Form of nitrogen leaching from dairy cow urine and effectiveness of dicyandiamide: not all soils are equal

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Abstract

Our hypothesis was that soil type and rainfall will influence the effectiveness of the nitrification inhibitor dicyandiamide (DCD) in decreasing N leaching from urine patches. Intact soil monolith lysimeters (50 cm diameter, 70 cm deep) were taken from three contrasting soil-types: silt loam, clay and sand. The lysimeters were irrigated to achieve either the average annual rainfall for the lysimeter site (1100 mm/year) or twice this amount. Urine with and without DCD was applied in late May (with a repeat application of DCD in July). Nitrogen leaching was measured through to December 2009. The movement of soluble N behaved differently between the three soils. Large amounts of urea were measured in the first drainage events from the clay, suggesting macropore flow. Large amounts of ammonium was leached from the sand (c. 32% of the total mineral N leached), possibly due to a low cation exchange capacity of the soil. DCD was effective in decreasing nitrate leaching from the silt (61%) and clay (36%) soils (as an average of both rainfall regimes), but not from the sand. This experiment suggests that DCD performance can be affected by soil-type, and that losses of soluble forms of N other than nitrate can also be significant on some soils.

Key Words

Nitrate leaching, nitrification inhibitor, soil-type, ammonium, urea.

Introduction

Nitrate leaching losses from intensively grazed pasture can be large because urine patches provide large nitrogen (N) loadings that exceed the pasture's capacity to take up N (Ledgard 2001). In addition to significant NO_3-N leaching, in some soils and climatic conditions, NH_4-N and organic-N (mainly as urea) can be leached from the soil profile as a result of bypass flow following urination (Wachendorf *et al*. 2005; Menneer *et al*. 2008). The use of the nitrification inhibitor dicyandiamide (DCD) is considered in New Zealand pastoral systems to be a technology that can decrease leaching of NO_3 and emissions of N_2O derived from urinary-N (Monaghan *et al*. 2007). Given the potential for its widespread use in pastoral agriculture, we compared the effectiveness of DCD on contrasting soils and under contrasting rainfall regimes using soil monolith lysimeters.

Methods

Soil-types

Sixteen intact soil monolith lysimeters (50 cm diameter by 70 cm deep) were collected from three regions in the North Island of New Zealand to provide a contrast in soil-types: a silt loam (Typic Orthic Allophanic Soil; Hewitt 1993); a slowly draining clay soil (Gleyed clay alluvial fulvi-appodic Soil; Hewitt 1993); and a free draining sand (Buried-allophanic Orthic Pumice soil; Hewitt 1993). Measured soil properties are presented in Table 1.

Table 1. Measured chemical (0-7.5 cm) and physical (0-15, 15-30 cm) soil properties.

	Soil-type 'Clay'	'Silt loam'	'Sand'
pH[a]	5.9	5.9	5.7
Organic Carbon (mg C/g)	9.6	6.5	10.7
Total N (mg N/g)	0.86	0.56	0.65
CEC[b] (cmol/ kg)	31	22	15
Base saturation (%)	78	53	41
Sand-silt-clay 0-15 cm (%)	4-37-59	31-47-22	66-25-9
Sand-silt-clay 30-50 cm (%)	2-21-77	42-57-1	69-26-5

[a] Measured at 1:2.1 air-dried soil:water ratio. [b] cation exchange capacity

The pastures at all locations were a permanent mixture of predominately perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) and had been under a regular cutting regime for at least 4 months prior to collection of the lysimeters to avoid the influence of excreta inputs.

Lysimeter collection and installation

The lysimeters were extracted using the method described by Menneer *et al*. (2008). Briefly, a metal cylinder casing with an internal cutting ring was pushed into the soil, the soil monolith was then undercut, lifted from the soil and a steel base plate with a central drainage hole was secured to the bottom of each lysimeter. The small gap between the soil monolith and the cylinder wall was sealed using petroleum jelly to prevent edge-flow effects (Cameron *et al*. 1992). The lysimeters were carefully transported to minimise soil disturbance and were installed at ground level at the AgResearch Ruakura Research Centre lysimeter facility, Hamilton. All lysimeters were watered to saturation and allowed to drain to field capacity, and were then exposed to natural weather conditions during April before application of treatments in May.

Experimental design and treatments

Treatments were three soil types (as described above), two rainfall regimes (annual average and twice the amount for the experimental site in the Waikato region) and ± DCD application, in a randomised block experimental design (4 replicates). Simulated rainfall was applied (if necessary) regularly and in small doses to the appropriate lysimeters as spray irrigation to meet the targeted annual rainfall regime (1100 and 2200 mm/year). Total water inputs (rainfall + irrigation) for each rainfall regime were based on the 30-year long-term average for the Waikato region.

Dairy cow urine was collected from dairy heifers and urea-N was added to adjust the final total N concentration to 10.0 g/l. This was then applied in a single application at an equivalent rate of 1000 kg N/ha in late May to simulate a dairy cow urine deposition. DCD was applied (10 kg/ha) to the designated lysimeters as a fine suspension spray following urine application and re-applied in mid-July. In the urine-only treatments, an equivalent volume of distilled water was sprayed onto each lysimeter to maintain the same moisture input to all lysimeters. Following treatment application, all lysimeters received 10 mm of spray irrigation to ensure the DCD was in contact with the soil.

Determination of N leaching losses

Leachates were collected from the lysimeters when drainage occurred, or weekly, for chemical analysis. Leachate samples were analysed for NO_3-N and NH_4-N using a Skalar SAN++ segmented auto flow analyser (Skalar Analytical B.V., Breda, Netherlands). Urea in leachate was determined colorimetrically (Douglas and Bremner 1970).

Results

Rainfall and drainage

Here, we report the first 7 months of the experiment from the application of the urine (May 22) through to the end of December. This covers the main drainage period. During this period there was 770 mm rainfall and an average of 445 and 985 mm drainage from the ‘average’ and ‘supplemented’ rainfall regimes, respectively.

Nitrate leaching

The amount of nitrate leached during the entire drainage followed the expected relationship with soil-type: sand > silt loam > clay (as an average of both rainfall regimes), Table 2. There were highly significant interactions ($P<0.001$) for the amounts of NO_3-N leached after urine application between soil-type and rainfall (data not shown), and between soil-type and DCD application.

Table 2. Effect of soil-type and DCD application on nitrate-N leached (kg NO_3-N/ha), as a mean of the two rainfall regimes imposed on the experiment.

Soil-type	Urine treatment	
	Control	+DCD
Silt loam	312	131
Clay	142	77
Sand	259	272
LSD (P=0.05)	54.6	

The DCD was ineffective in the sand. Decreases in NO_3-N leaching resulting from application of DCD were 58% and, 46% for the silt and clay soils, respectively (as an average of the two rainfall regimes). Surprisingly, there was no significant interaction between DCD application and rainfall. This is counter intuitive and the overall result may have been affected by the ineffectiveness of the DCD in decreasing NO_3-N leaching on the sand. Certainly, for the other two soils, DCD appeared to be less effective at the higher rainfall regime: there was a trend for a decrease in effectiveness from 69% to 54% for the silt loam and from 50% to 22% on the clay when comparing average and supplemented rainfall regimes.

Ammonium leaching

DCD application had no effect on NH_4-N losses from any of these soils. However, there was a highly ($P<0.001$) significant effect of soil-type and rainfall (Table 3). For the silt loam and clay soils, much of this NH_4-N was present in the early drainage; this suggests macropore flow on these two soils. However, for the sand, the concentration profiles show a smooth leaching curve indicative of 'piston flow' (Figure 1).

Table 3. Effect of soil-type and rainfall regime on ammonium-N leached (kg NH_4-N/ha), as a mean of control and DCD treatments. Data were square root transformed.

Soil-type	Rainfall regime Average	Supplemented	Level of significance
Silt loam	4	12	ns
Clay	29	63	**
Sand	68	204	***
Average LSD (P=0.05)	24.4		

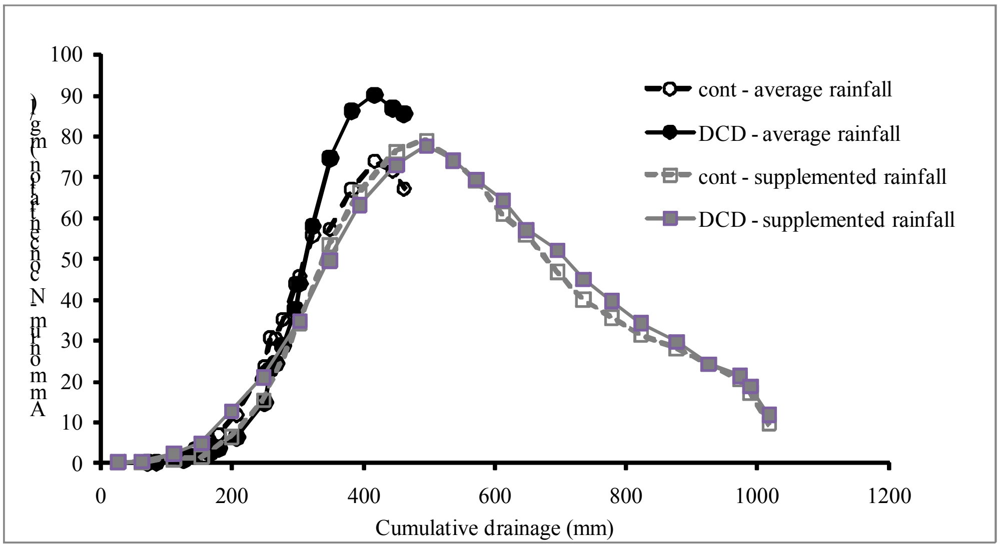

Figure 1. Concentration of NH_4-N in the drainage from the sand soil lysimeters

Urea leaching

There was a highly significant effect ($P<0.001$) of soil-type on loss of urea in drainage water, but no effect of rainfall regime or DCD application. Urea was measured in the first two drainage events and none was found in the leachate samples after that. This suggests the cause was initial macropore flow, with most urea lost from the more structured soils. Measured losses were: 123, 22 and 5 kg urea-N/ha for the clay, silt and sand soils, respectively.

Discussion

The contrasting textures and structure of these three soils affected the transport of urine-N, and its form, to 70 cm depth in the lysimeters. This has implications for the effectiveness of DCD in decreasing soluble N loss from urine patches.

DCD was effective on two of the three soils in decreasing nitrate leaching. The effectiveness of DCD has been reported before (Di and Cameron 2007; Monaghan *et al.* 2007) and, in some circumstances, offers potential as a practical mitigation technique in decreasing nitrate leaching from grazed pastures. However, a significant proportion of the applied N was leached as urea immediately after application in the clay soil, probably due to its highly prismatic structure. This has been recognised in some situations (Silva *et al.*

2007), but its immediacy means that there is a smaller pool of ammonium for any DCD to act upon in the soil surface.

Ammonium-N losses also occurred but were dependent on soil-type and rainfall. DCD had no significant effect on NH_4-N leaching, even though the mode of action is to hold N as NH_4-N in the soil. On the silt and the clay soils, the NH_4-N concentration profiles with the drainage suggest that losses were due to bypass flow and rapid movement to depth. However, in contrast, the sand soil leached substantial amounts of NH_4-N via piston flow (Figure 1), suggesting that the soil was unable to bind the ammonium. Qian and Cai (2007) found similarly large NH_4-N leaching from soils with low cation exchange capacity and low base saturation. This is one possible explanation for the NH_4-N leaching from the soil (Table 1), though further investigation is warranted. This downward movement of NH_4-N may also explain why the DCD was ineffective on this soil-type.

Conclusion

DCD decreased leaching of nitrate from the silt loam and clay soils tested in this experiment. Further benefit may be observed in the second winter under the average rainfall regime because the full elution curve was not completed on these soils in the first winter.

As well as nitrate, this experiment shows that losses of other forms of soluble N can also be large. Further work is required to explain the lack of DCD effect on the sand soil and the large NH_4-N leaching losses from this soil in this experiment. The relationship between the loss processes and soil-types needs to be fully understood so that a realistic assessment of the likely effect of DCD on decreasing soluble N losses across a range of situations can be evaluated.

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