The effect of DCD on nitrogen losses from sheep urine patches applied to lysimeters in autumn

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Abstract

The intensification of modern pastoral agriculture has increased the risk of environmental degradation. The use of nitrification inhibitor technology has been shown to reduce nitrate (NO_3^-) leaching losses and nitrous oxide (N_2O) emissions from New Zealand dairy pasture systems. However, published data on inhibitor usage to reduce these losses from intensive sheep winter grazing systems is also needed. A trial was conducted at Lincoln University using lysimeters in a Templeton silt loam soil. Four treatments (control, control + DCD, urine, urine + DCD) were applied in May 2009, with urine applied in patches at an N loading rate of 300 kg/ha with dicyandiamide (DCD) at 10 kg/ha. Water (simulating rainfall) was applied in spring to supplement natural rainfall. Nitrous oxide gas sampling and leachate collections were made for 4 months. Application of DCD reduced the N_2O emissions by up to 72% (4.55 kg N_2O-N/ha without DCD to 1.32 kg N_2O-N/ha with DCD) from late autumn applied sheep urine and also reduced the amount of NO_3^--N leached by up to 70% (147 kg NO_3^--N/ha to 44 kg NO_3^--N/ha). These results indicate that the use of DCD may be a useful technology to mitigate N losses from sheep break-fed pasture over winter. The need for further research in this area is discussed.

Keywords: nitrate leaching, nitrous oxide, nitrification inhibitor

Introduction

Leaching of nitrogen (N) from agricultural systems has been linked to increasing nitrate (NO_3^-) concentrations in ground and surface waterways globally (Di & Cameron 2002a). This has become a major environmental issue in the agricultural sector, and one that needs to be addressed. The impacts of NO_3^- leaching from soils into ground water and mitigation are clear (Ledgard *et al.* 2000; Di & Cameron 2003; Monaghan *et al.* 2007), with cow urine identified as a major source of NO_3^--N leaching losses from dairy grazed pasture systems. Significant reductions in NO_3^--N leaching losses and N_2O emissions of 60-70% and 80%, respectively, have been observed with the use of the nitrification inhibitor dicyandiamide (DCD) in dairy cow urine studies (Di & Cameron 2002a; 2004a,b; 2005; 2006). One study (Hoogendoorn *et al.* 2008) has reported similar reductions in N_2O emissions from sheep urine patches using DCD.

On sheep farms in Southland and Canterbury, livestock are typically stocked at low stocking rates of 10-14 standard stock units (s.s.u.)/ha between late spring and early autumn. At these stocking rates, leaching is unlikely to be a major problem. However, when sheep are 'break-fed' on pasture over winter, the stocking rate is markedly increased in the small area being grazed (often ≈ 2 000 s.s.u./ha), potentially leading to increased NO_3^- leaching loss and N_2O gas emissions. The objective of this study was to assess the potential effect of using a nitrification inhibitor (DCD) to reduce NO_3^- leaching losses and N_2O emissions from intensively grazed 'break-fed' pastoral sheep systems during winter and spring.

Methods

Lysimeter collection

Sixteen intact soil lysimeters (300 mm deep x 200 mm diameter) were collected from a long-term pasture (perennial ryegrass and white clover) soil (Templeton silt loam) on a Lincoln University sheep farm (see Di & Cameron (2004a) for methodology). The site was last grazed 3-4 months before sampling of the lysimeters. Soil fertility levels were pH 6.0 and Olsen P 23 µg P/mL. Stainless steel collars were attached to the top of each lysimeter to provide an annular water trough to assist with gas collection (Di & Cameron 2003). The lysimeters were then installed in a field trench facility, with leachate from the drainage tubes flowing to leachate collection containers below.

Experimental design and treatment application

Four treatments, each with four replicates, were allocated to the lysimeters in a randomised design: (i) control (no urine); (ii) control + DCD (10 kg/ha); (iii) urine (300 kg N/ha); and (iv) urine (300 kg N/ha) + DCD (10 kg/ha). The N application rate of 300 kg/ha was equivalent to a typical N loading rate under a sheep urine patch (Haynes & Williams 1993).

Before urine and DCD application, the pasture was cut to a residual of 500 kg DM/ha and lightly 'trampled' using a hoof-shaped tool simulating grazing by sheep. Two litres of urine collected from sheep in crates in mid-May 2009 was standardised (diluted from 15 g N/L using water) to a 'typical' N concentration for sheep urine (9 g N/L; Haynes & Williams (1993)). This urine was applied to eight lysimeters at the equivalent of 300 kg N/ha (Di & Cameron 2007) on the 19 May 2009.

The nitrification inhibitor DCD (fine particle suspension; FPS) application (10 kg a.i./ha) was applied 1 h later using an FPS sprayer, simulating on-farm application by a commercial spray contractor (Moir *et al.* 2007). Once the treatments had been applied, 10 mm of water (simulating rainfall) was applied to each lysimeter to wash the DCD into the soil as per recommendations (Di & Cameron 2007). Total water inputs to the lysimeters (rainfall and simulated rainfall) were 470 mm for the experimental period. Water inputs represented mean rainfall for winter in Southland or a wetter than average winter in Canterbury.

Measurements and data analysis

Gas samples were taken between 1 and 2 pm twice weekly for the first month and then once per week for the next 3 months (i.e. until background emission levels were reached). Gas samples were collected at 0, 20 and 40 minute intervals using a syringe to transfer the gas into glass vials. The concentration of N_2O in each gas sample was determined by gas chromatograph (Clough *et al.* 2007). Drainage water was collected from the base of each lysimeter on a twice-weekly basis or whenever a high amount of rainfall caused 5 mm of drainage to occur. Flow injection analysis was used to determine the concentration of NO_3^- and ammonium (NH_4^+) in the leachate (Cameron *et al.* 2007). The data sets were statistically analysed to test for treatment effects by conducting an analysis of variance (ANOVA) using Genstat 11. The NO_3^--N concentration interaction with cumulative drainage were statistically analysed using repeated measures analysis REML.

Results

N_2O gas emissions

The total amount of N_2O emitted during the trial period (late May to early October) from the sheep urine treatment was 4.55 kg N_2O-N/ha and this was significantly reduced ($P<0.01$; LSD=2.32) to 1.32 kg N_2O-N/ha with the application of DCD. This was equivalent to a 72% reduction in N_2O loss (Fig. 1). The total N_2O emissions from the control and control + DCD treatments over the trial duration were low, ranging from 0.24 to 0.28 kg N_2O-N/ha, and did not significantly differ from each other or the urine + DCD treatment (Fig. 1). The total emission factor (EF_3) from the sheep urine application was reduced from 1.44% without DCD to 0.35% using DCD.

Figure 1 Average total N_2O gas losses (kg N_2O-N/ha) from all lysimeter treatments. Vertical bars indicate standard errors of the mean. Letters above bars indicate significant differences based on LSD at P<0.05.

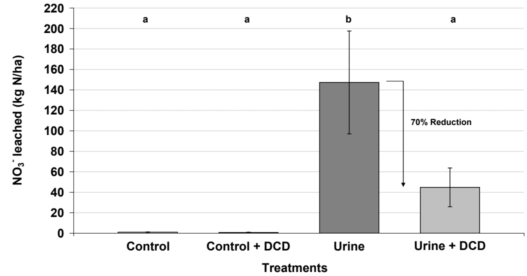
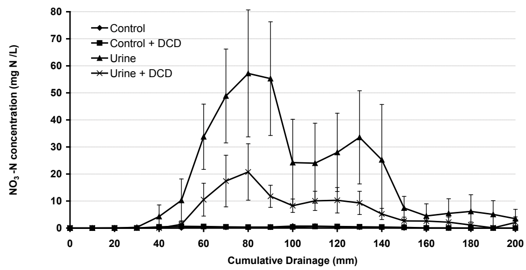


Figure 2 NO_3^--N concentrations (± SEM) in the drainage water from lysimeters as affected by urine and DCD treatments.

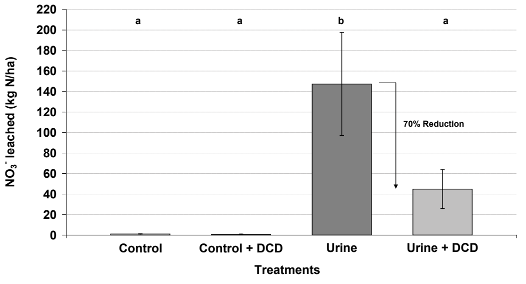


Nitrate leaching losses

Nitrate concentrations from the control and control + DCD treatments were low (<1 mg N/L) throughout the 4 month trial (Fig. 2). The application of 300 kg N/ha sheep urine enriched NO_3^--N concentrations in drainage water, peaking at a significantly ($P<0.001$; LSD=39.2) higher concentration than the other treatments at an average of 57.9 mg N/L when 80 mm of drainage had occurred. A second NO_3^--N concentration peak (33.5 mg N/L) occurred after 130 mm of drainage. When the DCD was applied at 10 kg/ha, the concentrations followed a similar trend, with peaks occurring at 80 and 120 mm cumulative drainage. However, these NO_3^--N concentration peaks at 20.7 mg N/L and 10.3 mg N/L were significantly ($P<0.001$) lower than for the urine alone treatment.

The total amount of NO_3^--N leached from the soil over the 4 month trial was small in the control (1.06 kg N/ha) and in the control + DCD treatment (0.71 kg N/ha) (Fig. 3). The application of 300 kg N/ha sheep urine to the lysimeter caused a significant increase ($P<0.01$; LSD=78.2) of 147.3 kg N/ha in total NO_3^--N leaching compared with the control. The application of DCD significantly reduced ($P<0.01$) this loss to 44.8 kg N/ha. This represents a 70% reduction in N leaching loss. The percentage of applied urine N (300 kg/ha) lost

Figure 3 Average total NO_3^--N leaching losses (kg N/ha) from all lysimeter treatments. Vertical bars indicate standard errors of the mean. Letters above bars indicate significant differences based on LSD at P<0.05.



through leaching without and with DCD averaged 49.1 and 15.0%, respectively.

Discussion

Nitrous oxide emissions

This study shows that treating soils with a nitrification inhibitor is an effective way of mitigating N_2O emissions from late autumn/early winter deposited sheep urine patches. DCD applied in May reduced N_2O emissions from sheep urine patch areas by 72%, similar to results reported for dairy cow urine (Di & Cameron 2005). Di *et al.* (2007) reported that the N_2O-N flux from 1000 kg N/ha cow urine peaked about 7 weeks after urine application in a study on a Templeton silt loam. This peak was greater (522 g N_2O-N/ha/day) than the average peak measured in this study (167 g N_2O-N/ha/day), probably due to the lower urine N loading in this study. Total emissions from urine was found to be 4.55 kg N_2O-N/ha and this was significantly reduced with DCD to 1.32 kg N_2O-N/ha. This 72% reduction is similar to those found in previous studies, for example a 73% reduction on Lismore soils with the application of 1000 kg N/ha (Di & Cameron, 2003).

Our N_2O results are similar to those of Hoogendorn *et al.* (2008). These workers reported sheep urine patch emission reductions of 40% at Invermay and 60-80% at Ballantrae where DCD was applied. Urine N loading and N concentration was identical to our study, although artificial urine was used. Also, treatments were applied in the spring in the study of Hoogendorn *et al*. (2008) (contrasting with early winter in our study), to low slope hill country. Total N_2O emissions from urine patches reported by Hoogendorn *et al.* (2008) were in the order of 0.1 to 0.78 kg N_2O-N/ha; lower than that seen in our study. The longer measurement period for our study (120 versus 31 to 56 days for Hoogendorn *et al.* 2008) explains this difference. Our study supports the findings of Hoogendorn *et al.* (2008), and further, demonstrates that DCD effectively reduces N_2O emissions from winter deposited sheep urine patches.

Nitrate leaching

Results from this study show that the treatment of the soil with 10 kg/ha of DCD was effective in reducing NO_3^--N leaching from sheep urine patches. The 70% reduction in the NO_3^--N leaching loss is similar to the 74% and 68% reductions in NO_3^--N leaching from the autumn application of 1000 kg N/ha in cow urine achieved by Di & Cameron (2004a; 2005).

Total NO_3^--N leaching losses from sheep urine without DCD (Fig. 3) were 1.7 times greater than losses from 1000 kg N/ha cow urine on the same soil type (Di & Cameron 2002b). Even though a lower N loading rate was applied, larger NO_3^--N leaching could have occurred due to the higher rainfall inputs in our study. Our lysimeters were smaller (shallower) than those used in the studies of Di & Cameron (2002b; 2007). Cameron *et al.* (1992) identified that smaller lysimeters (250 mm deep) are prone to preferential edge flow, when the internal edge of the lysimeter has not been sealed. However, as our lysimeters were carefully sealed with petroleum jelly immediately after sampling, preferential edge flow of solute is an unlikely explanation for our NO_3^--N leaching results.

When compared with the application of 300 kg N/ha of cow urine (Di & Cameron 2007), this sheep trial produced a greater leaching loss (by 88 kg N/ha) over a shorter (by 6 months) period. The peak NO_3^--N concentration (57.2 mg N/L at 80 mm drainage) also occurred earlier in this study than in other studies involving 1000 kg N/ha dairy cow urine applied to deeper (700 versus 300 mm) lysimeters. Application of DCD to our sheep urine treated lysimeters reduced the peak NO_3^--N concentration by 63%. This contrasts with the finding of McDowell & Houlbrooke (2009), who reported no significant effect of DCD on NO_3^- leaching from sheep urine. However, McDowell & Houlbrooke (2009) used a lower urine-N loading rate of 229 kg N/ha for sheep urine patches, had different N treatment regimes, and the results pertained to annual losses for winter grazed forage crops (triticale, followed by kale), not short-term break-feeding of pasture. Although not fully detailed by McDowell & Houlbrooke (2009), rainfall/irrigation inputs for Aug-May were also considerably less than the conditions of our study. Moreover, the lysimeter sampling site of McDowell & Houlbrooke (2009) was previously used for winter grazing crops (kale and swedes) for 2 years, whereas our site had been in long-term pasture. Such contrasting management regimes could potentially result in contrasting soil macroporosity/hydraulic properties, whereby the pasture soil could have greater macroporosity and drain more rapidly, increasing NO_3^- leaching in our study. Another factor that could explain the higher NO_3^- leaching in our study is that we simulated treading on our lysimeters, whereas McDowell & Houlbrooke (2009) did not. Stock treading of wet soils in winter has been indicated as a factor contributing to increased NO_3^- leaching (Drewry & Paton 2005).

Late-autumn/winter break-feeding of sheep has been identified as an important source of N leaching loss. In our study, DCD reduced N losses in the sheep urine patch from 152 to 45 kg N/ha. It is important to note that this value relates to a single sheep urine patch deposited in May under the particular climatic conditions that prevailed. Further work would be required to extrapolate or 'upscale' this result to estimate N losses under field conditions. For example, spatial-specific urine deposition data (e.g. Moir *et al.* 2006; Pleasants *et al.* 2007) could be used to estimate or model urine deposition patterns in the field, or in studies examining N losses from urine patches deposited at different times of the year. However, it must be recognised that the focus of our study has been the late autumn/early winter grazing. From a recent farm survey (Wild 2009) in Canterbury and Southland, winter break-feeding grazing systems had stocking densities ranging from 1 800 to 2 000 s.s.u./ha, and grazing for 24 h. Our results suggest that under such high stocking densities for winter grazing, there is an immediate need for further research of N leaching losses in this situation.

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