

Reducing nitrous oxide emissions from grazed winter forage crops

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Abstract

Wintering cows on forage crops leads to urine being excreted onto wet, compacted soils. This is likely to result in significant gaseous emissions of nitrous oxide (N_2O), which may be reduced through strategic applications of nitrification inhibitors. A study was established on a winter swede crop to (i) determine N_2O emissions from compacted soil treated with cattle urine, and (ii) quantify the effectiveness of a nitrification inhibitor, dicyandiamide (DCD), in reducing these emissions. Nitrous oxide emissions from the urine + compacted soil were significantly greater ($P < 0.001$) than from compacted soil without urine, with 3.2% of the urine-N being lost as N_2O . DCD application significantly reduced this loss ($P < 0.05$) to 0.8% of the applied urine-N. Expressed at a paddock scale, total N_2O emissions from the winter-grazed swede crop were 7.9 kg N ha^{-1} , which was reduced to 3.4 kg N ha^{-1} when DCD was applied.

Keywords: urine, dicyandiamide, nitrification inhibitor, soil compaction, nitrous oxide.

Introduction

Dairy farmers are under increasing pressure to alter their winter management practices to reduce associated environmental impacts. Winter grazing of brassica crops such as swedes and kale during high soil moisture conditions results in increased soil compaction, which reduces the volume of macro-pores (Houlbrooke *et al.* 2009). Under these anaerobic conditions, urine deposition could lead to relatively high emissions of nitrous oxide (N_2O), a potent greenhouse gas with a global warming potential *ca.* 300 times that of carbon dioxide over a 100-year time frame. Indeed, under pasture, compaction of soil can lead to a three-fold increase in denitrification-induced N_2O emissions compared to non-compacted soils (Menneer *et al.* 2005; Bhandral *et al.* 2007). Previous research has shown that nitrification inhibitors such as dicyandiamide (DCD) directly applied to grazed pasture reduce N_2O emissions from urine patches (Di *et al.* 2007). However, little is known about their effectiveness within a winter-grazed forage system, although one study on a Southland kale crop showed N_2O emissions from an artificial urine solution were reduced by 25% with DCD application

(Smith *et al.* 2008). The objectives of this study were to (i) determine N_2O emissions from a urine-affected winter “grazed” swede crop, and (ii) quantify the effectiveness of DCD in reducing these emissions.

Methods

Soil and site description.

The study was conducted on a poorly-drained Te Houka silt loam soil (Fragic perch-gley Pallic soil; Hewitt 2010) supporting a winter crop of swedes (*Brassica napus*; approx. 14 t DM/ha) in South Otago. Mean annual rainfall was 679 mm, while mean annual air temperature was 10.4°C . An enclosure within the swede paddock ($35 \times 20 \text{ m}$) was established to ensure cattle did not disturb the study site. Two trials were established to determine N_2O emissions from simulated urine patches deposited onto compacted soil. Trial 1 commenced on 15 June 2011 and included additional treatments to determine the effectiveness of DCD in reducing N_2O emissions. Trial 2 commenced on 20 July. Immediately prior to the start of each trial, all swedes inside the enclosed area were removed with minimal soil disturbance.

Treatments

Trial 1 included five treatments: (i) “non-compacted” soil, (ii) “compacted” soil, (iii) “compacted + DCD”, (iv) “compacted + urine” and (v) “compacted + urine + DCD”. A randomised block design was used, with six replicate plots ($1 \times 2 \text{ m}$) for each treatment. Trial 2 included only three of these treatments: (i) “non-compacted” soil, (ii) “compacted” soil, (iii) “compacted + urine”. Each treatment was again replicated six times, apart from the “non-compacted” treatment (three reps) and the treatments were not blocked as data analysis from the earlier trial suggested no benefit from blocking. “Compacted” treatments simulated pugging – technical staff used short (*ca.* 10 cm long) wooden blocks strapped to work boots to repeatedly apply a downward force to the soil. The footprint area of each block was based on bodyweight in order to apply a pressure of *ca.* 300 kPa. Care was taken to ensure the same level of compaction per area was applied to all “compacted” plots. Static chamber bases (250 mm internal diameter) were inserted into the gas sampling plots following compaction treatments and left for

one day before urine was applied. Soil sampling plots (1 m²) were established adjacent to the gas sampling plots, where an artificial urine solution was used to represent cow urine due to the challenges associated with collecting sufficient real cow urine.

Dairy cow urine for the gas sampling plots was collected for trials 1 and 2 on 21 June and 25 July, respectively, from cows grazing the swede crop. This had an N content of 1.90 and 0.85 g N/L, respectively. The N content of urine collected in the second sampling was increased using urea to match the concentration measured in the first sampling. Urine was applied at a rate of 10 L/m², resulting in an application rate of 190 kg N/ha. An artificial urine solution with the equivalent N concentration was applied to the soil sampling plots. The nitrification inhibitor DCD was applied as a fine spray at a rate of 10 kg DCD/ha within 2 hours of urine application in trial 1.

N₂O measurements

N₂O emissions were measured using the standard closed chamber technique (de Klein *et al.* 2003). The emissions were integrated over 130 and 96 days for trials 1 and 2, respectively, to estimate total emissions over the measurement period, which ceased at the end of October when the paddock was to be cultivated. Emission factors were then calculated using equation 1:

$$EF_3 = \frac{\text{Urine } N_2O - \text{Control } N_2O}{\text{Urine N applied}} \times 100 \quad (1)$$

where EF_3 is an emission factor (N₂O-N emitted as a percentage of urine-N applied), Urine N₂O and Control N₂O are the cumulative N₂O emissions from urine-treated and control plots, respectively (kg N ha⁻¹), and Urine N applied is in units of kg N ha⁻¹. EF_3 values were calculated for trial 1 on an individual block basis. In trial 2, where blocking was not employed, the average cumulative emission for non-urine treated plots was used.

Estimates of N₂O emissions at a paddock scale used assumptions for N and water excretion by the herd of 83 cows, which grazed the 2.8 ha swede crop over a 52-day period (crop allowance of 6.6 m²/cow/day). Based on cow feed intake data and changes in body condition score (D. Stevens, unpubl. data), and allowing for N retention for foetus development, N excretion was calculated as 129 g urine-N/cow/day and 95 g dung-N/cow/day. A water balance calculation suggested that each cow excreted, on average, 72 L water/day, of which 60 L was urine (the remainder in dung). Assuming no urine patch overlap, this translated to *ca.* 90% of the paddock surface being affected by urine patches. An emission factor of 0.25% was assumed to account for N₂O emissions from dung excretion to the paddock (Ministry for the Environment 2012)

Soil parameters

Soil physical measurements (bulk density, macroporosity (>30 µm diameter) and total porosity) were measured in non-compacted and compacted plots at the end of the trial. Soil mineral N and moisture contents were determined from samples collected from the 0–75 mm depth regularly throughout each trial. Six soil cores (25 mm diameter × 75 mm depth) were collected and thoroughly mixed before a subsample was extracted with 2M KCl solution (15 g wet soil: 100 g KCl) for 1 hour. Samples were filtered using GF/A glass-fibre filter papers (110 mm) and frozen until mineral N was analysed. Soil moisture content was determined by drying soil at 105°C for 24 hours, with water filled pore space (WFPS, %) calculated using bulk density data.

Results were statistically analysed by ANOVA (Genstat 13), where cumulative N₂O emissions required a log transformation to determine differences between treatments.

Results

Changes in soil moisture contents, soil mineral N levels and soil structure

A total of 156 mm of rain fell during the 4-month experimental period (Fig. 1), with soil temperature (5 cm depth) averaging 6°C (range of 2–15°C). With low evapo-transpiration rates over the winter months, soil moisture levels were correspondingly high in both trials, with WFPS averaging 80–100% for the first 2–3 months (Fig. 1), before declining to *ca.* 50% in October, due to good drying conditions (less rainfall, increasing temperatures). Compacted soils had a significantly higher ($P < 0.01$) WFPS than non-compacted soils in both trials. The WFPS of compacted soils in trial 1 was often above 100% due to surface ponding. A similar result was observed by de Klein *et al.* (2006). In our study, we have limited WFPS to the theoretical maximum of 100% (Fig. 1). Bulk density for the non-compacted soil was 1.00 g/cm³ in the 0–5 cm layer and increased to 1.22 g/cm³ in the 5–10 cm depth (Table 1). The simulated compaction significantly ($P < 0.01$) increased bulk density and reduced macroporosity in the 0–5 cm layer but had no effect on the 5–10 cm depth.

In trial 1, soil mineral N was only measured from the three non-urine treatments due to a laboratory error when making the artificial urine solution that was applied to the soil sampling plots. Soil ammonium-N (NH₄⁺-N) and nitrate-N (NO₃⁻-N) content in the “compacted”, “compacted + DCD” and “non-compacted” soils was low (≤ 20 kg N/ha) throughout the trial (Fig. 2a and 2b). Soil mineral N contents were determined for all three treatments during trial 2. Soil NH₄⁺-N content increased rapidly 4 days following urine application, slowly

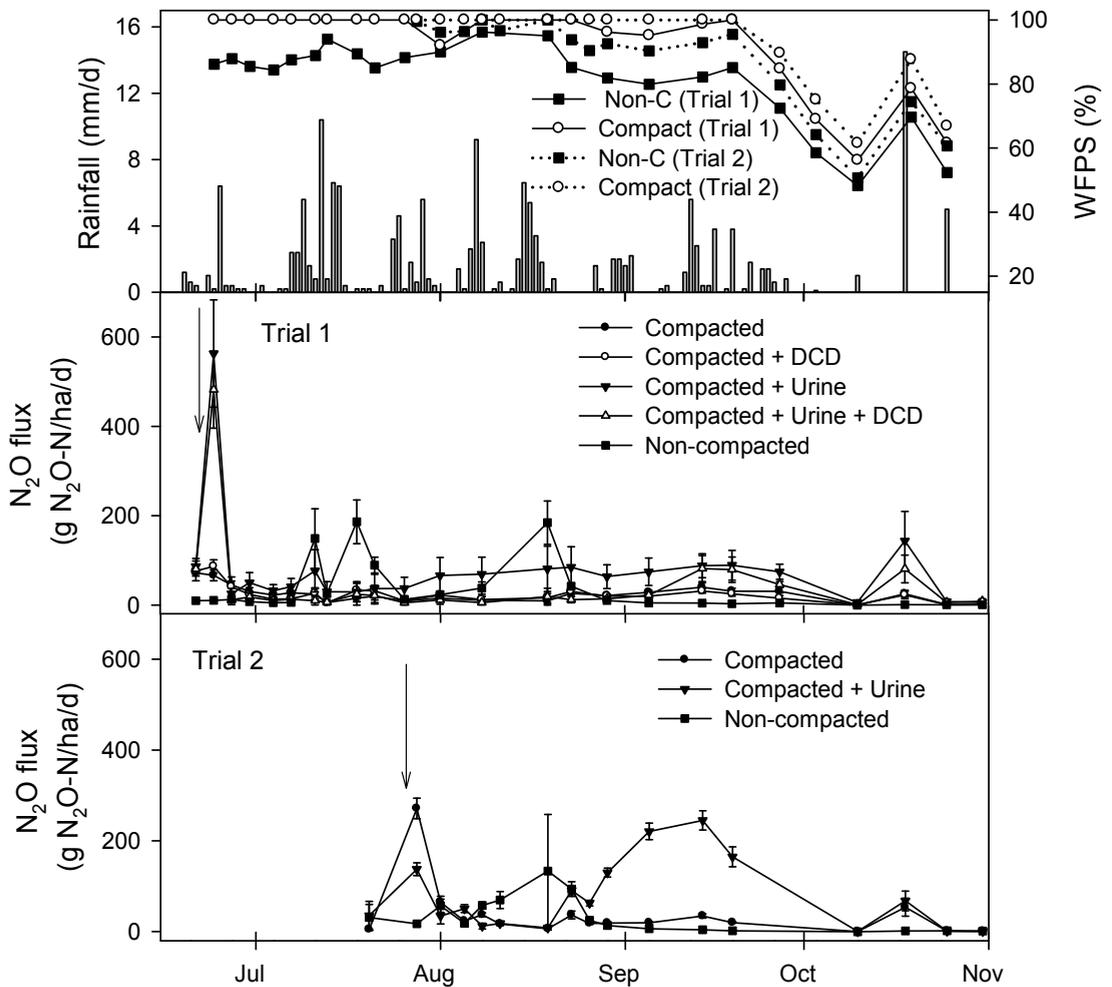


Figure 1. Rainfall (mm/day), water-filled pore space (WFPS) (%) and N₂O fluxes (g N₂O-N/ha/day) measured during trial 1 and 2 in the winter and spring months of 2011. For WFPS, ‘Non-C’ refers to non-compacted soil. ↓ indicates time of application of compaction and urine treatments. Error bars = ± SEM.

returning to background levels within 2 months (Fig. 2c). Soil NO₃-N levels increased in the urine treated soils three weeks following application, remaining high until the trial ceased when the paddock was to be cultivated (end of October: Fig. 2d). In contrast, NH₄⁺-N and NO₃-N levels in the “compacted” and “non-compacted” treatments were consistently low throughout trial 2 (Fig. 2c and 2d).

Nitrous oxide fluxes

In trial 1, N₂O fluxes were greatest from the “compacted + urine” and “compacted + urine + DCD” treatments immediately after urine application (563 and 482 g N₂O-N/ha/day, respectively: Fig. 1). Thereafter, fluxes declined, with the “compacted + urine” remaining stable at between 40–70 g N₂O-N/ha/day for ca. 4

months; the addition of DCD ensured fluxes were close to zero for ca. 2½ months before a small increase was observed. The “non-compacted” treatment exhibited periods of high flux activity throughout the trial, at times being greater than the fluxes measured from all other treatments. Fluxes from all five treatments declined to low levels by the end of the trial. Trial 2, initiated on 20 July, also showed a spike in N₂O fluxes from the “compacted” and “compacted + urine” treatments immediately following treatments being imposed (Fig. 2). Approximately 1 month later, N₂O fluxes from the “compacted + urine” treatment were elevated for 1 month before returning to low levels. As for trial 1, the non-compacted treatment produced N₂O fluxes that were, at times, greater than from the “compacted” treatment.

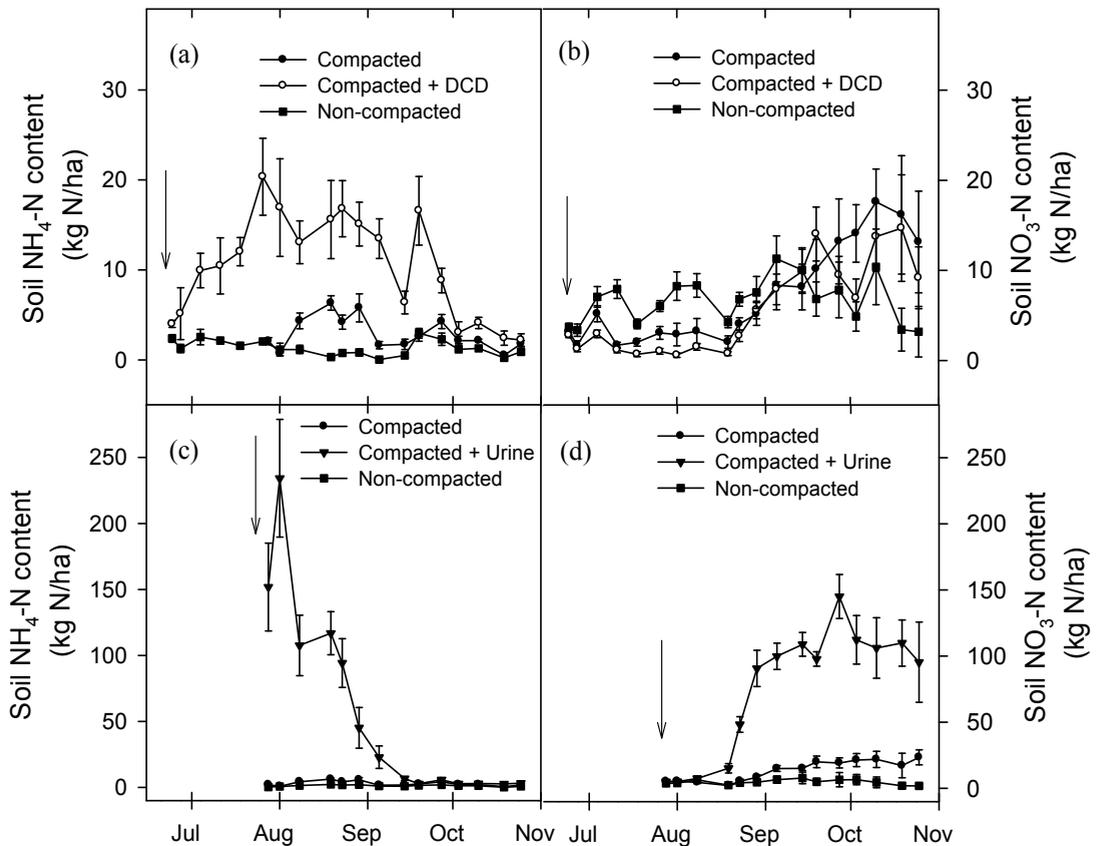


Figure 2. Soil mineral N concentrations following simulated winter grazing of a forage swede crop. Fig. 2a-b = Trial 1; Fig. 2c-d = Trial 2. ↓ indicates time of application of compaction and urine treatments. Note the different Y-axis scales used for Trials 1 and 2. Error bars = \pm SEM.

Cumulative N_2O losses for the “compacted + urine” treatment in both trials 1 and 2 were significantly greater than all other treatments ($P < 0.001$; Table 2). In trial 1, cumulative losses from the non-compacted soil were significantly greater than from compacted soil ($P < 0.05$), while cumulative losses from these two treatments were similar in trial 2.

The application of DCD significantly reduced N_2O

losses from the “compacted + urine” treatment by 50% in trial 1, whereas it had no effect on the “compacted” treatment (Table 2). The N_2O emission factors for the deposited urine in trials 1 and 2 were not significantly different ($P = 0.76$), at 3.0 and 3.3% of the applied N, respectively, averaging 3.2% across both trials. DCD application significantly reduced EF_3 to 0.9% ($P=0.03$), equivalent to a 71% reduction in N_2O emission from

Table 1. Physical data for soil pre- and post-compaction (mean \pm SEM; n=6).

| Treatment | Depth (cm) | Bulk density (g/cm ³) | Macroporosity (%) | Total porosity (%) |
|--|------------|-----------------------------------|-------------------|--------------------|
| Non-compacted | 0-5 | 1.00 (0.01) | 16.5 (0.6) | 62.3 (0.5) |
| Non-compacted | 5-10 | 1.22 (0.03) | 11.9 (1.2) | 54.1 (1.3) |
| Compacted | 0-5 | 1.12 (0.02) | 8.8 (0.2) | 57.7 (0.7) |
| Compacted | 5-10 | 1.21 (0.02) | 12.9 (0.8) | 54.2 (0.7) |
| P-value for Non-compacted vs Compacted | | | | |
| 0-5 cm | | ** | ** | ** |
| 5-10 cm | | NS | NS | NS |

** $P < 0.01$; NS not significant

urine patches. At a paddock scale, the N_2O emission from the swede crop over a 52-day period was 7.9 kg $\text{N}_2\text{O-N/ha}^{-1}$, which was reduced by 57% when DCD was applied; this was equivalent to a reduction from 5.2 to 2.2 g $\text{N}_2\text{O-N/cow/day}$.

Discussion

High N_2O emission from the compacted, urine-treated soil was primarily due to urine being deposited onto wet soil. Urine supplies readily available N and causes the release of soil organic C by hydrolysing organic matter (Uchida *et al.* 2008), leading to increased N_2O production when oxygen diffusion is restricted (Bhandral *et al.* 2007). Smith *et al.* (2008) found that total N_2O losses from compacted plots with and without urine applied were equivalent to 7.7 and 2.2 kg N/ha, respectively. Ball *et al.* (2012) attributed a three-fold increase in N_2O emissions from urine-treated pasture following compaction (trampling) to increased WFPS, aggregate destruction and suppression of grass growth. Although this study and others (e.g. Houlbrooke *et al.* 2009) have also shown changes in soil physical condition due to simulated compaction and pugging where urine was excluded, we observed significantly greater N_2O emissions from the non-compacted soil in trial 1 and no difference in losses from non-compacted and compacted soil in trial 2. With WFPS often at 100%, the compaction treatment probably stimulated complete denitrification, thereby favouring N_2 production over N_2O production (Dalal *et al.* 2003).

The estimated paddock scale emission of N_2O from the winter forage crop was high, despite the urine N concentration being relatively low at 1.9 g N/L. Cattle urine N concentration is typically 6–7 g N/L when the cattle are grazing pasture (de Klein *et al.* 2003; Menneer *et al.* 2008). The high emissions observed here may be a consequence of urine deposition onto compacted, poorly

aerated soil that encourages denitrification (Menneer *et al.* 2005). The high grazing densities (6.6m² crop/cow/day) and high rates of urine deposition per unit area are also likely to increase paddock emissions. Smith *et al.* (2008) measured an N_2O emission of 2.7 kg N/ha from a winter forage crop over a 5-month period, which is less than a third than measured here. Whilst their urine-N application rate was higher (387 kg N/ha), their calculated EF_3 value was only 1.41% and it was assumed only 25% of the surface area was affected by urine, which was primarily due to a lower urine volume of 20 L/cow/day compared to 60 L/cow/day in the current study. Nitrous oxide losses measured from an autumn-winter grazed Southland pasture were even lower, at between 0.4 and 1.9 kg $\text{N}_2\text{O-N/ha}$ over three years (de Klein *et al.* 2006), perhaps due to the presence of pasture utilising some of the surplus urinary N.

A single application of DCD within 1 day of grazing was effective at reducing N_2O emissions from the “grazed” winter forage crop, due mainly to its impact on urine patches. In their study of a winter forage crop, Smith *et al.* (2008) found that DCD reduced N_2O emissions per hectare by only 25%, compared to the 57% calculated here. The difference in calculated effectiveness between these two studies primarily relates to the assumed paddock area affected by urine (25 vs. 90% for their and our studies, respectively). While our reduction in N_2O emissions is based on experimental data where DCD was applied to a single urine patch and assumes no overlap of urine patches, DCD is likely to be as effective on areas where 2 or even 3 patches overlap, as Di *et al.* (2007) have shown that emissions can be reduced by 70% from urine applied at 1000 kg N/ha, which is five times the urine-N rate used in the current study.

In conclusion, while urine-affected, compacted winter forage soils can result in relatively large N_2O

Table 2. Cumulative nitrous oxide emissions (kg N/ha) from individual treatments, measured over 129 days (trial 1) and 95 days (trial 2), and associated emission factors (EF_3) for urine (\pm DCD) treatments. Also shown is the mean EF_3 value, calculated from the Compacted + Urine treatment, using results from both trials.

| Treatment | Trial 1 | | Trial 2 | | Mean |
|--------------------------|---------------------------|-------------------|---------------------------|-------------------|-------------------|
| | Cumulative loss (kg N/ha) | EF_3 (%) | Cumulative loss (kg N/ha) | EF_3 (%) | EF_3 (%) |
| Non-compacted | 4.04 | | 2.16 | | |
| Compacted | 2.49 | | 2.53 | | |
| Compaction + DCD | 2.42 | | | | |
| Compaction + Urine | 8.23 | 3.0 | 8.94 | 3.3 | 3.2 |
| Compaction + Urine + DCD | 4.08 | 0.9 | | | |
| sed | 0.24 | 0.7 | 0.72 | | |
| P-value | P < 0.001 | P = 0.03 | P < 0.001 | | |

losses, strategic use of DCD provides farmers with a management option for making significant reductions. Further research should examine timing and rate of DCD application, as this will influence its effectiveness on grazed winter forage crops.

ACKNOWLEDGEMENTS

David Stevens for providing estimates of N outputs from cattle and Neil Cox for statistical analysis. Funding was provided through a SFF project, jointly funded by the Ministry for Primary Industries (formerly MAF) and DairyNZ.

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