agresearch Farming, Food and Health. First
Te Ahuwhenua, Te Kai me te Whai Ora. Tuatahi

Quantifying the Variability of the Effectiveness of Nitrification Inhibitors on N_2O emissions (P21 lysimeter trial) – Interim 'Final' Report

Prepared for MAF

June 2008

2020 SCIENCE

New Zealand's science. New Zealand's future.

Quantifying the Variability of the Effectiveness of Nitrification Inhibitors on N_2O emissions (P21 lysimeter trial)

Prepared for Ministry of Agriculture & Forestry (MAF)

June 2008

CAM de Klein, KC Cameron, HJ Di, J Luo and RR Sherlock

Table of Contents

1. Introduction 1
2. Objectives 2
3. Materials and methods 2
   - 3.1 Experimental design 2
   - 3.2 Gas emission measurements 4
4. Milestones 6
5. Initial N_2O results 7
   - 5.1 Daily N_2O emissions from different soils studied at Lincoln University (14 May - 10 June 2008) 7
   - 5.2 Daily N_2O fluxes from soils studied at the Ruakura site (15 May and 27 May 2008) 12
6. Conclusions 16

1. Introduction

Recent research has shown that DCD can substantially reduce N_2O emissions from urine patches and grazed grassland with reduction potentials ranging from 60 to 80% (Di and Cameron 2002; 2003; 2006; Di et al. 2007; Smith et al. 2008a; 2008b)[1]. The research to date has been largely conducted on Canterbury soils (Lismore and Templeton) with some additional measurements made on two North Island soils (Taupo Pumice and Waikato Horotiu) and one Southland soil (Pukemutu). Although the results to date suggest similar N_2O reduction potentials from urine patches among these soils, a recent independent review for the PGGRC (Pastoral Greenhouse Gas Research Consortium) recommended that more research on the effectiveness of DCD should be conducted in a wider range of soil types and under different climatic conditions. Rainfall or irrigation is one of the key environmental drivers for N_2O emissions. In addition, rainfall/irrigation can displace DCD down the soil profile, away from where it is most effective, but very little is known about the impact of the rate of displacement of DCD on its effectiveness. Movement of DCD is largely dependent on the interaction of soil structure and rainfall/irrigation intensity.

Recently, the Pastoral Research Programme - Environment (P21) commenced a nitrification inhibitor programme of work, which includes detailed lysimeter studies investigating the effect of DCD displacement on reducing nitrate leaching in 6 different soils under two rainfall/irrigation regimes. Thus, there is a unique opportunity to use this N leaching study to also study the effectiveness of DCD on N_2O emissions – and hence the use of DCD as a mitigation strategy.

---

[1] Di HJ and Cameron KC (2002) *Soil Use and Management* 18, 395-403; Di HJ and Cameron KC (2003) *Soil Use and Management* 19, 284-290; Di HJ and Cameron KC (2006) *Biology and Fertility of Soils* 42, 472-480; Di HJ, Cameron KC and Sherlock RR (2007) *Soil Use and Management* 23, 1-9; Smith LC, de Klein CAM, Monaghan RM, Catto WD (2008a) *Australian Journal of Experimental Agriculture* 48, 160-164; Smith LC, de Klein CAM, Catto WD (2008b) *New Zealand Journal of Agricultural Research* (in press)

2. Objectives

- To improve confidence in the effectiveness of the nitrification inhibitor DCD as a novel N_2O mitigation technology in a wider range of key dairying soils.
- To understand the effect of rainfall/irrigation on DCD efficiency for N_2O reduction.

3. Materials and methods

3.1 Experimental design

The experimental design is given in Table 1.

Soil lysimeters:

Undisturbed soil monolith lysimeters, 50 cm diameter by 70 cm deep, were collected from each of the following pastoral soils and installed in lysimeter facilities at Lincoln University in Lincoln and Ruakura Research Centre in Hamilton:

Lincoln

- Canterbury (Lismore stony silt loam, near Winchmore)
- West Coast (Harihari hump & hollow, recent silt loam, Inchbonnie)
- Southland (Mataura recent silt loam, Wallacetown)

Ruakura

- Waikato (Horotiu sandy loam, Hamilton)
- Rotorua (Oropi sand, Rotorua)
- Northland (Waikare clay, Northland)

Treatments:

Treatments include: Control (no urine or DCD); Urine alone, applied on 14 May (Lincoln) and 15 May (Ruakura) 2008 and Urine plus a nitrification inhibitor (DCD solution @10 kg DCD/ha), applied in May 2008, with a second application of DCD in August 2008.

Two rainfall regimes (1,200 and 2,200 mm year $^{-1}$) are being employed. These are being achieved by using simulated rainfall/irrigation as required.

Table 1. Description of treatments for soil lysimeters [a,b].

Treatment	Soil	DCD (kg ha^{-1}) [c]
Control + rain 1	Lismore stony silt loam (Canterbury)	Nil
Control + rain 2	Lismore stony silt loam	Nil
Urine + rain 1	Lismore stony silt loam	Nil
Urine + rain 2	Lismore stony silt loam	Nil
Urine + rain 1 + DCD	Lismore stony silt loam	10
Urine + rain 2 + DCD	Lismore stony silt loam	10
Control + rain 1	Harihari hump & hollow, recent silt loam (West Coast)	Nil
Control + rain 2	Harihari hump & hollow, recent silt loam	Nil
Urine + rain 1	Harihari hump & hollow, recent silt loam	Nil
Urine + rain 2	Harihari hump & hollow, recent silt loam	Nil
Urine + rain 1 + DCD	Harihari hump & hollow, recent silt loam	10
Urine + rain 2 + DCD	Harihari hump & hollow, recent silt loam	10
Control + rain 1	Mataura recent silt loam (Southland)	Nil
Control + rain 2	Mataura recent silt loam	Nil
Urine + rain 1	Mataura recent silt loam	Nil
Urine + rain 2	Mataura recent silt loam	Nil
Urine + rain 1 + DCD	Mataura recent silt loam	10
Urine + rain 2 + DCD	Mataura recent silt loam	10
Control + rain 1	Horotiu sandy loam (Hamilton)	Nil
Control + rain 2	Horotiu sandy loam	Nil
Urine + rain 1	Horotiu sandy loam	Nil
Urine + rain 2	Horotiu sandy loam	Nil
Urine + rain 1 + DCD	Horotiu sandy loam	10
Urine + rain 2 + DCD	Horotiu sandy loam	10
Control + rain 1	Oropi sand (Rotorua)	Nil
Control + rain 2	Oropi sand	Nil
Urine + rain 1	Oropi sand	Nil
Urine + rain 2	Oropi sand	Nil
Urine + rain 1 + DCD	Oropi sand	10
Urine + rain 2 + DCD	Oropi sand	10
Control + rain 1	Waikare clay (Northland)	Nil
Control + rain 2	Waikare clay	Nil
Urine + rain 1	Waikare clay	Nil
Urine + rain 2	Waikare clay	Nil
Urine + rain 1 + DCD	Waikare clay	10
Urine + rain 2 + DCD	Waikare clay	10

[a] Fresh urine, (1000 kg N ha^{-1}) adjusted for N concentration, applied in a single application on 14 May (Lincoln) and 15 May (Ruakura) 2008.
[b] Total annual N fertiliser application 200 kg ha^{-1}, applied in 8 applications of 25 kg N ha^{-1}.
[c] DCD applied in solution to the soils in May and July/August, immediately after the urine has been applied in order to simulate grazing followed by DCD treatment on-farm.

There are 4 replicates of each treatment (except for the control treatment). In order to obtain data for a true control treatment (no urine or DCD), measurements of nitrous oxide emissions from a single lysimeter (50 cm diameter) at the Lincoln site and two mini lysimeters (25 cm diameter) at the Ruakura site for each soil type at each rainfall rate, are also being made.

A second set of lysimeters will be collected from each site to enable a second year of measurements to be made on fresh soil lysimeters that have not received any previous treatment.

3.2 Gas emission measurements

A chamber technique is being used to measure N_2O emissions. Nitrous oxide emission measurements are made by fitting headspace chambers to the top of the lysimeters. The rim of each lysimeter is fitted with a channel. This channel is filled with water to form a gas-tight seal when the headspace chambers are fitted during measurement.

Gas samples were taken on the same day that the treatments were applied. Gas samples are currently being collected twice per week for the first month and then will be collected once per week until background levels are reached (the maximum period is anticipated to be 5 months).

On each sampling day, N_2O measurements are carried out once between 12 noon and 2 p.m. Three headspace gas samples are taken during the cover period with each 12 ml gas sample being transferred into a 6 ml septum-sealed screw-capped glass vial. From 23 June 2008 only two headspace gas samples will be taken during the cover period.

Gas samples from lysimeters at the Lincoln site are being analysed by Lincoln University. Gas samples from the Ruakura site are being analysed by AgResearch Grasslands. Similar analytical protocols are being employed at each facility; the gas samples are analysed using gas chromatographs equipped with a ^{63}Ni-electron capture with oxygen-free N as a carrier gas.

The hourly N_2O emissions are being calculated for each chamber, from the increase in head space N_2O concentration over the sampling time. The hourly N_2O emissions (mg N m^{-2} h^{-1}) are calculated as follows:

$$N_2O\,flux = \frac{\delta N_2O}{\delta T} * \frac{M}{Vm} * \frac{V}{A} \qquad (1)$$

where δN_2O is the increase in head space N_2O over time (μL/L); δT is the enclosure period (hours); *M* is the molar weight of N in N_2O; *Vm* is the molar volume of gas at the sampling temperature (L/mol); *V* is the headspace volume (m^3); and *A* is the area covered (m^2).

These hourly emissions will be integrated over time, for each enclosure, to estimate the total emission over the measurement period. Emission factors (EF, N_2O-N emitted as % of N applied) will be calculated (equation 2). Reduction in N_2O emissions by the use of DCD will also be calculated.

$$EF = \frac{N_2O\ total\ (treatment) - N_2O\ total\ (control)}{Urine\ N\ applied} \times 100\% \qquad (2)$$

where EF is emission factor (N_2O-N emitted as % of urine-N applied), *N_2O total (treatment)* is the cumulative N_2O emission (kg N ha^{-1}) from the urine or urine plus DCD and *N_2O total (control)* is the cumulative N_2O emission (kg N ha^{-1}) from the control lysimeters, and *Urine N applied* is the rate of urine N applied (kg N ha^{-1}).

4. Milestones

- Define the N_2O study plan for this project by 30 April 2008 (achieved).
- Prepare and submit a framework report to MAF by 30 April 2008 (achieved).
- Complete the set-up phase for the N_2O measurements and start initial N_2O measurements before treatments are applied by 15 May 2008 (achieved).
- Prepare and submit a draft report on the experimental protocol for the N_2O measurements to MAF by 30 May 2008 (achieved).
- Conduct an evaluation of N_2O emissions from the application of animal urine and DCD for period of May to June and produce a report for MAF by 30 June 2008 (this report).
- Complete the analysis and estimation of the total N_2O emissions by 24 December 2008 (on-track).
- Complete the evaluation of N_2O emissions and produce a final report for MAF by 30 January 2009 (on-track).

5. Initial N_2O results

5.1 Daily N_2O emissions from different soils studied at Lincoln University (14 May - 10 June 2008)

Rainfall of 1,100 mm

- Daily N_2O fluxes from the three different soils, the Canterbury Lismore soil, the Southland Mataura soil, and the West Coast Harihari soil, under 1100 mm annual water inputs, are presented in Figures 1-3. Please note the differences in scales of the Y-axes for different soils.
- The highest daily flux so far was recorded in the Canterbury Lismore soil (1234 g N_2O-N/ha.day), followed by that in the Southland Mataura soil (1056 N_2O-N/ha.day), with the lowest recorded in the West Coast Harihari soil (442 N_2O-N/ha.day).
- In all three soils under 1100 mm annual water inputs, the nitrification inhibitor was effective in reducing the daily N_2O flux from the urine treated lysimeters.
- There were some small variations in the reduction of daily N_2O emissions by DCD in the three different soils, but it is too early to draw conclusions as to whether these variations are statistically significant.
- Total N_2O emissions and total reductions by DCD cannot be calculated, at this stage, because the emissions envelopes have not been completed.
- N_2O emissions from the Control lysimeters (no urine applied) were very low, confirming that most of the N_2O from grazed pastures is derived from animal excreta, particularly animal urine.

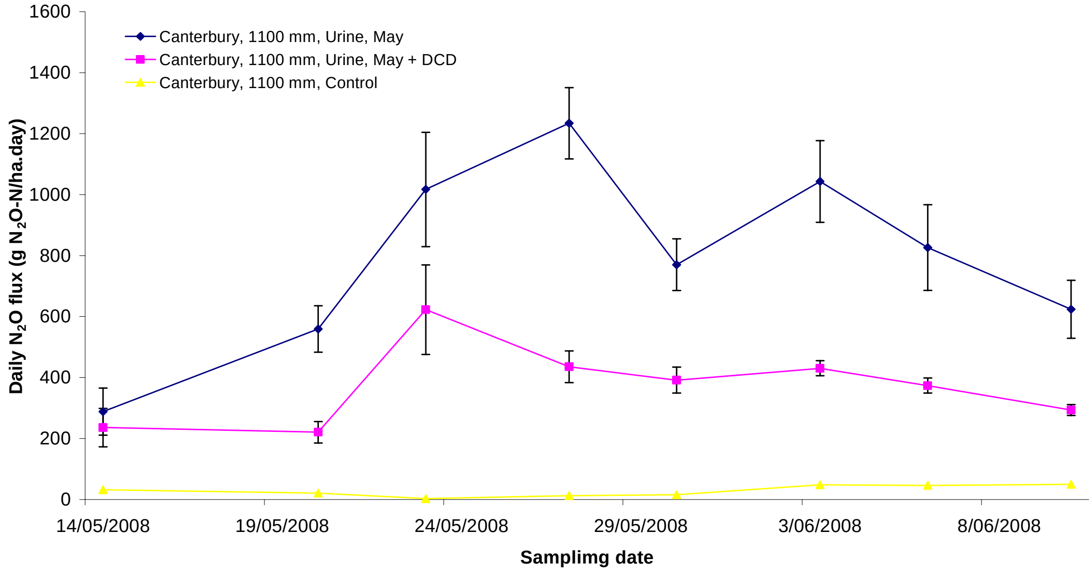

Figure 1. Daily N_2O flux from the Canterbury Lismore soil under 1100 mm annual water inputs (Error bars are ± standard errors of the mean).

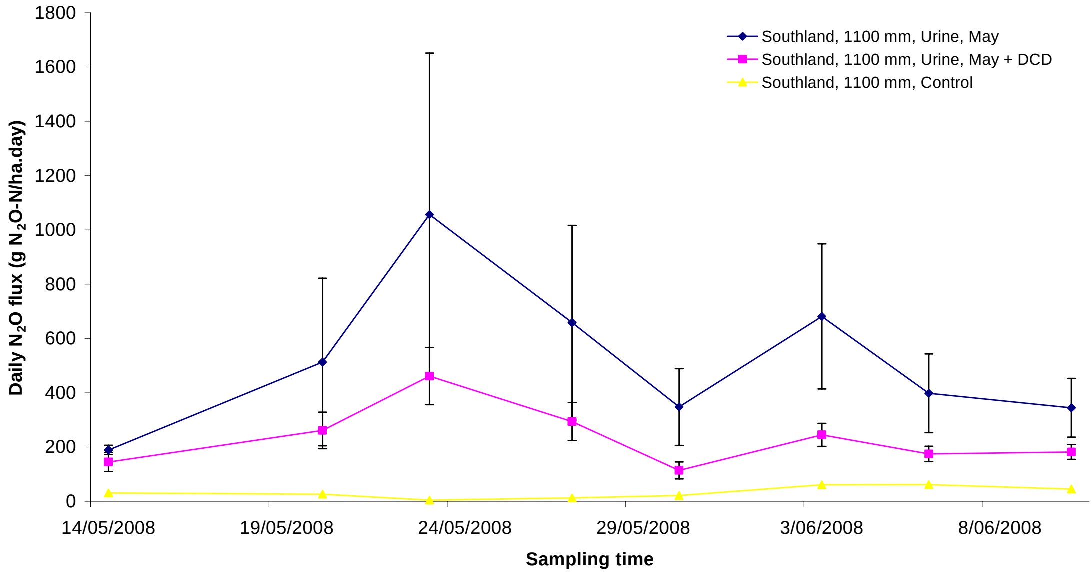

Figure 2. Daily N_2O flux from the Southland Mataura soil under 1100 mm annual water inputs (Error bars are ± standard errors of the mean).

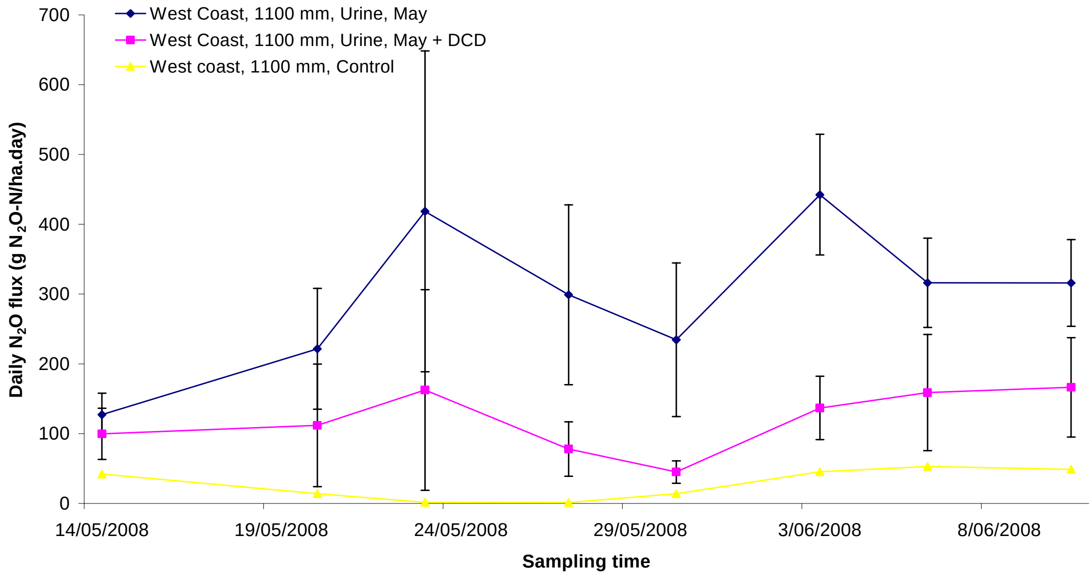

Figure 3. Daily N_2O flux from the West Coast Harihari soil under 1100 mm annual water inputs (Error bars are ± standard errors of the mean).

Rainfall of 2,200 mm

- Daily N_2O fluxes from the three different soils under 2200 mm annual water inputs are presented in Figures 4-6.
- Daily N_2O emissions under this higher water input regime were higher for the Canterbury Lismore soil (2223 g N_2O-N/ha.day), but slightly lower for the Southland Mataura soil (706 g N_2O-N/ha.day) and West Coast Harihari soil (211 g N_2O-N/ha.day) compared with those under 1100 mm water inputs.
- The nitrification inhibitor DCD was also effective in all three soils in reducing N_2O emissions from cow urine-N under this higher water input conditions.
- There were also some variations in the reductions of daily N_2O emissions by DCD in the three different soils, but it is too early to conclude whether these differences are statistically significant.
- Total N_2O emissions and reductions due to DCD cannot be calculated, at this stage, due to incomplete N_2O emissions envelopes.
- N_2O emissions from the Controls (no urine applied) were also very low compared with those from the urine treatments.

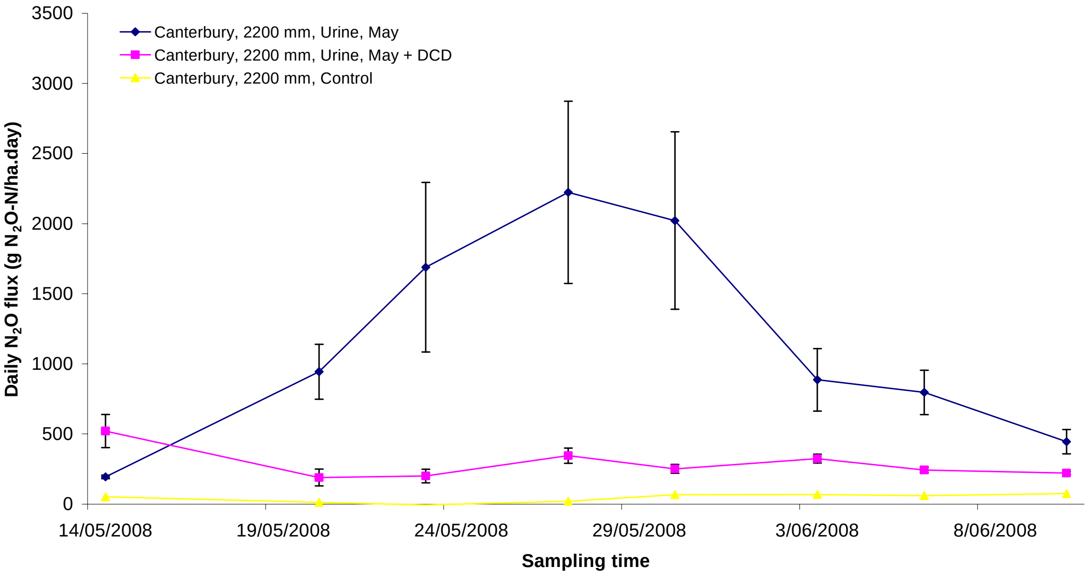

Figure 4. Daily N_2O flux from the Canterbury Lismore soil under 2200 mm annual water inputs (Error bars are ± standard errors of the mean).

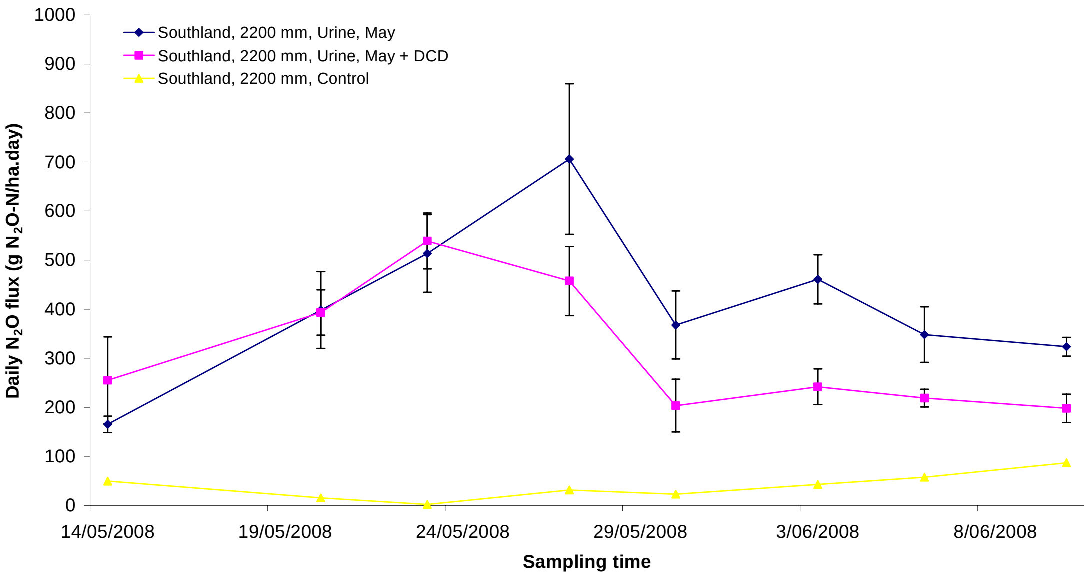

Figure 5. Daily N_2O flux from the Southland Mataura soil under 2200 mm annual water inputs (Error bars are ± standard errors of the mean).

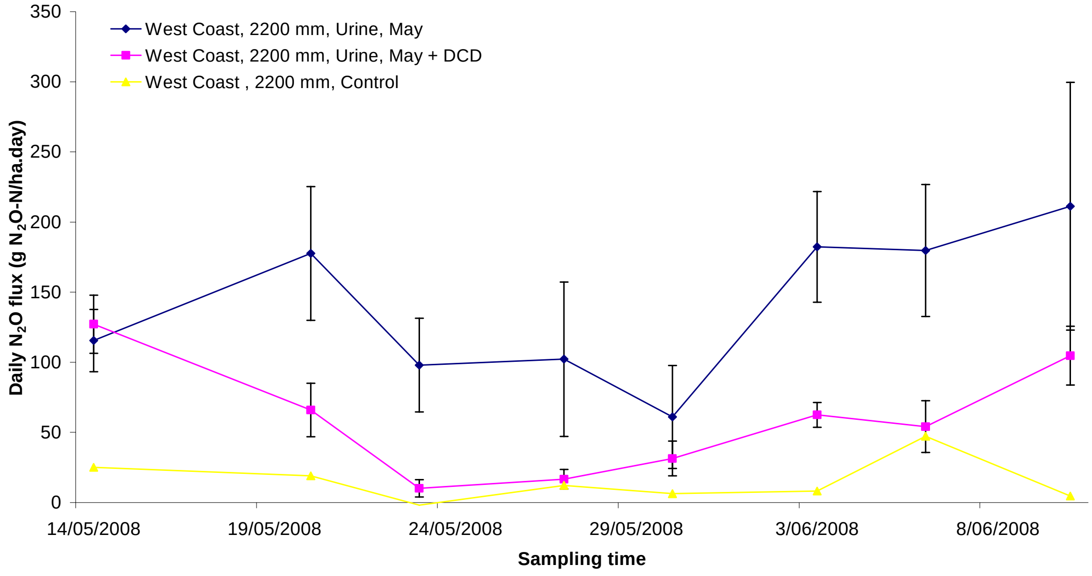

Figure 6. Daily N_2O flux from the West Coast Harihari soil under 2200 mm annual water inputs (Error bars are ± standard errors of the mean).

5.2 Daily N_2O fluxes from soils studied at the Ruakura site (15 May and 27 May 2008)

- Figs. 7-12 show daily N_2O fluxes for the various treatments on the 3 soils at the Ruakura study site. At the time of preparing this report, results were available for measurements made from 15 May to 27 May 2008 (12 days) for these three soils. Please note the differences in scales of the Y-axes for different soils.
- The N_2O fluxes from the Horotiu control treatments (no urine and DCD) remained low over the sampling periods.
- Dairy cow urine application sharply increased N_2O fluxes on all the soils, peaking within a couple of days.
- The magnitude of the N_2O fluxes varied between soils. The N_2O fluxes from application of urine were lower from the Waikato Horotiu sandy loam soil than from the Northland Waikare clay and Rotorua Oropi sand soils at most sampling times.
- It appears that the DCD application started to have an effect on N_2O emissions, with lower N_2O fluxes from the soils treated with DCD than those from the soils without DCD on some sampling days.
- It appears that the higher rainfall might have reduced the effect of DCD on reduction of N_2O emissions. This needs to be verified by taking more measurements.
- Measurements are being continued and effectiveness of DCD on N_2O emissions will be determined.

Rainfall of 1,100 mm

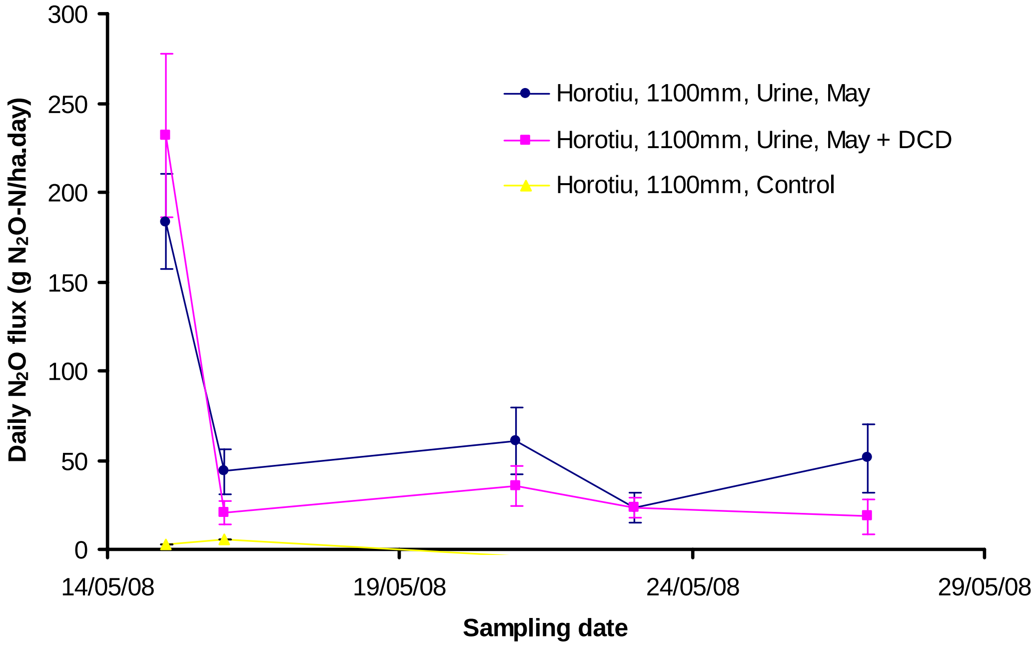

Figure 7. Daily N_2O flux from the Horotiu sandy loam soil under 1100mm annual water input (Error bars are ± standard errors of the mean).

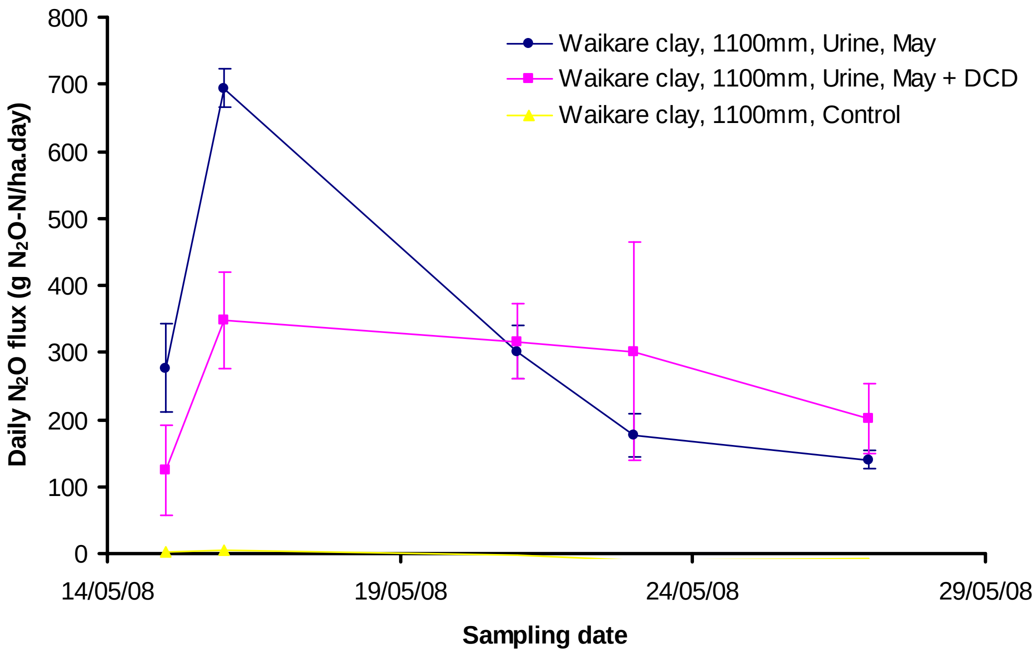

Figure 8. Daily N_2O flux from the Waikare clay soil under 1100 mm annual water input (Error bars are ± standard errors of the mean).

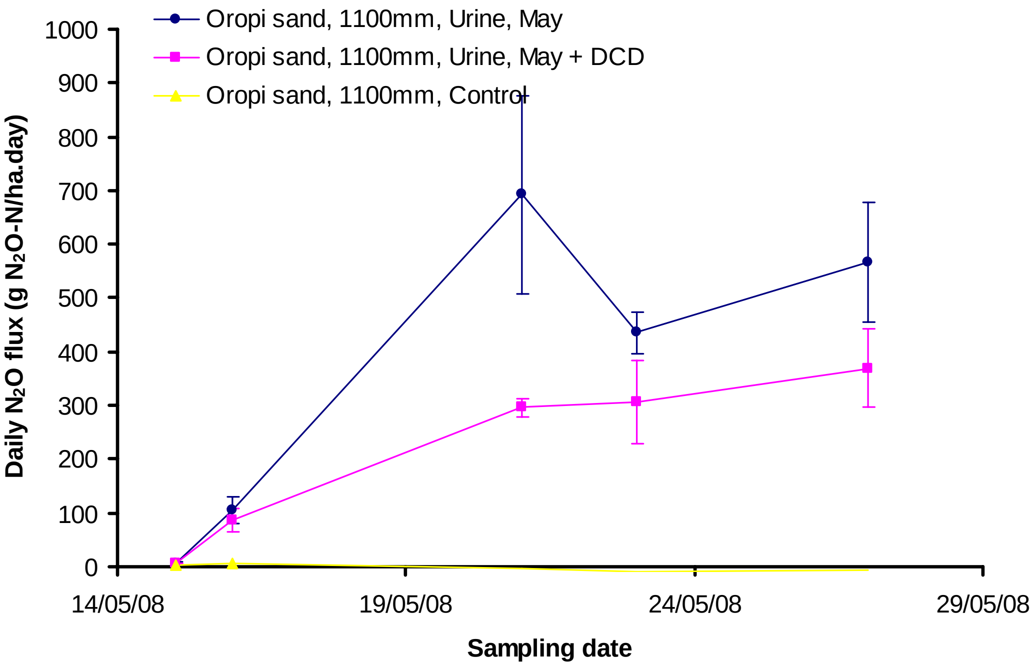

Figure 9. Daily N_2O flux from the Oropi sand soil under 1100 mm annual water input (Error bars are ± standard errors of the mean).

Rainfall of 2,200 mm

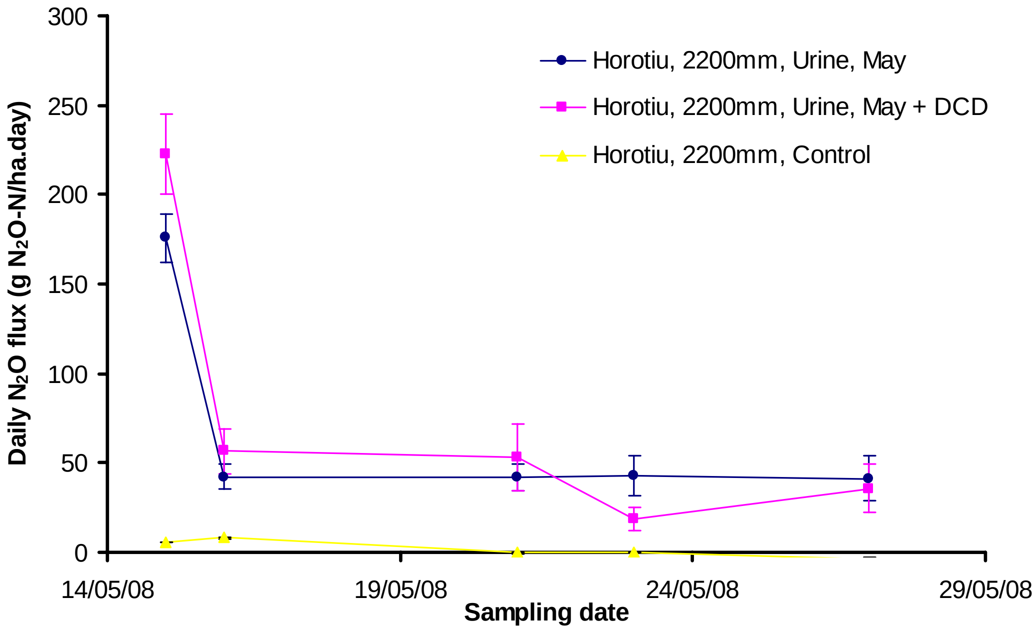

Figure 10. Daily N_2O flux from the Horotiu sandy loam soil under 2200 mm annual water input (Error bars are ± standard errors of the mean).

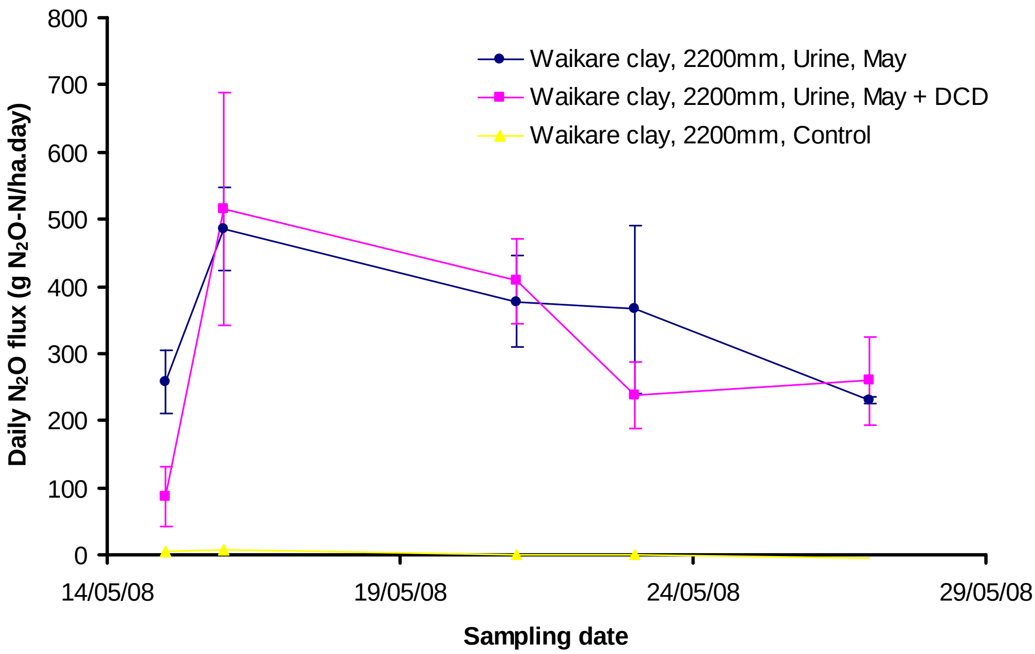

Figure 11. Daily N_2O flux from the Waikare clay soil under 2200 mm annual water input (Error bars are ± standard errors of the mean).

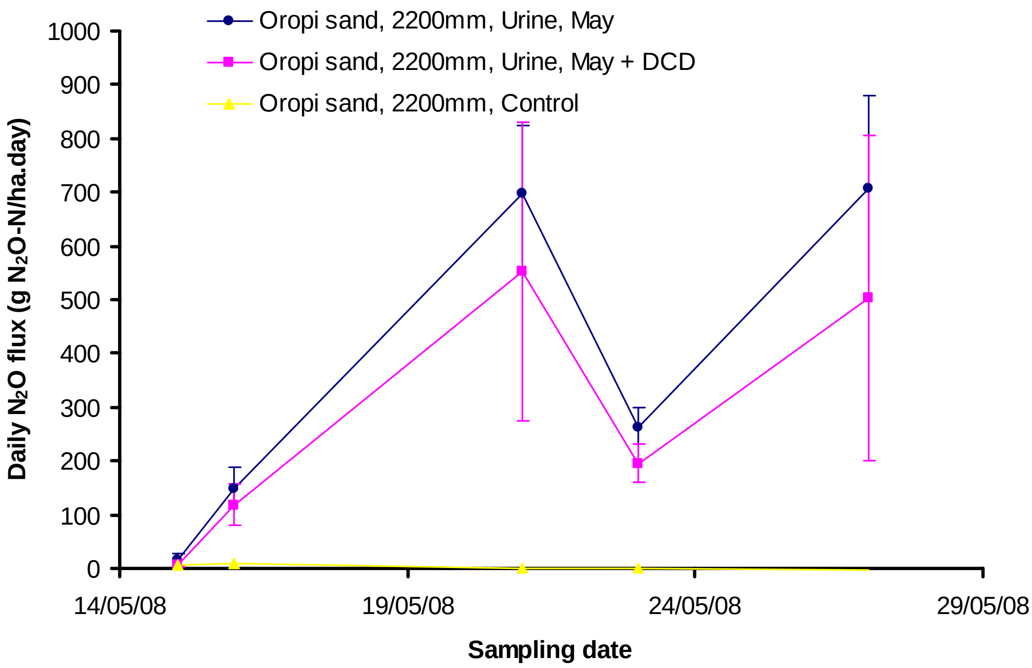

Figure 12. Daily N_2O flux from the Oropi sand soil under 2200 mm annual water input (Error bars are ± standard errors of the mean).

6. Conclusions

- DCD was found to be effective in reducing N_2O emission fluxes from all 6 soils studied.
- There were some small variations in the reduction of daily N_2O emissions by DCD in the different soils, but it is too early to draw conclusions as to whether these variations are statistically significant.
- Measurements need to be continued for a longer time period to be able to calculate the emissions reduction percentage for each soil at each of the two rainfall regimes.
- There appear to be some differences in emission patterns between the Lincoln and the Ruakura sites. Although the relative small number of samples collected at the time of reporting means that no conclusive reasons can be given for these differences, they are probably the effect of interactions between in rainfall patterns at each site and soil type.
- For example, the low emissions from the very freely draining Horotiu soil could be due to the rapid movement of NO_3 (and indeed DCD) down the profile following rainfall events. The low N_2O emission rates reported here are consistent with results from previous N_2O studies on this soil type.

- The results of leaching measurements from the lysimeters, currently being conducted under the P21 Environment programme, are likely to provide further insights into the reasons for any observed differences in N_2O emissions between soils and sites. However, these leaching results are not yet available.
- More definitive trends and conclusions will be reported in the final report when the N_2O emissions envelopes are completed and the leaching data are available.