitrifiers. The FPS was subsequently developed as a commercially available product called ‘eco-n™’ (Ravensdown Fertiliser Co-operative Limited, New Zealand).

Here we summarise this series of recent experiments examining eco-n™ and as a result recommend that new eco-n™ specific emission factors (EF1 and $EF3_{PR\&P}$) should be used where eco-n™ is specifically used as a N_2O mitigation tool. We then demonstrate how such a mitigation tool can be incorporated into the existing IPCC methodology when accounting for New Zealand's N_2O emissions from agriculture.

Reducing nitrate leaching and N_2O emissions via solution or FPS application of DCD

The following section summarises field experiments where DCD was applied to pasture soils either in solution or as a FPS. Research by Di and Cameron (2002; 2003; 2004a; 2005; 2006) examined the effectiveness of DCD in reducing nitrate leaching and direct N_2O emissions from fertiliser and bovine urine when applied as a solution or FPS. The practical details of these experiments are summarised in Table 1. In brief, the experiments were performed in lysimeters containing intact soil columns either 50 cm wide x 70 cm deep or 80 cm wide by 120 cm deep, with silt or sandy loam soils, and under perennial ryegrass (*Lolium perenne*) - white clover (*Trifolium repens)* pasture. Urine and fertiliser N were applied at rates that simulated urinary-N deposition rates in conjunction with typical farm fertiliser practices. Fertiliser (urea) was applied to all treatments unless otherwise specified at a rate of 200 kg N/ha/yr, split into 8 equal dressings. Freshly collected bovine urine was applied at a rate typical of a cow urinating on grazed pasture (1000 kg N/ha) in the autumn, winter or spring as noted (Table 1). Experimental procedures and methods for determining leachate volumes, nitrate concentrations, N_2O emissions and DM yields are described in detail in the references given (Table 1). In the initial studies DCD was applied as a solution (Di and Cameron 2002; 2003; 2004c) while in the later studies it was applied as a FPS (Di and Cameron 2005; 2006). Application of DCD in a solution form was effective (as discussed below) but this was replaced by an FPS method because it was more practical to perform at the farm scale while still maintaining the high degree of soil coverage offered by the DCD solution and its effectiveness, as noted below. Large volumes of water required to dissolve the DCD created practical difficulties, hence the development of a FPS application method (as noted above) which was shown to be equally effective.

On average, over all trials, the application of DCD reduced NO_3-N leaching by 61% and if the lowest rate of DCD used is excluded ((Di and Cameron 2005), treatment 2, 5 kg DCD), since it is not the commercially recommended rate, then the reduction in NO_3-N leaching averaged 69%. Similarly, the overall average reduction in N_2O emissions was 72%. Even when the DCD was applied 10 days after the urinary-N deposition event ((Di and Cameron 2006), treatment 9) the reduction in N_2O emissions was still 56%. Table 3 summarises those trials where N_2O emissions were monitored and presents emission factors, i.e. the mass of N_2O-N expressed as a fraction of the gross N applied (urine + fertiliser) or as a fraction of the urine-N applied (urine-N).

Currently there is no financial incentive for New Zealand farmers to mitigate N_2O emissions by applying products such as nitrification inhibitors. Thus for most farmers to adopt a new management practice that is going to add to the monetary cost of farm operations there must be an economic return. Such an economic return from the use of DCD, as described above, occurs as increased DM production. Table 4 summarises DM production increases as assessed by hand harvesting of pasture together with total annual pasture production and the % N content of the pasture. The average increase in pasture DM production over all trials was 29% when DCD was applied. However, when DCD was applied after urine deposition in autumn and then in mid winter (Di and Cameron 2005; Di and Cameron 2006) the average DM increase was 33%. Most of this increase occurred in the urine patch areas.

Eco-n™ specific emission factors

The period of greatest risk, with regard to N_2O emissions and NO_3^- leaching, is during the late-autumn/winter/early-spring when soils are wet and drainage is causing NO_3^- leaching. This is also the time of the year when N_2O emissions are greatest (de Klein et al. 2004). At this time of year soil temperatures are at their lowest which ensures the longest period of DCD effectiveness.

Given the consistency in the experimental data presented above we conclude that the use of a DCD solution or FPS that is sprayed onto the pasture after grazing, can significantly reduce NO_3-N leaching and N_2O emissions from urinary-N and fertiliser N. We propose that where eco-n™ is applied to the soil surface, both following grazing in autumn (May) and during the late winter period (August), at the recommended rate of 10 kg/ha of the active ingredient on both occasions, that the default N_2O emission factors used for calculating an N_2O inventory be amended to take into account the significant reductions in NO_3-N leaching and N_2O emissions that occur.

We propose that where eco-n™ is specifically used the following default N_2O emission factors are conservatively amended as follows:

(i) The emission of N_2O from fertiliser (EF1) that is applied to eco-n™ treated pasture be adjusted from the current IPCC default value of 0.01 kg N_2O-N/kg fertiliser N to a new value of 0.005 kg N_2O-N/kg N i.e. a 50% reduction in the emission of N_2O from fertiliser N.

(ii) The emission of N_2O from N excreted onto pasture ($EF3_{PR\&P}$), that is then treated with eco-n™ within 10 days of grazing, be adjusted from a default value of 0.01 kg N_2O-N/kg N excreted to a new value of 0.005 kg N_2O-N/kg N excreted i.e. a 50% reduction in the emission of N_2O from excreta N deposited onto pasture.

(iii) That when eco-n™ is used the fraction of N leached (FRACLEACH) is reduced from the current default value of 0.07 to a value of 0.0455 i.e. a 35% decrease in the amount of N that is lost through leaching and runoff. While the above research results show an average 60% reduction in nitrate leaching we have chosen a conservative value of 35%.

(iv) In addition we propose that the use of eco-n™ increases DM production by 10-15%. This conservative value takes into account differing DM responses in the urine and non-urine affected areas of the pasture.

The eco-n™ effectiveness period

Since DCD is a biodegradable compound, forming carbon dioxide, water and ammonia, it has a limited life-time in the soil (Amberger 1989; Mc Carty and Bremner 1989). This life-time depends on factors such as soil temperature and the initial DCD application rate (Di and Cameron 2004a). At a soil temperature of 8^{o}C, the half-lives of DCD and ammonium were shown to be 111-116 days and 243-491 days, respectively (Di and Cameron 2004a). The conclusion drawn by Di and Cameron (2004a) was that, in New Zealand, DCD would be most effective in inhibiting nitrification and thus reduce nitrate leaching in late autumn-winter-early spring in most parts of New Zealand when daily average soil temperatures are below 12^{o}C and when drainage is high. In New Zealand this would typically be from May through to September, a 5 month period.

An approach for the implementation of eco-n™ specific emission factors

The full complement of Tables and worksheets for developing New Zealand's N_2O inventory, using the IPCC methodology, can be found in New Zealand's greenhouse gas inventory (Brown and Petrie 2006)**.** Tables 5 to 9 present some of those that are relevant and which have been amended as described below to account for the implementation of the specific N_2O mitigation option for eco-n ™ grazed pastures.

Prior to commencing with these calculations it is necessary to know on a national basis how many animals are grazing eco-n™ treated pastures. This is known to a high precision in New Zealand since the product application areas are recorded using global positioning system (GPS) technology. Due to the manufacturer's requirement for GPS methodology to be used during eco-n™ application, the land area, and thus the number of animals under an eco-n™ regime, will be known.

In the following example, for 2004, we demonstrate how eco-n™, used as an N_2O mitigation tool, could be accounted for in the New Zealand IPCC inventory methodology. It should be noted that adoption of the philosophy described in this manuscript, for including a mitigation tool in the IPCC inventory methodology in other countries will depend on the mitigation tool concerned and the availability of suitable data.

In the following scenario we assume that

- 25% of New Zealand's dairy cow herd were farmed under an eco-n™ regime.
- Eco-n™ was applied in the autumn (May) and again in late-winter/early spring (August) at a rate of 10 kg DCD/ha within 10 days of grazing (which is the standard commercially recommended practice for the use of eco-n™).
- Following the eco-n™ application in May and August, eco-n™ is effective for 5 months of the year with respect to direct N_2O emissions from fertiliser and excreta N (i.e. May to September).
- Nitrogen leaching predominately occurs in the autumn/winter periods (May to September) thus the use of eco-n™ is therefore effective for the entire leaching period i.e. effectively the whole year with respect to indirect N_2O emissions.

- The reduction in N leaching due to eco-n™ is conservatively assumed to be 35%, which is less than the measured reductions described above.
- Excreta N_2O emissions are reduced by 50% thus $EF3_{PR\&P}$ is reduced by 50% over the 5 month effective period of eco-n™ use.
- Fertiliser N_2O emissions are reduced by 50% thus EF1 is reduced by 50% over the 5 month effective period of eco-n™ use.
- Fertiliser use is spread evenly throughout the year.

Table 5 presents data for N excretion associated with anaerobic lagoons. It can be seen that the livestock class 'dairy cattle' has been sub-divided into dairy cows with 'nil' eco-n™ (75% of dairy cows) and dairy cows with 'plus' eco-n™ regimes. Because the farming system is identical under both regimes there is no need to differentiate with regard to the percentage of animal waste going into lagoons. As noted above extra DM may be produced under the eco-n™ regime. If this resulted in animals being offered a higher DM intake then consideration might be given to placing a new value in the 'plus' eco-n™ line of the table, for N excretion (Nex; kg/head/yr).

For dairy cattle in New Zealand the predominant animal waste management system (AWMS) is N excretion onto pasture range and paddock (PR&P) with 95% of N excreted onto the paddock in dairy systems (Table 6). Once dairy cow numbers have been identified and entered under the 'nil' and 'plus' eco-n™ lines the only adjustment that might need to be made is the amount of N excreted by the dairy animal as noted above.

The next step is to split the fertiliser inputs between non-dairy farms and dairy farms and then to divide the latter into 'nil' and 'plus' eco-n™ regimes. Thus the appropriate amounts are entered in the column 'Amount of N input to soil (kg)', in Table 7. Again use of GPS and accurate industry and farm records enable the collation of this information. The next number that needs to be entered into Table 7 is the emission factor EF1 for both 'nil' and ‘plus’ eco-n™ use. Here New Zealand (NZ) specific factors apply, except for the ‘plus eco-n™’ line where a value of 0.0079 is entered. This is calculated as follows:

$$EF1 \text{ ' } plus\ eco - n\text{'} = (NZ\ specific\ EF1) - \left(NZ\ specific\ EF1 \times \frac{50\%}{100\%} \times \frac{5}{12} \right) = 0.0079 \qquad [1]$$

Where the NZ specific EF1 value is 0.01 (kg N_2O-N/kg N), 50% represents the reduction in EF1 from fertiliser that occurs when eco-n™ is used, as recommended above, and $\frac{5}{12}$ is the fraction of the year that the eco-n™ product is effective for. Note that we make the assumption that fertiliser use is evenly distributed throughout the year. If farmers were applying all their fertiliser in the 5 month period where eco-n™ is effective then the calculations could be adjusted to allow for reduced emissions from the entire fertiliser input.

Direct emissions of N_2O are then collated for grazing animal production (Table 8). Here it is necessary to insert the N excretion that occurs under a ‘nil’ eco-n™ regime, a total of 1,382,159,244 kg N, which is the total N excretion shown in Table 6 (1,524,431,244 kg N) minus the N excreted under the ‘plus’ eco-N™ regime (142,272,000 kg N). Then on the following line the mass of N excreted under the ‘plus’ eco-N™ regime is inserted, 142,272,000 kg N (Table 8). Next the emission factor $EF3_{PRP}$ is inserted in Table 8. For the ‘nil’ eco-n™ regime, a NZ specific factor equalling 0.01 kg N_2O-N/kg N is used (Brown and Petrie 2006). While for the ‘plus’ eco-n™ N excreta a factor is derived as follows:

$$EF3_{PRP} \text{ ' } plus\ eco - n\text{'} = (NZ\ specific\ EF3_{PRP}) - \left(NZ\ specific\ EF3_{PRP} \times \frac{50\%}{100\%} \times \frac{5}{12} \right) = 0.0079 \qquad [2]$$

Where the New Zealand specific $EF3_{PRP}$ value is 0.01 (kg N_2O-N/kg N), 50% represents the reduction in $EF3_{PRP}$ from N excreted that occurs when eco-n™ is used, as recommended above, and $\frac{5}{12}$ is the fraction of the year that the eco-n™ product is effective for (N.B. This is conservative as described later).

Indirect emissions of N_2O from the 'nil' and 'plus' eco-n™ regimes are then calculated by first inserting the appropriate masses of fertiliser N and N excreta values into Table 9, and then calculating the 'plus' eco-n™ $Frac_{LEACH}$ value as follows:

$$Frac_{LEACH}\ '\,plus\ eco-n' = NZ\ specific\ Frac_{LEACH} \times \left(1 - \frac{35\%}{100\%}\right) = 0.0455 \qquad [3]$$

In equation [3] the New Zealand specific $Frac_{LEACH}$ value is 0.07 (Thomas et al. 2005) and 35% is the assumed reduction in nitrate leaching, occurring on an annual basis as described above, and implemented nationally, regionally or at an individual farm scale.

Thus by appropriately differentiating the data inputs into 'nil' and 'plus' eco-n™ regimes and by suitably amending the worksheets the IPCC inventory methodology can be modified in a clear and transparent manner as shown above. Thus any reductions in N_2O emissions that occur as a result of the N_2O mitigation tool, in this case eco-n™, can be assigned to that particular tool. Any downstream benefits of emissions reductions, such as carbon credit trading, could then potentially be aligned with the product used and the users of the product.

Modelling eco-n™ farm management options

A model farm, based on New Zealand Ministry of Agriculture and Forestry farm monitoring data for the Waikato/Bay of Plenty area of New Zealand, was constructed in OVERSEER™ (Ledgard et al. 1999). This model farm carried 277 Friesan cows over a 261 day lactation period with 83300 kg Milk Solids (MS) produced (301 kg MS/cow). All cows were carried on the farm over the winter period with yearlings 'never on farm'. The effective grazing area was 102 ha with 20 ha receiving effluent from the milking shed sump (2.7 cows/ha). Fertiliser N (150 kg) was applied to non effluent areas at 50 kg N/ha in May, June and July.

Supplements brought into the model farm included 91 tonnes of maize silage and 38 tonnes of palm kernel meal.

The OVERSEER™ model does not currently adjust nitrate leaching and greenhouse gas emissions for the proposed eco-n™ scenarios. (It is possible to control the N_2O emission factors and the fraction of excreta and fertiliser leached, but this does not allow the model to use site specific or seasonal leaching factors). Hence the OVERSEER™ results were calculated using the default parameters and the adjustments to nitrate leaching and greenhouse gas emissions for the eco-n™ scenarios were made subsequently.

Five alternative scenarios were developed based on possible farmer behaviour that might occur as a result of the extra 10-15% DM production that the use of eco-n™ would produce on the dairy farm. In essence these alternative farmer behaviours are likely to be either:

(i) an increase in stocking rate to utilise the extra DM produced,

(ii) a reduction of other farm inputs such as N fertiliser and brought in supplements while maintaining existing production levels,

(iii) a combination of these scenarios.

The five alternative scenarios to the base farm model were therefore assessed using the OVERSEER™ model. These scenarios were:

(i) Stocking rate was increased from 2.7 to 3.1 cows/ha to utilise the extra 15% DM produced. This assumed that:
- o the production per cow remained constant,
- o the amount of supplements brought in remained constant and,
- o the N fertiliser regime remained constant (50 kg N/ha in May/June/July).

(ii) Stocking rate was increased from 2.7 to 2.9 cows/ha with the same production rate per cow and assuming:

- o no supplements were purchased and,
- o the N fertiliser regime remained constant (50 kg N in May/June/July).

(iii) Stocking rate was increased from 2.7 to 3.0 cows/ha with the same production rate per cow and assuming,

- o winter fertiliser N was displaced i.e. 50 kg less N fertiliser/ha was used (50 kg N/ha in May/June) resulting in a reduction of 350 kg DM/ha.

(iv) Stocking rate was increased (3.0 cows/ha) with the same production rate per cow and assuming,

- o winter fertiliser N was displaced i.e. 100 kg less N fertiliser was used (50 kg N/ha in May) resulting in a reduction of 700 kg DM/ha.

(v) No change in cow numbers occurred (2.7 cows/ha) but production rate per cow was maintained and assuming:

- o No supplements were brought onto the farm,
- o No N fertiliser was used.

Applying the emission factors, described above, to OVERSEER™ outputs showed that eco-n™ reduced N_2O emissions from all three sources: excreta, fertiliser and indirect emissions (Table 10). Despite the increased stocking rates, in the OVERSEER™ scenarios, (i) through to (iv), excreta N_2O emissions were reduced by 135 kg CO_2 equivalents/ha/yr when eco-n™ was applied under a 5 month effective period. When the stocking rate was kept constant, scenario (v), the reduction in excreta N_2O emissions was further increased to 313 kg CO_2 equivalents/ha/yr. As is commonly acknowledged (de Klein et al. 2001) excreta N_2O emissions dominated the N_2O emissions from the grazed pasture systems. Fertiliser N_2O emissions were also reduced under the eco-n™ adjusted OVERSEER™ scenarios. When fertiliser inputs were maintained the N_2O emission reductions were 159 kg CO_2 equivalents/ha/yr under a 5 month effective eco-n™ period. Indirect N_2O emissions were also reduced by up to 159 kg CO_2 equivalents/ha/yr under the eco-n™ scenarios. Expressed as a percentage of the total base farm N_2O emissions, the N_2O emissions for the scenario farms fell to values of 89 to 58 % for a 5 month eco-n™ effective period.

At the same time as N_2O emissions were being reduced by the eco-n™ regimes there were changes in the amounts of methane (CH_4) emitted which were a function of the scenario farm stocking rates. As stocking rate increased so too did the CH_4 emissions. However, despite the increases in CH_4 resulting from the increases in stocking rate the overall GHG production (kg CO_2 equivalents/kg MS) for each farm scenario was still lower with eco-n™ usage. For a 5 month effective period GHG production decreases ranged from 0.9 to 2.1 kg CO_2 equivalents/kg MS.

The eco-n™ effectiveness period and weighting of N_2O emissions

A recent report (de Klein et al. 2004) concluded that N_2O emissions from urine patches in winter were similar to those found in spring and autumn but higher than those found in summer, thus autumn to spring emissions dominated. The effect of soil temperature on DCD shows a half-life for ammonium of 241–491 days at 8^{o}C compared with 55–64 days at 20^{o}C (Di and Cameron 2004a). Given that the bulk of soil N_2O emissions will potentially occur in the months where soil conditions are wetter (de Klein et al. 2004) and providing eco-n™ is applied as prescribed in the autumn and late winter then logic dictates that the emission factors ($EF3_{PRP}$ and EF1) should be weighted in favour of this.

In our previous examples we assumed the unlikely situation where N_2O fluxes are of equal duration and magnitude throughout the year. So that in a 12 month calendar year 8.3% of the annual emission occurs every month, or in other words during the 5 month effective period 41.5% of the annual N_2O emissions occur. In reality this will not be the case due to higher denitrification rates in the late-autumn (May) to early spring (September) due to wetter soils, a higher likelihood of soil compaction, and low plant N demand (Menneer et al. 2005). Thus, in the next example we assume a more realistic scenario where 84% of the annual emissions occur in the 5 month effective period i.e. 16.8% of the annual emissions occur every month of these 'wetter' months. Thus our weighting factor for this scenario is equal to $\frac{84.0\%}{41.5\%}$ or a factor of 2.02. This weighting can then be included in our emission factor calculations as shown for the EF3 'plus eco-n™' derivation below, where factors in equation [4] are as previously described in equation [1]:

$$EF3_{PRP}\ '\ plus\ eco-n' = \left(NZ\ specific\ EF3_{PRP}\right) - \left(NZ\ specific\ EF3_{PRP} \times \frac{50\%}{100\%} \times \frac{5}{12} \times 2.02\right) = 0.0058 \quad [4]$$

Based on a weighting factor of 2.02, a weighting where 84% of the annual N_2O emissions occur over the late-autumn early-spring period, we re-examined the model farm scenarios listed above, using OVERSEER™ and values for EF1, EF3 and $Frac_{LEACH}$ of 0.0058, 0.0058 and 0.0455 respectively. Results are presented in Table 11. It can be seen that N_2O emissions as a percentage of the base farm decreased to values of 71-47%. The GHG production rates fell by 1.5 to 2.5 kg CO2 equivalents/kg MS produced despite increases in CH_4 resulting from the increases in stocking rates.

With respect to eco-n™ further research is ongoing to determine the appropriate weighting factor to be used. However , based on the summary of peer reviewed and published results presented above, a 5 month effectiveness period with a weighting factor of 1.00 is both defendable and usable when considering adaptation of the IPCC inventory methodology to calculate agricultural N_2O emissions where eco-n™ is used as a mitigation tool.

Conclusion

Given that the summary of peer reviewed research publications and the conservatively modelled OVERSEER™ scenarios corrected for eco-n™ usage all indicate reduced emissions of N_2O, it is appropriate that eco-n™ scenarios are considered for New Zealand's agricultural soil GHG inventory. We have demonstrated a method of accounting for the effects of a N_2O mitigation tool in the IPCC inventory methodology for agricultural soils. This method relies on GPS technology to enable land area and animal data to be accurately quantified. While we have used the eco-n™ mitigation product and a dairy cow scenario to demonstrate this accounting methodology in a New Zealand pasture situation, the method demonstrated could be readily applied to other IPCC approved mitigation tools or other animal types and for other proven values of emission reductions.

References

Amberger A. 1989. Research on dicyandiamide as a nitrification inhibitor and future outlook. Commun. Soil Sci. Plant Anal. 20:1933-1955.

Brown L. and Petrie S. 2006. New Zealand's Greenhouse Gas Inventory 1990-2004 [Online]. Available by Ministry for the Environment http://www.climatechange.govt.nz/resources/reports/nir-apr06/index.html (posted 31 July 2006).

de Klein C.A.M., Li Z. and Sherlock R.R. 2004. Determination of the N_2O emission factors from animal excreta or urea fertiliser, following a winter application in two regions of New Zealand. A final report of an N_zO net study from August 2003 to June 2004. Prepared for Ministry of Agriculture and Forestry.

de Klein C.A.M., Sherlock R.R., Cameron K.C. and van der Weerden T.J. 2001. Nitrous oxide emissions from agricultural soils in New Zealand - a review of current knowledge and directions for future research. J. R. Soc. N.Z 31:543-574.

Di H.J. and Cameron K.C. 2002. The use of a nitrification inhibitor, dicyandiamide (DCD), to decrease nitrate leaching and nitrous oxide emissions in a simulated grazed and irrigated grassland. Soil Use & Mgt. 18:395-403.

Di H.J. and Cameron K.C. 2003. Mitigation of nitrous oxide emissions in spray - irrigated grassland by treating the soil with dicyandiamide, a nitrification inhibitor. Soil Use & Mgt. 19:284-290.

Di H.J. and Cameron K.C. 2004a. Effects of temperature and application rate of a nitrification inhibitor, dicyandiamide (DCD), on nitrification rate and microbial biomass in a grazed pasture soil. Aust. J. Soil Res. 42:927-932.

Di H.J. and Cameron K.C. 2004b. Effects of the nitrification inhibitor dicyandiamide on potassium, magnesium and calcium leaching in grazed grassland. Soil Use & Mgt 20:2-7.

Di H.J. and Cameron K.C. 2004c. Treating pasture soil with a nitrification inhibitor, eco-nTM, to decrease nitrate leaching in a deep sandy soil under spray irrigation - a lysimeter study. New Zeal. J. Agr. Res. 47:351-361.

Di H.J. and Cameron K.C. 2005. Reducing environmental impacts of agriculture by using a fine particle suspension nitrification inhibitor to decrease nitrate leaching from grazed pastures. Agr. Ecosys. & Environ. 109:202-212.

Di H.J. and Cameron K.C. 2006. Nitrous oxide emissions from two dairy pasture soils as affected by different rates of a fine particle suspension nitrification inhibitor, dicyandiamide. Biol. Fert. Soils 42:472-480.

Ledgard S.F., Williams P.H., Broom F.D., Thorrold B.S., Wheeler D.M. and Willis V.J. 1999. Overseer^{TM} - A nutrient budgeting model for pastoral farming, wheat, potatoes, apples and kiwifruit. Proceedings of the workshop Best soil management practices for production.

Mc Carty G.W. and Bremner J.M. 1989. Laboratory evaluation of dicyandiamide as a nitrification inhihibitor. Commun. Soil Sci. Plant Anal. 20:2049-2065.

Menneer J.C., Ledgard S.F., McLay C. and Silvester W. 2005. Animal treading stimulates denitrification in soil under pasture. Soil Biol. Biochem. 37:1625-1629.

Ministry for the Environment. 2006. New Zealand's Greenhouse Gas Inventory 1990-2004 ME number: 746. Ministry for the Environment, Wellington, New Zealand.

Mosier A., Kroeze C., Nevison C., Oenema O., Seitzinger S. and Van Cleemput O. 1998. Closing the global N_2O budget: nitrous oxide emissions through the agricultural nitrogen cycle - OECD/IPCC/IEA phase ii development of IPCC guidelines for national greenhouse gas inventory methodology. Nutr. Cycl. Agroecosyst. 52:225-248.

Thomas S.M., Ledgard S.F. and Francis G.S. 2005. Improving estimates of nitrate leaching for quantifying New Zealand's indirect nitrous oxide emissions. Nutr. Cycl. Agroecosyst. 73:213-226.

Table 1: Experimental overviews and treatments. Fertiliser N (urea) was applied to all treatments, at a rate of 200 kg N/ha/yr split into 8 dressings. The exception to this was in Di & Cameron (2002), where treatment 1 received nil fertiliser, and treatments 7 and 8, where the urea was split evenly into 4 dressings. Urine-N was applied in all treatments unless stated, in the season shown, at rate of 1000 kg N/ha. DCD was applied as a solution in studies 1-5 and as a fine particle suspension (FPS) in studies 6 and 7. All studies simulated treading using an artificial hoof.

Di & Cameron Reference	Soil surface texture	Soil pH	Pasture age[a] (y)	Irrigation (mm)	Treatments	Urine application season	Total N (kg)	DCD[b] (kg/ha)	Total DCD (kg)
(2002)	silt-loam	5.9	4	100 mm flood every 3 weeks 1364 total (564 rain & 800 irrig'n)	1	nil	0	0	0
					2	nil	200	0	0
					3	Aut.	1200	0	0
					4	Aut.	1200	7.5[c]/15.0[d]	75
					5	Aut.	1200	0	0
					6	Aut.	1200	7.5[c]/15.0[d]	75
					7	Spr.	1200	0	0
					8	Spr.	1200	7.5[c]/15.0[d]	45
(2003)	silt loam	5.9	5	50 mm spray every 2 weeks 850 total (490 rain & 360 irrig'n)	1	Aut.	1200	0	0
					2	Aut.	1200	15[e]	15
					3	Aut.	1200	15[f]	30
					4	Aut.	1200	15[g]	15
					5	Spr.	1200	0	0
					6	Spr.	1200	15[e]	15
					7	Spr.	1200	15[h]	75
					8	Spr.	1200	7.5[i]	75

[a]Pastures were all perennial ryegrass (*Lolium perenne*) - white clover (*Trifolium repens*). [b]DCD = dicyandiamide, [c]kg per urea application, [d]kg per urine application, [e]after urine application, [f]15 kg after urine application and 15 kg in late winter, [g]mixed with urine, [h]15 kg mixed with urine application then 15 kg quarterly, [i]7.5 kg after urine application and 7.5 kg after each urea application.

Table 1 continued: Experimental overviews and treatments. Fertiliser N (urea) was applied to all treatments, at a rate of 200 kg N/ha/yr split into 8 dressings. The exception to this was in study No. 1 where treatment 1 received nil fertiliser and treatments 7 and 8 where the urea was split evenly into 4 dressings. Urine-N was applied in all treatments unless stated, in the season shown, at rate of 1000 kg N/ha. DCD was applied as a solution in studies 1-5 and as a fine particle suspension (FPS) in studies 6 and 7. All studies simulated treading using an artificial hoof.

Reference	Soil surface texture	Soil pH	Pasture age[a] (y)	Irrigation (mm)	Treatments	Urine application season	Total N (kg)	DCD[c] (kg/ha)	Total DCD (kg)
(2004c)	silt loam	5.8	>10	50 mm spray	1	Aut.	1200	0	0
				every 2 weeks	2	Aut.	1200	15[e]	15
				1600 total	3	Aut.	1200	15[j]	30
(2005)	sandy loam	5.8	>10	50 mm spray	1	Aut.	1200	0	0
				every 2 weeks	2	Aut.	1200	5[j]	15
				1200 total (500 rain & 700 irrig'n)	3	Aut.	1200	10[j]	30
(2006)	silt loam sandy loam	5.9	5	30 mm spray	1	Aut.	1200	0	0
				every week	2	Aut.	1200	7.5[j]	15
				1200 total	3	Aut.	1200	10[j]	20
				(500 rain &	4	Aut.	1200	15[j]	30
				700 irrig'n)	5	Win.	1200	0[j]	0
					6	Win.	1200	10[j]	20
					7	Aut.	1200	0[j]	0
					8	Aut.	1200	10[j]	20
					9	Aut.	1200	10[k]	20

[a]Pastures were all perennial ryegrass (*Lolium perenne*) - white clover (*Trifolium repens*). [b]DCD = dicyandiamide, [c]kg per urea application, [d]kg of per urine application, [e]15 kg after urine application, [f]15 kg after urine application and 15 kg in late winter, [g]15 kg mixed with urine application, [h]15 kg mixed with urine application then 15 kg quarterly, [i]7.5 kg after urine application and 7.5 kg after each urea application, [j]after urine application and in mid-winter, [k]ten days after urine application and mid-winter.

Table 2: Summary of the mass of NO_3-N leached, the percentage reduction in NO_3-N leaching when eco-n™ was used, the fraction of N applied leached; N_2O-N emissions and their respective reductions in emissions when eco-n™ was used in the five research trials.

Di & Cameron Reference	Treatment	Total N Applied (kg)	DCD[a] (kg/ha)	NO_3-N leached (kg)	Leaching reduction (%)	Fraction of N applied leached	N_2O-N (kg/ha)	Reduction in N_2O Loss (%)
(2002)	1	0	0	4.8	-	-	-	-
	2	200	0	7.9	-	0.040	-	-
	3	1200	0	516	-	0.430	-	-
	4	1200	7.5[b]/15.0[c]	128	75	0.107	-	-
	5	1200	0	488	-	0.407	-	-
	6	1200	7.5[b]/15.0[c]	112	77	0.093	-	-
	7	1200	0	397	-	0.331	46.0	-
	8	1200	7.5[b]/15.0[c]	230	42	0.192	8.5	82
(2003)	1	1200	0	-	-	-	26.7	-
	2	1200	15[d]	-	-	-	7.0	74
	3	1200	15[e]	-	-	-	7.6	72
	4	1200	15[f]	-	-	-	4.5	83
	5	1200	0	-	-	-	18.0	-
	6	1200	15[d]	-	-	-	4.5	75
	7	1200	15[g]	-	-	-	4.8	73
	8	1200	7.5[h]	-	-	-	2.5	86
(2004c)	1	1200	0	85	-	0.071	-	-
	2	1200	15[d]	22	74	0.018	-	-
	3	1200	15[i]	20	76	0.017	-	-
(2005)	1	1200	0	134	-	0.112	-	-
	2	1200	5[i]	116	13	0.097	-	-
	3	1200	10[i]	43	68	0.036	-	-
(2006)	1	1200	0	-	-	-	23.1	-
	2	1200	7.5[i]	-	-	-	8.2	65
	3	1200	10[i]	-	-	-	6.9	70
	4	1200	15[i]	-	-	-	6.2	73
	5	1200	0[i]	-	-	-	31	-
	6	1200	10[i]	-	-	-	8.4	73
	7	1200	0[i]	-	-	-	37.4	-
	8	1200	10[i]	-	-	-	14.6	61
	9	1200	10[j]	-	-	-	16.3	56

[a]DCD = dicyandiamide, [b]kg per urea application, [c]kg per urine application, [d]15 kg after urine application, [e]15 kg after urine application and 15 kg in late winter, [f]15 kg mixed with urine application, [g]15 kg mixed with urine application then 15 kg quarterly, [h]7.5 kg after urine application and 7.5 kg after each urea application, [i]after urine application and in mid-winter, [j]ten days after urine application and mid-winter.

Table 3: Emission factors (EF) for N_2O-N calculated as the mass of N_2O-N divided by the mass of N applied, either gross-N (fertiliser + urine) or urine-N only (urine-N)

Di & Cameron Reference	Treatment	DCD[a] (kg/ha)	EF (gross-N)	EF (urine-N)	Reduction in EF (%)
(2002)	7	7.5[b]/15.0[c]	0.038		-
	8	0	0.007	0.02	82
(2003)	1	0	0.022	-	-
	2	15[d]	0.006	-	73
	3	15[e]	0.006	-	73
	4	15[f]	0.004	-	82
	5	0	0.015	-	-
	6	15[d]	0.004	-	73
	7	15[g]	0.004	-	73
	8	7.5[h]	0.002	-	87
(2006)	1	0	0.019	0.023	-
	2	7.5[i]	0.007	0.008	65
	3	10[i]	0.006	0.007	70
	4	15[i]	0.005	0.006	73
	5	0[i]	0.026	0.027	-
	6	10[i]	0.007	0.007	73
	7	0[i]	0.031	0.036	-
	8	10[i]	0.012	0.014	61
	9	10[j]	0.014	0.016	56

[a]DCD = dicyandiamide, [b]kg per urea application, [c]kg per urine application, [d]15 kg after urine application, [e]15 kg after urine application and 15 kg in late winter, [f]15 kg mixed with urine application, [g]15 kg mixed with urine application then 15 kg quarterly, [h]7.5 kg after urine application and 7.5 kg after each urea application, [i]after urine application and in mid-winter, [j]ten days after urine application and mid-winter.

Table 4: Increases in DM yields under DCD applications and the average total annual yields.

Di & Cameron Reference	Treatment	DCD[a] (kg/ha)	Increase in DM (%)	%N	Average DM yield (tonne/ha/y)
(2002)	1	0	-	3.5[d]	11.0[d]
	2	0	-	-	-
	3	0	-	-	-
	4	7.5[f]/15.0[g]	49[b]	4.1[e]	15.0[e]
	5	0	-	-	-
	6	7.5[f]/15.0[g]	-	-	-
	7	0	-	-	-
	8	7.5[f]/15.0[g]	18[c]	-	-
(2004c)	1	0	-	3.3	15.9
	2	15[h]	14	3.5	18.2
	3	15[i]	33	3.1	21.1
(2005)	1	0	-	2.9	15.3
	2	5[i]	0	2.9	15.3
	3	10[i]	33	3.1	20.3

[a]DCD = dicyandiamide [b]average of autumn urine treatments + DCD, [c]average of spring urine treatments + DCD, [d]without DCD, [e]with DCD, [f]kg per urea application, [g]kg per urine application, [h]15 kg after urine application, [i]after urine application and in mid-winter

Table 5

Module	2004 Agriculture (New Zealand)
Submodule	Domestic livestock emissions
Worksheet	4.1 (supplemental) for worksheet 4.1 (2 of 2)
Sheet	Nitrogen excretion from anaerobic lagoons (AWMS=AL)

Livestock type	Number of animals (3 yr average) (1000s)	Nitrogen excretion (Nex) (kg/head/yr)	Percentage of nitrogen excretion in AWMS=AL[2]	Nitrogen excretion from AL (kg N)
Non-dairy cattle	4,528			nil
Dairy cattle nil eco-n	*3,839*	*117.0*	*5%*	*22,458,333*
Dairy cattle plus eco-n	*1,280*	*117.0*	*5%*	*7,486,111*
Poultry	23,183			nil
Sheep	39,572			nil
Swine	385	16.0	55%	3,386,618
Goats	137			nil
Deer	1,720			nil
Horses	78			nil
Total (Nex_{AL})				33,331,062

Table 6

Module	2004 Agriculture (New Zealand)
Submodule	Domestic livestock emissions
Worksheet	4.1 (supplemental) for worksheet 4.5 (3 of 5)
Sheet	Nitrogen excretion from anaerobic lagoons (AWM S=PR&P)

Livestock type	Number of animals (3 yr average) (1000s)	Nitrogen excretion (Nex) (kg/head/yr)	Percentage of nitrogen excretion in AWMS=AL[2]	Nitrogen excretion from AL (kg N)
Non-dairy cattle	4,528	72.5	100%	328,280,000
Dairy cattle nil eco-n	*3,839*	*117.0*	*95%*	*426,704,850*
Dairy cattle plus eco-n	*1,280*	*117.0*	*95%*	*142,272,000*
Poultry	23,183	0.6	3%	417,294
Sheep	39,572	14.8	100%	585,665,600
Swine	385			no
Goats	137	9.5	100%	1,301,500
Deer	1,720	22.0	100%	37,840,000
Horses	78	25.0	100%	1,950,000
Total (Nex_{AL})				1,524,431,244

Table 7

Module	2004 Agriculture (New Zealand)
Submodule	Agricultural soils
Worksheet	4.5 (1 of 5)
Sheet	Direct nitrous oxide emissions from agricultural soils (excluding histosols)

Type of N input to soil	Amount of N input to soil (kg)	Emission factor for direct emissions (EF1) (kg N_2O-N/kg N)	Direct soil emissions (excl. histosols) (Gg N_2O-N)	Direct soil emissions (excl. histosols) (Gg N_2O)
Synthetic fertiliser (F_{SN}) on non-dairy farms	93,214,800	0.01	0.932	1.465
Synthetic fertiliser (F_{SN}) nil eco-n on dairy	163,125,900	*0.01*	1.631	2.563
Synthetic fertiliser (F_{SN}) plus eco-n on dairy	54,375,300	*0.0079*	0.430	0.676
Animal Waste (F_{AW})	39,061,018	0.01	0.397	0.614
N-Fixing crops (F_{BN})	3,708,000	0.01	0.037	0.058
Crop residue (F_{CR})	8,607,006	0.01	0.086	0.135
Total			3.508	5.512

Table 8

Module	2004 Agriculture (New Zealand)
Submodule	Agricultural soils
Worksheet	4.5 (3 of 5)
Sheet	Direct nitrous oxide emissions from animal production (grazing animals)

Pasture, range and paddock AWMS	N excretion for AWMS PRP (kg N)	Emission factor for AWMS ($EF_{3\ PRP}$) (kg N_2O-N/kg N)	Total direct animal prodn. emissions of N_2O-N (Gg)	Total direct animal prodn. emissions of N_2O (Gg)
PRP nil eco-n	1,382,159,244	0.01	13.822	21.720
PRP plus eco-n	142,272,000	0.00792	1.126	1.770

Table 9

Module	2004 Agriculture (New Zealand)
Submodule	Agricultural soils
Worksheet	4.5 (5 of 5)
Sheet	Indirect nitrous oxide emissions from nitrogen used in agriculture (leaching) and total nitrous oxide emissions from agricultural soils.

	Synthetic fertiliser applied to soil (N_{FERT}) (kg N)	Total nitrogen excreted by livestock (kg N)	Fraction of nitrogen that leaches ($Frac_{LEACH}$)	Emission factor (EF_5) (kg N_2O-N/ kg N leached)	Indirect N_2O emissions from leaching (Gg N_2O-N)	Indirect N_2O emissions from leaching (Gg N_2O)
nil eco-n	163,989,000	1,431,757,900	0.07	0.025	2.793	4.388
plus eco-n	181,251,000	142,272,000	0.0455	0.025	0.368	0.578
						4.967

Table 10: OVERSEER™ model outputs for annual farm GHG emissions (kg CO_2 equivalents/ha/yr) emitted from the various farm scenarios corrected with the proposed new eco-n™ conservative emission factors, assuming an eco-n™ effective period of 5 months and a weighting factor of 1.0 for these 5 months.

Form of emissions		eco-n™ Scenarios[a] Base farm	i	ii	iii	iv	v
Methane		5736	6526	6110	6422	6297	5756
N_2O emissions	Excreta[b]	1673	1538	1511	1489	1438	1360
	N fertiliser	765	606	606	390	192	0
	Indirect	509	474	446	437	403	350
	Sub-Total	2947	2618	2563	2316	2034	1709
N_2O emissions as a % of base farm emissions		100	89	87	79	69	58
CO_2 emissions	Lime	95	82	82	82	82	82
	N fertiliser	363	363	363	242	121	0
	Energy	234	266	248	262	257	234
	Other	186	187	73	187	187	73
	Sub-Total	878	905	773	780	654	396
Capital		249	249	249	249	249	249
Processing		1778	2022	1888	1990	1952	1778
Total (CO_2 equivalents)		11588	12313	11576	11750	11179	9881
Total as % of base farm		100	106	100	101	96	85
kg CO_2 equivalents/kg MS		14.2	13.3	13.4	12.9	12.5	12.1
kg CO_2 equivalents/kg MS as a % of the base farm		100	93	94	91	88	85

[a]Assumes eco-n applied in autumn and winter/early spring at 10 kg/ha and is effective for 5 months of the year
[b]That eco-n™ was effective for 5 months of the year with respect to emissions from fertiliser and excreta N. However, considering that N leaching predominately occurs in the autumn/winter periods the eco-n™ was assumed to be effective for the full leaching period i.e. the whole year with respect to indirect N_2O emissions.

Table 11: OVERSEER™ model outputs for annual farm GHG emissions (kg CO_2 equivalents/ha/yr) emitted from the various farm scenarios corrected with the proposed new eco-n™ conservative emission factors applied, assuming an eco-n™ effective period of 5 months with a weighting factor of 2.02 for these 5 months.

Form of emissions		eco-n™ Scenarios[a]					
		Base farm	i	ii	iii	iv	v
Methane		5736	6526	6110	6422	6297	5756
N_2O emissions	Excreta[b]	1673	1158	1138	1122	1083	1024
	N fertiliser	765	446	446	287	142	0
	Indirect	509	474	446	437	403	350
	Sub-Total	2947	2079	2031	1846	1628	1374
N_2O emissions as a % of base farm emissions		100	71	69	63	55	47
CO_2 emissions	Lime	95	84	84	84	84	84
	N fertiliser	363	363	363	242	121	0
	Energy	234	266	248	262	257	234
	Other	186	187	73	187	187	73
	Sub-Total	878	900	768	775	649	391
Capital		249	249	249	249	249	249
Processing		1778	2022	1888	1990	1952	1778
Total (CO_2 equivalents)		11588	11776	11046	11282	10775	9548
Total as % of base farm		100	102	95	97	93	82
kg CO_2 equivalents/kg MS		14.2	12.7	12.7	12.3	12.0	11.7
kg CO_2 equivalents/kg MS as a % of the base farm		100	89	89	87	85	82

[a]Assumes eco-n applied in autumn and winter/early spring at 10 kg/ha and is effective for 5 months of the year
[b]That eco-n™ was effective for 5 months of the year with respect to emissions from fertiliser and excreta N. However, considering that N leaching predominately occurs in the autumn/winter periods the eco-n™ was assumed to be effective for the full leaching period i.e. the whole year with respect to indirect N_2O emissions.