# Incorporation of the nitrification inhibitor DCD into New Zealand's 2009 National Inventory

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# Incorporation of the Nitrification Inhibitor DCD into New Zealand's 2009 National Inventory.

*to*

## Ministry of Agriculture and Forestry
(31st October 2008)

*Prepared by*


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EXECUTIVE SUMMARY

- This paper presents the development and implementation of a methodology to incorporate a nitrous oxide ($N_2O$) mitigation technology, the nitrification inhibitor DCD, into the agriculture section of New Zealand's greenhouse gas national inventory. A national value of reduced GHG emissions for the 2007 calendar year has been obtained. This has been derived from the establishment of defensible changes to the emission factors $EF_{3PR\&P}$, $EF_1$ and parameter $Frac_{leach}$ for use with DCD application. These emission factors and parameters were modified because extensive field-based research has demonstrated significant and consistent reductions in $N_2O$ emissions and nitrate leaching where DCD is applied.

- In New Zealand's National Inventory for nitrous oxide emissions in agriculture, country-specific values for $EF_1$, $EF_{3PR\&P}$, and $Frac_{leach}$ are currently set at 0.01 kg $N_2O$-N $kg^{-1}$ N fertilizer, 0.01 kg $N_2O$-N $kg^{-1}$ N excreta and 0.07 kg $NO_3$-N leached $kg^{-1}$ N applied.

- Dicyandiamide (DCD) is an environmentally safe and extensively researched nitrification inhibitor that has been demonstrated to reduce $N_2O$ and/or nitrate leaching in pastoral grassland systems grazed by dairy cattle based on 28 peer-reviewed published New Zealand studies.

- The proposed method to incorporate DCD mitigation of $N_2O$ emissions into New Zealand's agricultural inventory is an amendment of the existing IPCC methodology currently used. Activity data on animal numbers is drawn from the national official statistics agency, Statistics New Zealand annual agricultural survey. This survey has recently included questions on the area that DCD is applied to, with respect to soils beneath pastures grazed by dairy cattle.

- DCD product is applied to pastures based on research that has identified “Good Practice” to maximise emission reductions. “Good Practice” promotes the application of DCD at a rate of 10 kg $ha^{-1}$ twice per year in autumn and early spring within seven days of the excreta or fertiliser nitrogen being applied. “Good Practice” application methods include fine particle suspensions or granule formulations.

- The peer reviewed literature on DCD use in grazed pasture systems is critically reviewed and recommendations are given, on a national basis, for reductions in emission factors $EF_1$, $EF_{3PR\&P}$, and $Frac_{leach}$ of 67%, 67% and 53% respectively.

- All other emission factors and parameters relating to animal excreta and fertilizer use ($Frac_{GASM}$, $Frac_{GASF}$, $EF_4$ and $EF_5$) remain unchanged when DCD is used as an $N_2O$ mitigation technology. A physicochemical argument is presented to demonstrate that DCD should have no effect on ammonia volatilisation during May-Sept when DCD is applied to soils. This is supported by the results of two field studies.

- The reductions in the emission factors and parameters are then used along with the fraction of dairy land affected by DCD to calculate DCD weighting factors. The appropriate weighting factor is then used as an additional multiplier in the current methodology for calculating indirect and direct $N_2O$ emissions from grazed pastures.

- For the 2007 year, the standard inventory practice showed that excreta-N from dairy cattle produced 12.821 Gg $N_2O$ year$^{-1}$. Applying the demonstrated methodology to incorporate the effect of DCD, where 3.5% of the effective dairying area received DCD, reduced these emissions to 12.728 Gg $N_2O$ year$^{-1}$. Thus DCD mitigated 0.093 Gg of $N_2O$, a 0.73% decrease.

- A discussion of the potential barriers to mitigation technology impacts is presented including permanence, additionality, uncertainty, leakage, transaction costs, measurement and monitoring costs, property rights, potential co-benefits and adverse impacts.

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# 1. Introduction.

The Intergovernmental Panel on Climate Change (IPCC) has standard guidelines by which signatories to the Kyoto Protocol can calculate their greenhouse gas emissions. Within these guidelines there are procedures specific to agricultural systems. In grazed pasture systems, nitrous oxide ($N_2O$) emissions largely arise from nitrogen (N) application to soils in the form of fertilizer and excreta deposited by animals during grazing.

The IPCC guidelines for agricultural inventory development, for Tier one, stipulate default key parameters and emission factors to be used (IPCC 1996). With respect to $N_2O$ emissions from New Zealand's agricultural soils: the direct emissions of $N_2O$ from N fertilizer inputs to soil ($EF_1$), the direct emissions from waste in the pasture range and paddock animal waste management system ($EF_{3PR\&P}$) and the N input to soils that is lost through leaching and run-off ($Frac_{leach}$) are of greatest significance. Consequently $N_2O$ research and inventory development in New Zealand has focused on producing country-specific values for $EF_1$, $EF_{3PR\&P}$, and $Frac_{leach}$.

For $Frac_{leach,}$ the New Zealand country-specific emission factor of 0.07 kg $NO_3$-N $kg^{-1}$ of N applied was revised downwards from a value of 0.30 following a farm systems modelling exercise that utilised the OVERSEER® nutrient budget model that has been calibrated for New Zealand conditions (Thomas et al. 2005). The modelling exercise was performed for three levels of animal productivity (low, average and high) over three time periods (1990, 2000, and 2010) and it demonstrated that the IPCC default methodology overestimated $NO_3^-$ leaching. An international peer reviewed publication summarised this work (Thomas et al. 2005). Similarly the revision of the $EF_{3PR\&P}$ emission factor evolved downwards from 0.02 to 0.01 kg $N_2O$-N $kg^{-1}$ N excreted, and its acceptance came about as a result of three internationally accepted peer reviewed publications (Carran et al. 1995; Muller et al. 1995 and de Klein et al. 2003). The latter publication was a comprehensive study involving measurements across New Zealand (de Klein et al. 2003). The downward revision of $EF_1$ from 0.0125 to 0.010 kg $N_2O$-N $kg^{-1}$ N fertilizer was the outcome of a review performed by Kelliher and de Klein (2006) and a revision of $EF_1$ by the IPCC which now provides a default $EF_1$ value of 0.010 kg $N_2O$-N $kg^{-1}$ (IPCC 2006). This downwards revision has also been supported by recent publication of peer reviewed work in New Zealand (Luo et al. 2007).

Thus the New Zealand country-specific values for $EF_1$, $EF_{3PR\&P}$, and $Frac_{leach}$ are now set at 0.01 kg $N_2O$-N $kg^{-1}$ N fertilizer, 0.01 kg $N_2O$-N $kg^{-1}$ N excreta and 0.07 kg $NO_3$-N $kg^{-1}$ of N applied reflecting New Zealand's unique national circumstances.

In this report, we propose the inclusion of an $N_2O$ mitigation technology within New Zealand's national greenhouse gas inventory submission to the UNFCCC in 2009. Recently, Smith et al. (2007) listed several potential barriers to the successful adoption of on-farm mitigation activities and technologies. These barriers include permanence, additionality, uncertainty, leakage, transaction costs, measurement and monitoring costs and property rights. For a mitigation technology to be successfully adopted, it is considered that creative policies need to be implemented to overcome such barriers. It is also necessary to consider potential co-benefits and trade-offs of a mitigation technology. Here we present a mitigation technology that can be applied on-farm, with these potential barriers, co-benefits and trade-offs described and considered.

# 2. Nitrification inhibition: Dicyandiamide.

Due to the significance of excreta-N and fertilizer-N as $N_2O$ emission sources in the New Zealand agricultural soils greenhouse gas inventory, further research in New Zealand has targeted the mitigation of the $N_2O$ emissions from fertilizer-N and animal excreta-N deposited during grazing. These studies have focused on the use of a nitrification inhibitor dicyandiamide (DCD; $C_2H_4N_4$). An extensive body of New Zealand based field research relating to the mitigation of $N_2O$ and nitrate ($NO_3^-$) leaching using DCD is now available in the internationally peer reviewed literature detailing the unique application methods and circumstances for New Zealand pastoral agriculture.

Dicyandiamide has been studied for over 80 years with no reported environmental side effects. It is a white or colourless crystal. In soils, it is biotically mineralised or degraded by specific enzyme activity (Schwarzer and Haselwandter, 1991) via guanylurea, guanidine and urea to yield carbon dioxide and ammonium (Rathsack, 1955; Vilsmeier, 1980; Rodgers et al., 1985). Dicyandiamide has a bacteriostatic mode of action, so it does not kill soil bacteria but rather inhibits or reduces their activity. Hence DCD is an ideal inhibitor to be used in an agricultural system. Currently DCD is the only nitrification inhibitor applied to pastoral farms in New Zealand.

A search of the CAB abstract data base (using "DCD + New Zealand") reveals 28 publications demonstrating the mitigating effect of DCD on either the direct or indirect $N_2O$ emission pathways (Di and Cameron, 2008; Zaman et al. 2008; Kelliher et al. 2008; Menneer et al. 2008a, 2008b; Ledgard et al. 2008; Hoogendoorn et al. 2008; Smith et al. 2008a, Smith et al. 2008b; Cameron et al. 2007; Moir et al. 2007; Di and Cameron 2007; Di et al. 2007; Ledgard et al. 2007; Bryant et al. 2007; Vogeler et al. 2007; Clough et al. 2007; Di and

Cameron 2006; Smith et al. 2005; Di and Cameron 2005; Cameron and Di 2004; Di and Cameron 2004a; Di and Cameron 2004b; Di and Cameron 2004c; Di and Cameron 2003; Di and Cameron 2002; Cookson and Cornforth 2002; Francis, 1995). These studies have demonstrated the effect of DCD on nitrate leaching and/or $N_2O$ emissions, determined effective application rates, examined formulations and resulted in the market appearance and farmer uptake of DCD products in New Zealand.

# 3. "Good Practice" Application Guidelines

As a result of the concerted and extensive body of published work conducted within New Zealand, it is now well recognized that DCD reduces $N_2O$ emissions and nitrate leaching when applied according to recommended guidelines. These guidelines have evolved as a consequence of this body of published work and have been refined for New Zealand conditions as the studies continued. The initial published studies examined the effect of DCD rates (up to 15 kg DCD $ha^{-1}$) and the timing of DCD applications with respect to season and time since excreta-N deposition (e.g. Di and Cameron, 2002; 2003; 2004b; 2005). This body of literature lead to the current recommendations where it is advocated that DCD be applied at the rate of 10 kg DCD $ha^{-1}$ once in late autumn and once in late winter, and within 7 days of excreta-N deposition (grazing). This captures the period when soil temperatures are coolest (10°C or less), and thus DCD has its greatest efficacy (Kelliher et al. 2008), and when nitrate leaching losses are potentially at their peak.

Commercial supply of DCD to farmers is currently provided by two farmer-owned fertiliser cooperatives (Ravensdown and Ballance Agri-Nutrients), who together supply 95% of national fertiliser demand. Both companies promote the same "good practice" guidelines with respect to DCD application, where one company (Ravensdown) supplies the product as a fine particle suspension formulation (commercially sold as 'eco-n™') while the other supplies it as a granule formulation (commercially sold as ‘DCn™’). Ravensdown also require the use of approved spray applicators for applying the suspension product, where each applicator has a global positioning system (GPS) to provide proof of placement. This ensures a record is made of the application area, rate and date. A large proportion of Ballance's granular DCD product is applied using authorised certified spreaders to ensure the appropriate rate is applied: if required, information on date of application is obtainable. A small proportion of granular DCD sold by Ballance is applied on-farm directly by farmers using their own spreading equipment: “good practice” guidelines are provided to these farmers by the company. Ravensdown and Ballance together employ more than 120 field advisory staff, spread across the country providing an extension services promoting, among other things, on-farm DCD use following “Good Practice” guidelines.

As DCD applications onto pastoral soils also lead to a reduction in nitrate leaching from urine patches, this technology has been included as a mitigation option within ‘Overseer™’, an on-farm nutrient budgeting software tool freely available on the world wide web to farmers and farm advisors (http://www.agresearch.co.nz/overseerweb-/!download.aspx). Commercial suppliers’ specifications on the application of DCD are provided within this software tool. For the main part, the specifications are the same, where two applications are recommended, with the first in autumn within 7 days of grazing and the second application within 2 to 4 months of the autumn application. The specific timing will be dependent on the region, as local soil temperatures and rainfall patterns will dictate the ‘Good Practice’ guidelines, based on the research outlined in Section 3.1.

# 4. Incorporating DCD into New Zealand's $N_2O$ emissions inventory.

## 4.1 Concept.

The proposed new mitigation methodology, detailed below, is largely an amendment of the existing inventory methodology for nitrous oxide. Currently New Zealand's agricultural soils-$N_2O$ inventory follows a standard tier one approach but with New Zealand specific emission factors, parameters and activity data as noted below.

Conceptually the proposed mitigation methodology establishes revised emission factors and parameters for fertilizer-N, urine-N and nitrate leaching ($EF_1$, $EF_{3PR\&P}$ and $Frac_{leach}$) for where DCD application occurs on intensively grazed pastures. The revised DCD emission factors and parameters, in conjunction with the DCD affected land area, are used to calculate weighting factors (see section 4) which are applied during those months where DCD is most effective (see below).

These DCD weighting factors are applied to a 5 month window of the year (May, June, July, August, and September) where it has been established that relatively low soil temperatures optimise DCD efficacy (Kelliher et al. 2008). Specify temperature level.

Activity data for animal numbers and animal type are derived from Statistics New Zealand annual agricultural survey data – as has been the norm. However, it is now possible, based on additional questions in the latest agricultural survey and the information acquired, for this activity data to be further split into DCD affected land and non-DCD treated land with animal numbers and animal type also matched to these land areas.

Given that:

i. the animal numbers subject to a DCD application regime can be determined,
ii. the amount of nitrogen applied to soil as animal excreta can be determined,
iii. the period of DCD efficacy is known from field-based research,
iv. the percentage reductions in $EF_1$, $EF_{3PR\&P}$ and $Frac_{leach}$ attributable to DCD application can be determined based on field-based research.

We can now calculate the effect DCD has on mitigating $N_2O$ emissions and include this in New Zealand's national inventory.

Currently, DCD applications are largely confined to soils beneath pasture grazed by dairy cattle due to the favourable economics of application to this farming system and thus the inventory revision incorporating the use of DCD reflects this and pertains only to dairy cattle at the present time. However, the inventory process described below can equally be applied to other livestock types if required. Note the effect of DCD on fertilizer-N applied to these soils is not included in the inventory developed here due to a lack of suitable activity data.

Figure 1 presents a conceptual diagram indicating how the various components are linked and used to incorporate DCD into the New Zealand's national $N_2O$ inventory.

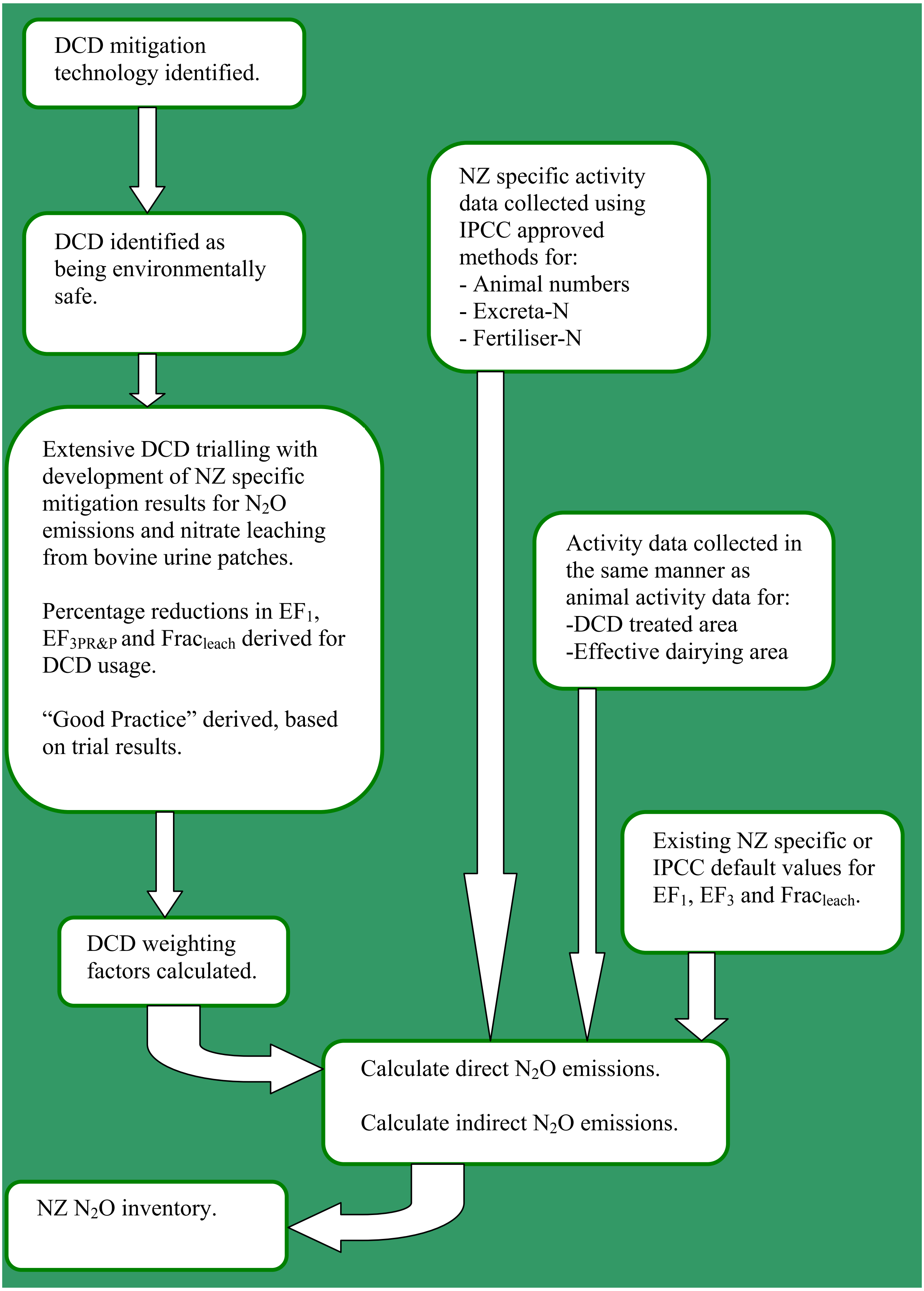


Figure 1 Conceptual diagram demonstrating the incorporation of DCD into New Zealand's $N_2O$ emissions inventory.

## 4.2 Data requirements for incorporating DCD into the national inventory.

### 4.2.1 Duration of the DCD effect

A review of all relevant and available international literature showed that the rate of DCD degradation in soils was dependent on soil temperature, with slower degradation rates in cooler soils (Kelliher et al. 2008). Based on this review, the average soil temperatures measured during New Zealand DCD field trials, and long term average soil temperatures throughout New Zealand, the application of DCD is considered to be most effective over the period May – September when soil temperatures, on average, are ≤ 12°C. DCD is also effective outside this period in those locations where soil temperatures remain lower for a longer period of the year, potentially up to 8 months at some locations in New Zealand. Thus the five month period noted above is conservative if recommended DCD application rates and timings of applications are observed (section 2).

### 4.2.2. Incorporating DCD: Revising parameters and emission factors.

Previous to this report there have been several reports commissioned by the Ministry of Agriculture and Forestry to examine the effects of DCD on $N_2O$ emission factors (Kelliher et al. 2007; Clough et al. 2006). One of these led to a peer reviewed publication of a conceptual methodology for implementing DCD mitigation into New Zealand's inventory (Clough et al. 2007). After reading these reports and further consultation with key scientists involved in DCD research, we chose the most appropriate peer reviewed publications to base our revision of $EF_{3PR\&P}$, $EF_1$, and $Frac_{leach}$ (Tables 1, 2 and 3). Importantly, these studies provide the best available national coverage and reflect best DCD management practice, the latter having evolved as the research data has been assimilated, mostly over the last 5 years as noted above.

These peer reviewed studies consistently demonstrate reductions in $N_2O$ emissions from urine and fertilizer applied to pasture soils (e.g. Di et al. 2007; Smith et al. 2008a; Smith et al. 2008b; McTaggart et al. 1997) as described below.

*Revision of $EF_{3PR\&P}$*

The evidence for revision was assessed with respect to two earlier reports done for MAF by Clough et al. (2006) and Kelliher et al. (2007). Clough et al. (2006; 2007) evaluated data from several published studies (Di and Cameron 2002; 2003; 2006) performed on silt loams and sandy loams, where DCD rates ranged from 7.5 to 15 kg $ha^{-1}$, on average, the application of a DCD treatment reduced $N_2O$ emissions 73% ($n$ = 9). Based on this a conservative recommendation was made, due to the limited data set in terms of soil types and climates, for the reduction in $N_2O$ emissions to be 50%.

Kelliher et al. (2007) re-evaluated these data and data published after Clough et al. (2006). These additional data came from Di et al. (2007) and they are given in Table 1. Data for the Lismore and Templeton soils are common to the three assessments, but the data in Table 1 came from trials with a DCD application rate of 10 kg $ha^{-1}$, now considered best management practice. Thus, data from earlier trials for these two soils were not included in this assessment. For Kelliher et al. (2007), the data of Smith et al. (2008a,b) were not available from published papers. Recent publications made these data available for this assessment. We are aware of no other data that could have been included in this assessment.

Table 1. Reductions in $EF_{3PR\&P}$ for New Zealand field trials.

| Reference | Soil | Soil (texture-drainage) | Reduction in $EF_{3PR\&P}$ (%) | Month(s) DCD applied |
|---|---|---|---|---|
| Di et al. 2007 | Lismore | silt loam - good | 67 | May + August |
| Di et al. 2007 | Templeton | fine sandy - imperfect | 73 | June |
| Di et al. 2007 | Horotiu | sandy loam - good | 61 | May + July |
| Di et al. 2007 | Taupo | pumice - good | 69 | August |
| Smith et al. 2008a | Pukemutu | silt loam – poor | 54 | June |
| Smith et al. 2008b | Pukemutu | silt loam - poor | 78 | April |
| | | Mean (± std dev) | 67 ± std dev 9 | |

On average, for the six trials presented in Table 1, DCD application (10 kg DCD $ha^{-1}$) to the soils receiving cattle urine corresponded to a 67 ± 9% (± standard deviation) reduction in $EF_{3PR\&P}$ when compared with the application of urine alone (control). This applied to soil urine patches over 43 – 89 days when direct nitrous oxide emissions from treated plots became indistinguishable from the controls (Kelliher et al. 2008). These trials represent soils across New Zealand. Although, as stated earlier, temperatures were similar during the trials, but rainfall and drainage rates varied by about 2-fold between sites.

*Revision of $EF_1$*

In a glasshouse trial, conducted recently in New Zealand, urea fertilizer (90 kg N/ha) alone or urea plus DCD (13 kg/ha) were applied to soil in pots. The soil water content was 80% of the field capacity, maintained by daily watering. The application of DCD with urea fertilizer corresponded with a 65% reduction in EF1 over a 35-day-long measurement period compared with the application of urea fertilizer alone, Table 2 (Asing et al. 2008). This percentage reduction for $EF_1$ was similar to the values shown for $EF_{3PR\&P}$ in Table 1.

Table 2. Reduction in $EF_1$

| Source | Soil | % reduction in EF1 | Month(s) of inhibitor application |
|---|---|---|---|
| Asing et al. 2008 | Manawatu fine sandy loam | 65 | Unknown, but 15 – 20 °C air temperature in glasshouse |
| McTaggart et al. 1997 | Winton clay loam | 70† | April, August in the northern hemisphere |

†See text below for explanation of this mean value ( $n$ = 4)

Because there was only one New Zealand study of DCD + $EF_1$, we make an exception to include the U.K study of McTaggart et al. (1997). This is a seminal paper discussing the effects of DCD on urea fertilizer and $N_2O$ emissions, in a temperate pastoral agricultural system. Earlier, near Edinburgh, UK, urea fertilizer was applied to grassland in three dressings (120 kg N $ha^{-1}$) with or without DCD (12.5 kg $ha^{-1}$) in early spring (April) and late summer (August). Rainfall was plentiful and soil temperatures were < 17 °C. On average, DCD application with urea fertilizer corresponded with a 70% mean (± std dev 9%) reduction in $EF_1$ over a 60 day measurement period when compared with the control, which was the application of urea fertilizer alone (McTaggart et al. 1997). Considering these two studies we recommend that the same percentage reductions should apply for the effect of DCD application on $EF_1$ and $EF_{3PR\&P}$.

*Revision of $Frac_{leach}$*

Previously Clough et al. (2006; 2007) examined a number of published studies (Di and Cameron 2002; 2003; 2004; 2005; 2006) carried out on silt loams and sandy loams, where DCD rates were 5 to 15 kg $ha^{-1}$, on average, the application of a DCD treatment reduced nitrate leaching by 61% (± std dev 24%, $n$ = 7) and if the lowest rates of DCD application were excluded from these studies this became 69% (± std dev 13%, $n$ = 6). Based on this, a very conservative recommendation for the reduction in nitrate leaching was made at 35% (Clough et al. 2006).

For the revision of $Frac_{leach}$ in this current report we utilised the expert judgement of authors of the seminal peer-reviewed papers including Professors Keith Cameron and Hong Di and Drs. Stewart Ledgard and Ross Monaghan. We also had available data from a greater range of soil types than for previous reports. For the field trials conducted at Lincoln, located in the Canterbury region of the South Island, Professors Cameron and Di advised the $Frac_{leach}$ data from their two most recently published studies be used. These studies were conducted on mineral soils whose drainage was classified as good (Lismore) and imperfect (Templeton). The nitrification inhibitor (DCD) application rate was 10 kg DCD $ha^{-1}$ and this treatment corresponded with similar reductions in $Frac_{leach}$ for these two soils (63 and 68%, respectively). To put these drainage classes into context 74% of New Zealand's land area in improved pasture have soils classified with good drainage, while 17% have imperfect drainage and a further 9% have poor drainage according to Sherlock et al. (2001).

A poorly-drained mineral soil, Pukemutu silt loam, beneath pasture grazed by dairy cattle was studied for four years in the Southland region of the South Island. The trial was unique due to its inclusion of cattle grazing. There were twelve plots with artificial drainage to support the intensive grazing regime typical of this region. Dr Monaghan supplied us a copy of his manuscript that has been submitted for publication in a peer-reviewed journal (Monaghan et al. 2008). The nitrification inhibitor (DCD) application rate was 10 kg DCD $ha^{-1}$ and there were two to three applications each year (see Table 3). This treatment regime corresponded with an annual reduction in $Frac_{leach}$ that averaged 38 ± 14% (± standard deviation).

In the centre of New Zealand's North Island, there is an area of pumice soils that have good drainage and these are volcanic in origin. Dairy farms are located in this area. For context, the area of pumice soils, beneath pasture grazed by dairy cattle is estimated to be 9% of New Zealand's total effective area grazed by dairy cattle (9% of 1,742,242 ha; Dr Stewart Ledgard, personal communication, 15 October 2008). The $Frac_{leach}$ data for pumice soils comes from three recently-published studies. The nitrification inhibitor (DCD) application rate was 10 kg DCD $ha^{-1}$ for Cameron et al. (2007), 15 kg DCD $ha^{-1}$ for Menneer et al. (2008a) and 18 kg DCD $ha^{-1}$ for Menneer et al. (2008b) and there were one to two applications each year (see Table 3). These treatment regimes corresponded with an annual reduction in $Frac_{leach}$ that averaged 42 ± 20% (± standard deviation). Thus, compared to the Lismore mineral soil with good drainage, DCD application to these soils was generally less effective and the effect was more variable.

From data of the seven trials presented in Table 3, DCD application to the soils with cattle urine corresponded with percentage reductions in $Frac_{leach}$ compared with the application of urine alone (control) as follows: 63% for mineral soils with good drainage, 68% for mineral soils with imperfect drainage, 38% for mineral soils with poor drainage and 42% for pumice soils with good drainage. These trials represented soils across New Zealand and the percentage reduction in $Frac_{leach}$ weighted by these four average values equated to 53 ± 15% (± standard deviation).

Table 3 Reductions in $Frac_{leach}$ for New Zealand field trials.

| Source | Soil | Drainage class | Reduction in $Frac_{leach}$ (%) | Month(s) of inhibitor application |
|---|---|---|---|---|
| Di and Cameron 2007 | Lismore silt loam | good | 63 | May |
| Di and Cameron 2005 | Templeton fine sandy loam | imperfect | 68 | May |
| Monaghan et al. 2008 | Pukemutu silt loam | poor | 38 (average of 4 years data) | March, April + August/September |
| Cameron et al. 2007 | Taupo sandy pumice | good | 34 | May + August |
| Menneer et al. 2008a | Te Ngai sandy loam pumice | good | 17 | May |
| Menneer et al. 2008a | Te Ngai sandy loam pumice | good | 62 | July |
| Menneer et al. 2008b | Kuratau loamy sand pumice | good | 54 | May |
| | Weighted Mean† (± stdev) | | 53 (± stdev 15) | |

† See text above for explanation of this calculation.

### 4.2.3 Activity data for animal numbers affected by DCD.

For the current New Zealand agricultural soils greenhouse gas inventory, the livestock population data are obtained from Statistics New Zealand through the official national agricultural production census and surveys. For dairy cattle a feeding standards Tier 3 (as defined by the IPCC 1996) model approach is used to determine animal dry matter intake. These same dry matter intake data are then multiplied by dry matter N content data which provides the calculation for animal nitrogen intake and considers N in product (meat and milk for dairy cattle), excreta ($N_{ex}$) and the subsequent $N_2O$ emissions.

In 2007, Statistics New Zealand expanded the agricultural census questionnaire to include data on the use of nitrification inhibitors. Dicyandiamide is the only nitrification inhibitor applied to New Zealand pastoral soils. This data now enables the matching of the land area that inhibitors have been applied to with the animal numbers on the land affected by DCD application.

### 4.2.4 Activity data for nitrogen inputs: excreta-N and fertilizer-N.

*Excreta-N*

A feeding standards Tier 3 model approach is applied on a monthly basis, and is used with animal productivity data, (animal age, and productivity and population information) to determine dry matter intake. These same dry matter intake data and associated N content data are then used to calculate animal excreta ($N_{ex}$) on a monthly basis while deducting for N in product.

*Fertilizer-N*

Data on nitrogen fertilizer use is currently determined on an annual basis from the fertilizer industry sales records. This data is not currently available on a monthly basis neither is it available for specific animal types or soil types thus there is no monthly break down of fertilizer-N use by the dairy industry.

National, annual scales of N fertilizer onto soils was previously disaggregated by animal type (Kelliher et al. 2007). This was based on expert judgement (Dr Hilton Furness, FertResearch, Personal Communication, 8 March 2007) and indicated that 70% of all N fertilizer that is sold annually was applied to soils associated with dairy cattle. The use of fertilizer N has increased since 1990 (Table 4) and further refinement of this data is required as discussed below. However, as noted above the effect DCD on fertilizer N is not considered in this report.

Table 4 Excreta N applied to soils grazed by dairy cattle and an approximation of the associated quantity of fertilizer N applied to these soils. The N fertilizer data for 1990 and 2007 came from Dr Hilton Furness (Pers. Comm., 28 October 2008).

| Year | Fertilizer | Excreta | (Fertilizer-N+Excreta-N)/Excreta-N |
|---|---|---|---|
| | tonnes N | tonnes N | |
| 1990 | 59,265 | 357,411 | 1.17 |
| 2007 | 315,920 | 597,773 | 1.53 |
| Increase from 1990 to 2007 | 256,655 | 240,362 | |

# 4.3. Does DCD use influence other emission factors or parameters?

## 4.3.1. Indirect emissions - ammonia volatilisation

**$Frac_{GASM}$ and $Frac_{GASF}$**

The IPCC methodology identifies ammonia ($NH_3$) volatilisation as an indirect source of $N_2O$ emissions, due to the subsequent downwind deposition of ammonia and/or ammonium salts becoming an N source for soil microbial processes and the subsequent production of $N_2O$. In discussions with scientists, it has been suggested that when DCD is applied, due to the conservation of ammonium in the soil system, ammonia volatilisation may be enhanced and thus $Frac_{GASM}$ (total excreta-N emitted as $NO_x$ or $NH_3$) and $Frac_{GASF}$ (total fertilizer N emitted as $NO_x$ or $NH_3$) could become elevated. Examination of trial data and theory however, suggest this is unlikely.

The ammonia volatilisation process is a physicochemical reaction, whereby urea (applied either as urine or as urea fertilizer) is hydrolysed by urease to generate ammonium, $NH_4^+{}_{(aq)}$, bicarbonate, $HCO_3^-{}_{(aq)}$ and hydroxide ($OH^-$) (equation 1).

$$CO(NH_2)_{2(aq)} + 3H_2O_{(l)} \xrightarrow{\text{urease}} 2NH_4^+{}_{(aq)} + HCO_3^-{}_{(aq)} + OH^-{}_{(aq)} \qquad (1)$$

The generation of bicarbonate and hydroxide rapidly increases the soil solution pH at the soil surface to >8.5 or beyond, increasing the proportion of the dissolved ammoniacal-N present as volatilisable $NH_{3(aq)}$. This change in equilibrium consequently results in the generation of $H^+$ ions, thereby lowering the soil solution pH over the next 5-10 days (equation 2). The fraction of aqueous ammoniacal-N in the soil solution as $NH_3$ at pH 6, 7, 8 and 9 can be calculated to be approximately 0.0004, 0.004, 0.04 and 0.3 respectively (Dr Sherlock pers comm. Oct. 2008), thus as soil pH falls, $NH_3$ fluxes are rapidly reduced. This process is considered to be the major factor limiting the loss of ammoniacal-N from urine patches (Sherlock and Goh, 1985).

$$NH_4^+ + H_2O \longrightarrow NH_3 + H_2O + H^+ \qquad (2)$$

Because the ammonia volatilisation process occurs independently of nitrification and biological denitrification, nitrification inhibitors such as DCD should have no effect on the rate and amount of $NH_3$ volatilised from urine and urea fertilizer. Field studies conducted in New Zealand, where DCD was applied at 15 kg active ingredient $ha^{-1}$ to an imperfectly drained Templeton fine sandy loam soil (Di and Cameron, 2004) and a freely drained Pumice soil (Menneer et al., 2008a), have shown that DCD application did not affect $NH_3$ volatilisation rate.

Other variables that are known to influence $NH_3$ volatilisation include soil temperature, wind speed and soil pH buffering capacity. Generally wind speed and certainly soil temperatures are lower during the period of DCD use, although neither of these will have a positive effect on $NH_3$ volatilisation if DCD is present.

Therefore, the values used for $Frac_{GASM}$ and $Frac_{GASF}$ remain unchanged as a result of using DCD as an $N_2O$ mitigation technology.

# 5. Incorporation of the mitigation methodology, revised emission factors and parameters into New Zealand's national greenhouse gas inventory.

The agricultural census data states that the total effective dairy grazing area is 1,743,242 ha. Within this area there are currently 61,837 ha under a DCD regime (3.55% of the effective dairying area) according to the agricultural census. Based on the work described above we define the emission factors and parameters as in Table 5, with a 67% reduction in $EF_{3PR\&P}$, 67% reduction in $EF_1$ and a 53% reduction in $Frac_{leach}$.

Table 5

| | DCD NOT used | % reduction in EF where DCD used | Emission factor if DCD was used on 100% of effective area. |
|---|---|---|---|
| $EF_{3PR\&P}$ | 0.0100 | 67 | 0.0033 |
| $EF_1$ | 0.0100 | 67 | 0.0033 |
| $Frac_{leach}$ | 0.0700 | 53 | 0.0329 |

Using the following formula, the reductions in the emission factors are used to establish monthly DCD weighting factors with a weighting based on the proportion of effective dairying land under a DCD regime and the actual reduction in the emission factor as a consequence of DCD use with the equation as follows:

$$DCD\ weighting\ \ factor = \ (1 - \frac{\%\ reduction\ in\ EF_x}{100} \times \frac{DCD\ treated\ area}{Effective\ dairy\ area}) \qquad (3)$$

These DCD weighting factors are then aligned with the period of DCD usage (Table 6).

When calculating the national dairy cattle excreta-N $N_2O$ emissions inventory, DCD mitigation of $N_2O$ emissions and nitrate leaching is considered to apply only to the excreta deposited directly onto pasture since not enough detailed work has been performed to determine the effect of DCD on reducing the $N_2O$ emissions or nitrate leaching from the application of dairy shed effluent onto pasture. For dairy cattle, during the period of the year that milking occurs this equates to 95% of the total excreta of milking cows since some excreta-N is collected on the milking platform and non paddock areas. During the non milking winter period (June, July) all of the excreta-N is returned to pasture. Thus the DCD weighting factors are applied to all excreta –N that falls directly onto pasture which is 95% of excreta-N during May and September but effectively 100% (95%+5%) of excreta-N during June and July (Table 5 and Table 6).

It is also worthy of note that the excreta-N monthly deposition amount of the dairy industry is not constant throughout the year but highly dynamic (Table 6) and it is at its lowest during the months of May and June (< 26647 tonne) with higher excretion rates during the period pre-calving to late lactation. Thus a monthly approach to DCD mitigation fully captures the effect of DCD on this dynamic excreta-N profile.

As noted above no attempt has been made to calculate DCD mitigation of N fertilizer use in the dairy industry until monthly sector specific fertilizer N data are available. However, once available it will be a simple matter of applying the DCD weighting factor in conjunction with $EF_1$ and the land area treated.

Table 6 Emission factors, parameters and weighting factors for DCD regimes and non-DCD regimes.

| | Excreta deposited during grazing | | | | Excreta in waste management systems | | | |
|---|---|---|---|---|---|---|---|---|
| DCD not used | $EF_{3PR\&P}$ | 0.01 | | | $EF_{3PR\&P}$ | 0.01 | | |
| | EF4 | 0.01 | | | EF4 | 0.01 | | |
| | EF5 | 0.025 | | | EF5 | 0.025 | | |
| | $Frac_{gasm}$ | 0.2 | | | $Frac_{gasm}$ | 0.2 | | |
| | $Frac_{leach}$ | 0.07 | | | $Frac_{leach}$ | 0.07 | | |
| DCD used | Monthly weightings | $EF_{3PR\&P}$ | $Frac_{leach}$ | Monthly N excreted (tonnes)‡ | Monthly weightings | Direct | $Frac_{leach}$ | Monthly N excreted (tonnes)‡ |
| | Jan | 1.000 | 1.000 | 52457 | Jan | 1.000 | 1.000 | 2761 |
| | Feb | 1.000 | 1.000 | 49740 | Feb | 1.000 | 1.000 | 2618 |
| | Mar | 1.000 | 1.000 | 52053 | Mar | 1.000 | 1.000 | 2740 |
| | Apr | 1.000 | 1.000 | 35228 | Apr | 1.000 | 1.000 | 1854 |
| | May | 0.967 | 0.974 | 26647 | May | 1.000 | 1.000 | 1402 |
| | Jun | 0.967 | 0.974 | 31393 | Jun | - | - | 0 |
| | Jul | 0.967 | 0.974 | 61499 | Jul | - | - | 0 |
| | Aug | 0.967 | 0.974 | 53823 | Aug | 1.000 | 1.000 | 2833 |
| | Sep | 0.967 | 0.974 | 51905 | Sep | 1.000 | 1.000 | 2732 |
| | Oct | 1.000 | 1.000 | 50368 | Oct | 1.000 | 1.000 | 2651 |
| | Nov | 1.000 | 1.000 | 50134 | Nov | 1.000 | 1.000 | 2639 |
| | Dec | 1.000 | 1.000 | 57244 | Dec | 1.000 | 1.000 | 3013 |

‡N excreta for the national dairy herd in 2007 for: mature dairy cows (4137697), growing heifers 0-1 years (673291), growing heifers 1-2 years (726725), and bulls (49261), population numbers in brackets.

Table 7 Fraction of excreta deposited on grazed and ungrazed areas.

| Excreta deposited on pasture. | | Excreta deposited on non-grazed areas. | |
|---|---|---|---|
| Proportion for milking cows | 0.95 | Proportion for milking cows | 0.05 |
| Proportion for non milking cows | 1 | Proportion for non milking cows | 0 |

Thus to calculate direct $N_2O$ emissions from grazed pasture (Gg $N_2O$ year$^{-1}$) the following formula is used when DCD is applied:

$$Direct\ N_2O\ emissions\ from\ pasture = excreta - N \times 0.95 \times EF_{3PR\&P} \times DCD\ weighting\ factor \times \frac{44}{28} \quad (4)$$

Thus when DCD is not applied e.g. the month of January the DCD weighting factor for $EF_{3PR\&P}$ equals a value of 1.000 but when DCD is applied e.g. May it equals 0.967 when DCD is applied to 3.55% of the effective grazing area, excreta-N has units of kg year$^{-1}$, 0.95 represents the fraction of the excreta deposited onto pasture (Table 7) and $\frac{44}{28}$ converts N mass to an equivalent mass of $N_2O$. Indirect $N_2O$ emissions resulting from gaseous losses of N from the grazed pasture are calculated as per normal and $Frac_{gasm}$ does not change as a result of DCD application (Table 7). Indirect emissions (Gg $N_2O$ year$^{-1}$) due to nitrate leaching are affected by DCD application as noted above and are calculated as follows:

$$Indirect\ N_2O\ emissions\ \ from\ \ pasture = excreta - N \times 0.95 \times Frac_{leach} \times EF_5 \times DCD\ weighting\ \ factor \times \frac{44}{28} \tag{5}$$

Thus when DCD is not applied e.g. the month of January in 2007, the DCD weighting factor for indirect $N_2O$ emissions equals a value of 1.000 but when DCD is applied e.g. May it equals 0.974 when DCD is applied to 3.55% of the effective grazing area, excreta-N has units of kg year$^{-1}$, 0.95 represents the fraction of the excreta deposited onto pasture (Table 7) and $\frac{44}{28}$ converts N to $N_2O$.

Table 8 presents the effect of incorporating this DCD mitigation methodology on the $N_2O$ emissions from dairy excreta-N for the year 2007.

At this time, the effect of DCD on $EF_1$ is not included due to the unavailability of agricultural statistics capturing monthly N fertilizer use applied to pasture grazed by dairy cattle.

Table 8 $N_2O$ emissions from the dairy industry for 1990 (base year), 2007 with no DCD mitigation included, and for 2007 with DCD mitigation included. Figures in bold indicate changes due to DCD mitigation. The area using DCD is 61,837 ha (3.5% of effective grazing area).

| **1990 without DCD** | | | | $N_2O$ emissions (Gg year$^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dairy Population | Excreta-N (kg) | Excreta-N (kg/head) | Direct Grazing | Indirect Volatile Grazing | Indirect Leaching Grazing | Direct AWMS | Indirect Volatile AWMS | Indirect Leaching AWMS | Total |
| Milking Cows - Mature | 2621378 | 295132405 | 113 | 4.41 | 0.88 | 0.77 | 0.19 | 0.05 | 0.04 | 6.33 |
| Growing Heifers - 0-1 | 576908 | 19439373 | 34 | 0.29 | 0.06 | 0.05 | 0.01 | 0.00 | 0.00 | 0.42 |
| Growing Heifers - 1-2 | 522444 | 39720540 | 76 | 0.59 | 0.12 | 0.10 | 0.02 | 0.01 | 0.01 | 0.85 |
| Breeding Bulls | 30558 | 3118492 | 102 | 0.05 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.07 |
| Total | 3440815 | 357410811 | | 5.34 | 1.07 | 0.93 | 0.22 | 0.06 | 0.05 | 7.67 |

| **2007 without DCD** | | 2621378 | | $N_2O$ emissions (Gg year$^{-1}$) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dairy Population | Excreta-N (kg) | Excreta-N (kg/head) | Direct Grazing | Indirect Volatile Grazing | Indirect Leaching Grazing | Direct AWMS | Indirect Volatile AWMS | Indirect Leaching AWMS | Total |
| Milking Cows - Mature | 4137697 | 513670084 | 124 | 7.67 | 1.53 | 1.34 | 0.32 | 0.08 | 0.07 | 11.02 |
| Growing Heifers - 0-1 | 673291 | 23216999 | 34 | 0.35 | 0.07 | 0.06 | 0.01 | 0.00 | 0.00 | 0.50 |
| Growing Heifers - 1-2 | 726725 | 55828414 | 77 | 0.83 | 0.17 | 0.15 | 0.04 | 0.01 | 0.01 | 1.20 |
| Breeding Bulls | 49261 | 5017806 | 102 | 0.07 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.11 |
| Total | 5260850 | 597733302 | | **8.923** | 1.78 | **1.562** | 0.38 | 0.09 | 0.08 | **12.821** |

| **2007 with DCD** | | | | **$N_2O$ emissions (Gg year$^{-1}$)** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Dairy Population | Excreta-N (kg) | Excreta-N (kg/head) | Direct Grazing | Indirect Volatile Grazing | Indirect Leaching Grazing | Direct AWMS | Indirect Volatile AWMS | Indirect Leaching AWMS | Total |
| Milking Cows - Mature | 4137697 | 513670084 | 124 | 7.58 | 1.53 | 1.33 | 0.32 | 0.08 | 0.07 | 10.91 |
| Growing Heifers - 0-1 | 673291 | 23216999 | 34 | 0.34 | 0.07 | 0.06 | 0.01 | 0.00 | 0.00 | 0.49 |
| Growing Heifers - 1-2 | 726725 | 55828414 | 77 | 0.83 | 0.17 | 0.14 | 0.04 | 0.01 | 0.01 | 1.19 |
| Breeding Bulls | 49261 | 5017806 | 102 | 0.07 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.11 |
| Total | 5260850 | 597733302 | | **8.841** | 1.78 | **1.550** | 0.38 | 0.09 | 0.08 | **12.728** |

When 3.55% of the effective dairy land area receives DCD then the $N_2O$ emissions are reduced by 0.093 Gg $N_2O$ year$^{-1}$, a 0.73% decrease in the emissions compared to when DCD is not used. Uncertainty in this decrease can be assessed by varying the revised DCD parameters to be plus or minus one standard deviation of the mean. If this is done and all parameters are included then there is a decrease in $N_2O$ emissions of 0.079 – 0.108 Gg $N_2O$ year$^{-1}$ or (0.62 – 0.84 %), Table 9.

Table 9 Emissions of $N_2O$ (Gg year$^{-1}$) when the DCD application area is 3.5% of the effective grazed area and the reductions in the emission factors and parameters are applied. Shown are the values when the mean values are applied either alone or in combination and for the ranges of plus and minus one standard deviation of the mean. Numbers in brackets represent the percentage reduction in $N_2O$ emissions relative to no DCD mitigation being applied.

| Revised DCD parameter used | $N_2O$ emissions (Gg year$^{-1}$) when applying revised emission factors and parameters | | |
|---|---|---|---|
| | - std dev | mean | + std dev |
| $EF_{3PR\&P}$ and $Frac_{leach}$ | 12.742 | **12.728** | 12.713 |
| (method used above) | (0.62) | (0.73) | (0.84) |
| $EF_{3PR\&P}$ only revised | 12.750 | 12.739 | 12.728 |
| | (0.50) | (0.64) | (0.73) |
| $Frac_{leach}$ only revised | 12.813 | 12.810 | 12.807 |
| | (0.06) | (0.09) | (0.11) |

This proportional methodology also presents the opportunity to investigate wider uptake of the DCD mitigation option by a larger percentage of the dairy industry. For example if 50% of the effective dairy area received DCD then the reduction would equate to 1.322 Gg $N_2O$ year$^{-1}$ (a 10.31% reduction). In a similar manner the methodology allows for the economic impact of the mitigation methodology to be assessed.

# 6. Overcoming the potential barriers to mitigation technology impacts

For a mitigation technologies to be successful they need to overcome several potential barriers. These barriers include permanence, uncertainty, leakage, transaction costs, measurement and monitoring costs and property rights. In addition, there is a need to consider potential co-benefits and adverse impacts of a new mitigation technology. Here we discuss how these perceived potential barriers do not impede the successful impacts of DCD as an on-farm mitigation technology.

Permanence refers to the maximum capacity over time for a mitigation technology to reduce greenhouse gas emissions or enhance sinks. Mitigation of $N_2O$ emissions is permanent in the case of nitrification inhibitors. Nitrification inhibitors reduce emissions over a finite time period of months, dependant on the decay rate of the product in the soil which is influenced by temperature and leaching references. There is no evidence of subsequent production of nitrous oxide that has been mitigated.

A factor arising when critiquing the potential for long-term reduction in $N_2O$ emissions through the ongoing use of DCD is the possible adaptation of the soil microbial populations. However, DCD is bacteriostatic (Amberger 1989); therefore the *Nitrosomonas sp.* bacteria and associated ammonia monooxygenase enzyme will recover following the eventual decomposition of the DCD. Long term field studies to date have shown no reduction in the efficacy of DCD to inhibit nitrification following repeated applications over several years (Moir et al. 2007).

Uncertainty has two components: (i) mechanism uncertainty and (ii) measurement uncertainty (Smith et al., 2007). Given that $N_2O$ production and emission are the result of two complex microbial processes (nitrification and denitrification), the measured reduction in direct $N_2O$ emissions from the application of DCD following "Best Practice" guidelines is remarkably consistent (Table 1: Section 3.2.2). However, we are dealing with a biological system which has inherent biological variability. A large volume of research has been conducted to understand and quantify the reduction in $Frac_{leach}$ for differing soil types. We have used the statistical approach of adopting the mean reduction in the DCD revised parameters and stated the uncertainty based on ± one standard deviation. This approach provides a realistic assessment of the mitigation potential its variability.

Some mitigation technologies may result in a loss of agricultural production, which may act as a barrier to adoption, particularly if there is a high demand for the agricultural product. This may then result in leakage, i.e. an increase in production in areas not limited by the adoption of a mitigation technology to meet agricultural product demand (Smith et al., 2007). In the case of adopting DCD as an $N_2O$ mitigation technology, whereby N losses from the agroecosystem are reduced, there is no risk of a loss in agricultural production. There may however be a limit to its adoption due to a lack of perceived pasture response compared to alternative pasture enhancing products such as nitrogen fertiliser. Leakage is not seen as a barrier to adoption.

Under a carbon market system, the net return to a farmer for adopting a mitigation activity such as DCD application to pastures farmers will need to account for the transaction cost of application. While transaction costs are considered to be a barrier to adoption (Smith et al., 2007), this will ultimately depend on several factors including (i) market value of greenhouse gases, (ii) cost of DCD and its application, (iii) value of farm product, and (iv) N efficiency gains due to mitigation practice. Using a model farm, Clough et al. (2007) presented a number of scenarios describing the impact of DCD application to dairy pastures on the total kg $CO_2$ equivalents per hectare of farmland and as a percentage of the milk produced after allowing for on-farm N efficiency gains. An analysis of the data presented in the scenarios, using 2007 costs of DCD application, returns from milk solid (MS) production and the 2007 New Zealand Treasury value of NZ$22/tonne $CO_2$, shows a sufficient financial benefit exists for adoption by dairy farmers. Currently the financial analysis performed by one of the fertiliser companies supplying DCD shows that DCD is the cheapest way to obtain additional dry matter on the farm. Dry matter from grain and silage currently costs in excess of 30 cents $kg^{-1}$ DM, urea 10 – 45 cents $kg^{-1}$ DM and DCD 6 – 17 cents $kg^{-1}$ DM, with the range dependant on region and climatic conditions (Ravensdown, 2008).

Measurement and monitoring costs will not act as a barrier to the adoption of DCD, as there are strict guidelines associated with the application of DCD, where the principle commercial company supplying this service only allowing application of DCD through approved commercial contractors. Considering the extent of research conducted within New Zealand on the benefits of DCD application to pastures, the consistency of the results and ensuring the application guidelines are adhered to, it is suggested that there is a requirement for only a limited ongoing measurement and monitoring programme, thus any cost associated with this will be minimal. In terms of the area of DCD-treated pastures, this is now captured within the official annual agricultural production survey.

Property rights and the lack of clear single party land ownership may be considered as a barrier in some areas (Smith et al., 2007), however in New Zealand there is clear ownership of pastoral farms, thus a contract employing a mitigation technology and the potential resulting benefit will remain with the same party. However, due to the sharemilker system extensively employed in the dairy system within New Zealand, the ownership and liability of greenhouse gases and the costs and benefits of their mitigation has yet to be determined. Also multiple ownership of land by Maori may also cause uncertainty as to ownership and liability of greenhouse gases. In other on-farm practices, clear accountability and ownership has been established and will no doubt occur in this case.

Smith et al. (2007) list several additional constraints including the availability of capital, risk attitudes and availability of extension services. These and others listed by Smith et al. are not relevant to the mitigation option presented here, as the practice is already commercially available. Adoption will be encouraged if the market price of greenhouse gases is attractive and/or the co-benefits are cost effective. The commercial companies providing inhibitor products have trained field staff providing an extension service, supported by agricultural scientists who have experience in researching and applying this mitigation technology.

When considering the impacts of a mitigation technology, one needs to consider potential co-benefits and adverse impacts of the technology, as very few options only provide a 'win-win' outcome (Smith et al., 2007). Application of DCD to pastoral soils has been shown to reduce direct $N_2O$ emissions from N fertilizer and excreta ($EF_1$ and $EF_{3\ PRP}$) and reduce nitrate leaching ($Frac_{leach}$), without any adverse affects on other emission factors and parameters (see section 3.3). A co-benefit of the adoption of DCD application to pastures through improved N use efficiency is an increase in pasture production. However, the extent to which this may occur varies as it will depend upon the amount of N retained within the soil root zone (Moir et al., 2007; Menneer et al., 2008). The pasture response may result in farmers reducing N fertilizer inputs thereby maintaining animal production levels to that pre-DCD use. However, if the farmer does not alter nitrogen fertilizer and/or supplementary feed inputs, thereby increasing agricultural production, the benefits of adopting DCD remain attractive due to a decrease in $CO_2$ equivalents per kg MS produced (Clough et al., 2007).

Other co-benefits are achieved as a result of DCD reducing nitrate leaching. These include the improvement of ground and surface water quality and a decreasing potential for eutrophication as N loadings decrease. A second benefit for farmers in terms of DCD reducing nitrate leaching occurs because of a decrease in the leaching of cations that normally leach in conjunction with the leaching nitrate. Di and Cameron (2004c) found that the use of DCD reduced calcium, potassium and magnesium leaching by the equivalent of 50%, 65%, 52%, respectively. This has potential implications for the maintenance of soil pH and reducing the inputs of lime over the long-term.

# 7. Future improvements in inventory incorporation methodology

### 7.1 *Monthly nitrogen fertilizer statistics*

Currently nitrogen fertilizer activity data are taken from national annual sales records provided by the fertilizer companies and this provides no data on DCD affected and unaffected fertilizer-N applications. Ideally this data needs to be broken-down into monthly data, by animal type, to improve the data on DCD mitigation of fertilizer N applied during the 5 month efficacy period of DCD. Ultimately a monthly regional data base of N fertilizer sales needs to be established for the most effective capture of DCD mitigation technology on N fertiliser.

Alternatively a fully comprehensive section of the agricultural census needs to be included that provides the following information: type of N fertilizer used, the months of application and the total amount applied in these months.

## 7.2 *Future product/formulation*

Thought must also be given as to how future products appearing on the market, that claim to be nitrification inhibitors, are both assessed and granted 'mitigation status' sufficient to be used and counted in the national inventory. A company introducing a new product will have to also meet all environmental and food/health regulatory requirements in New Zealand. So documentation along these lines is required. Given that DCD sets a bench mark, any future product could be verified in relation to DCD in terms of its period of efficacy and its mitigation potential.

## *7.3 Ongoing refinement of general nitrous oxide emission factors under UNFCCC "Good Practice"*

Future improvements in the national agricultural inventory will also come about due to New Zealand's ongoing programme to further refine $N_2O$ emission factors. For example the effect of animal species on $N_2O$ emissions is being studied. Any trials currently examining $N_2O$ emissions will need to consider DCD treatments as a matter of course.

# 8. Reviewer's comments and suggested procedure for modifying estimation of $N_2O$ emissions from grazed pasture when using DCD.

## *8.1 Reviewer comments*

A reviewer of this report noted that the proposed mitigation methodology, whereby DCD is applied directly to pastures to inhibit nitrification and associated $N_2O$ emissions, during a 5-month period (cooler part of the year) is generally satisfactory. But that the proposed method of calculation needed to be modified. This modification was suggested because the routine agricultural practice in NZ is to use some synthetic N fertiliser during the grazing season. Thus there is fertiliser N on the pasture in addition to the urine and dung N deposited during grazing. The reviewer noted that this creates a problem in that two separate IPCC emission factors are then involved, and that there is no recognised mechanism for using a "hybrid factor".

The reviewer went onto suggest that the proposed change set out above was scientifically defensible subject to separate data on urine-N and fertiliser-N being used. In which case, the methodology would then become consistent with IPCC good practice guidelines. The reviewer notes that the proposed methodology is not consistent because the separate contributions to emissions from fertiliser-N and from urine-N (which have different IPCC emission factors), and their corresponding reduction factors arising from DCD use, have not been separately determined.

*8.2 Reviewer comments*

The following modifications to the procedure are suggested by the reviewer for modifying the proposed mitigation methodology for estimating of $N_2O$ emissions from grazed pasture when using DCD:

i. Determine the average % decrease in direct $N_2O$ emission from applied synthetic N fertiliser (essentially from urea) ($EF_1$), when also applying DCD, using plots or lysimeters *which have only received urea ± DCD.*

ii. Similarly determine the average % decrease in $N_2O$ emission from deposited urine ($EF_{3\text{-}PR\&P}$), using only urine ± DCD.

iii. Use equation 3 (p. 24) in CC MAF POL_0809-37 document, replacing $EF_x$ by $EF_1$, to calculate the DCD weighting factor for $EF_1$, and

iv. Use the equation *separately*, replacing $EF_x$ by $EF_{3\text{-}PR\&P}$, to calculate the DCD weighting factor for $EF_{3\text{-}PR\&P}$.

v. Calculate the $N_2O$ emissions from *the urine* deposited on grazed pasture according to Equation 4 (p. 26), using this DCD weighting factor for $EF_{3\text{-}PR\&P}$.

vi. But in addition calculate the direct $N_2O$ emissions from the fertiliser N applied to grazed pasture as fertiliser-N x $EF_1$ x DCD weighting factor for $EF_1$ x (44/28).

*8.2 Response to reviewer comments*

The reviewer makes some salient and logical points. The significance of fertiliser urine-N actually co-occurring with fertiliser-N is a point of much debate. Cows grazing and depositing excreta onto pastures will in practically all instances be doing so onto pasture that has a fertiliser-N history. Any effect of the fertiliser in terms of $N_2O$ flux will have been 'long gone', since animals graze pasture several weeks after urea-N fertiliser application, and these fluxes are accounted for under the fertiliser-N component of the $N_2O$ inventory.

It is perhaps more likely that fertiliser-N will be applied soon after grazing to stimulate pasture production prior to the next grazing. This may concur with a DCD application within 10 days of grazing and thus both urine-N and fertiliser-N maybe together under the DCD regime.

Thus it would appear that to meet IPCC good practice requirements EF data are required for:

(a) Urine only. But where will this be performed on trial sites with a prolonged absence of N fertiliser history? Does this mean the plant and soil microbial response will be 'standard'?

(b) Urine + DCD. Again will this be performed on trial sites with a prolonged absence of N fertiliser history? Does this mean the plant and soil microbial response will be 'standard'?

(c) Control. No urine or fertiliser.

If we choose a site and shut out cows and remove N fertiliser for a couple of months prior to applying treatments a, b, and c are the treatments representative of real practice? Such issues have/are currently being debated by $N_zO$-net and trials formulated.

The rate of N applied as fertiliser is very small compared to the rate of urine-N, 25-50 and 750-1000 kg N $ha^{-1}$ respectively, some 3-5%. It's a question of wether or not the combination of fertiliser and urine behave together as they do when they are separate entities or if there is some synergistic effect on $N_2O$ emissions when they are together. Thus another way to explore this would be to use a $^{15}N$ labelled urea fertiliser to distinguish between fertiliser and urine $N_2O$ emissions when both N sources are combined.

In the interim there are three manuscripts currently just published, in press or in review that examine either ‘urine only’ or ‘urine+DCD’ treatments in the absence of any recent fertiliser applications.

- Clough *et al.* 2009, The mitigation potential of hippuric acid on bovine urine $N_2O$ emissions: an *in situ* determination of its effect. *Soil Biology and Biochemistry* (revised and submitted for review). Treatments included a control, urine only and urine + DCD at 10 kg DCD/ha. These treatments were applied to pasture on 2nd of April 2008 when soil temperatures were approximately 17$^{o}$C (they declined further as time went on). Over time soil ammonium concentrations remained elevated in the +DCD treatment indicating DCD was effective in inhibiting nitrification for at least 78 days (length of trial). Where upon the $N_2O$ EF values were 1.13 in the urine only treatment and 0.46 in the ‘urine+DCD’ treatment respectively, i.e. a 60% reduction in the EF.

- Singh et *al*. 2009, Influence of dicyandiamide on nitrogen transformations and losses in pasture soil cores. *Australian Journal of Experimental Research* (in press). In brief there were 8 treatments:
    - T1 control
    - T2 control + DCD(25 kg/ha)
    - T3 urine (144 kg/ha)
    - T4 urine (144 kg/ha) + DCD
    - T5 urine (290 kg/ha)
    - T6 urine (290 kg/ha) + DCD
    - T7 urine ( 570 kg/ha)

- T8 urine (570 kg/ha) + DCD

The volumes of urine differed due to N rate and thus WFPS values were 64, 68 and 78%. These treatments were applied to intact sandy loam soil cores (10 cm deep x 10 cm diam.) with pasture cut away, maintained in a glasshouse at 15-20$^oC$. The addition of DCD reduced total $N_2O$ emissions over 50 days by 33, 56, and 80% in the T4, T6, and T8 treatments respectively.

- Singh *et al.* 2008, Decomposition of dicyandiamide (DCD) in three contrasting soils and its effect on nitrous oxide emission, soil respiratory activity, and microbial biomass—an incubation study. *Australian Journal of Soil Research* 46: 517–525. In brief there were 4 treatments:
    - Control
    - 600 mg N/kg bovine urine
    - 600 mg N/kg bovine urine + 10 mg DCD/kg soil
    - 600 mg N/kg bovine urine + 20 mg DCD/kg soil

These treatments were applied to three soil types (Tokomaru silt loam, Manawatu Sandy loam and an Egmont brown loam). Sieved re-packed soils (80g oven dry soil equivalent) were placed into 125 mL plastic cups and then placed in Agee jars (1.8 L) and gas sampled at t0 and t24 (0 h and 24 h respectively) with a ½ h opening of the seal every 24 h, with soils incubated at 25$^oC$ for 58 days at 80% of field capacity Percentage reductions in $N_2O$-N emissions were as follows (Table 10):

Table 10 Percentage reduction in urine treatments when DCD was applied (Singh et al., 2008)

| Treatment | Soil type | | |
|---|---|---|---|
| | Tokomaru Silt loam | Manawatu sandy loam | Egmont brown loam |
| 10 mg DCD/kg soil | 85 | 56 | 42 |
| 20 mg DCD/kg soil | 90 | 57 | 45 |

Of these studies only one is performed in situ, and this clearly showed the $N_2O$ reductions of the order proposed in the methodology outlined above. The other studies are incubations used to examine relativities between urine-N rate or soil types. In the Singh et al. 2009 (above) the highest urine rates start to approach bovine urine-N rates and they achieved an 80% reduction in urine –N despite the relatively warm temperature of the incubation. While a range in percentage reductions occurred as a function of soil type in Singh et al. 2008.

For fertiliser only applications the work of Luo et al. (2007) is perhaps the best data set which shows the $N_2O$ emissions from urea but more data are required to determine the effect of DCD on urea only treatments.

If the reviewers proposed changes are taken up there is therefore a need to obtain more treatment specific DCD data that pertains to urine or fertiliser only treatments. However these should be performed in such a way as to optimise or to link to existing data sets.

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