Reducing nitrate leaching losses from a Taupo pumice soil using a nitrification inhibitor *eco-n*

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Abstract
The decline in water quality in Lake Taupo has been attributed to nitrogen (N) leaching from surrounding land areas. Pastoral agriculture has been identified as a significant contributor to this N transfer to the lake through animal urine deposition. There is therefore an immediate need for new management options to reduce N losses. The objective of this study was to measure the effectiveness of using a nitrification inhibitor (*eco-n*) to reduce nitrate leaching losses from a pasture soil of the Taupo region. A 3-year study was conducted using 20 lysimeters on Landcorp's 'Waihora' sheep and beef farm, within 10 km of Lake Taupo. The results show that animal urine patches were the main source of nitrate leaching (>95% of the total annual loss) and that *eco-n* significantly ($P<0.05$) reduced nitrate leaching losses from urine treated lysimeters. When the lysimeter results were combined with a detailed GPS survey and GIS analysis of urine patch coverage of the farm it is concluded that *eco-n* reduced annual nitrate leaching losses by between 23 and 32%, with an average reduction of 27%. Thus *eco-n* represents a practical technology that pastoral farmers could adopt today, to assist them to meet new water quality standards in sensitive catchments near Lake Taupo and the upper Waikato River.
Keywords: nitrate, urine patch, nitrification inhibitor, eco-n

Introduction
Environment Waikato has set a target 'to reduce the manageable sources of nitrogen flowing into Lake Taupo by 20%' (Environment Waikato 2007). Environment Waikato's variation No.5 to the Waikato Regional Plan contains new policy and rules to manage land use in the Taupo catchment area. The new rules cap the annual average amount of nitrogen leached from farmland. This represents a considerable challenge to the farmer who wants to increase production because most of the nitrogen that is leached from pastoral farms comes from urine that is deposited by grazing animals, rather than directly from fertiliser (Scholefield *et al*. 1993; Ledgard *et al*. 1999; Di & Cameron 2002a, 2002b).

One of the management options that has the potential to reduce nitrate (NO_3^-) leaching from agricultural land is the use of nitrification inhibitors which slow down the conversion of ammonium (NH_4^+) to NO_3^- in the soil (Amberger 1989). Recently, Di and Cameron (2002c, 2004) demonstrated that NO_3^- leaching losses from grazed dairy pastures on sedimentary soils can be substantially decreased by treating the soil with a nitrification inhibitor, DCD. The objective of this trial, therefore, was to measure the effectiveness of using a DCD-based nitrification inhibitor (*eco-n)* to reduce nitrate leaching from a typical pasture soil in the Taupo region.

Since it is practically impossible to collect all of the water that drains from a paddock of free-draining soil, such as a Taupo pumice soil, it is very difficult to quantify the amount of nitrate leaching losses that occur at the paddock scale. A further complication to quantifying leaching losses at the paddock scale is that in a grazed pasture there are two distinct contrasting areas; (i) animal urine patch areas and (ii) inter-urine patch areas. The difference between these two areas is commonly observed as relatively large differences in pasture growth. The differences in nitrate leaching losses between these different areas are also considerable, with over 90% of nitrate leaching being reported to originate from urine patch areas and less than 10% originating from inter-urine patch areas (Ledgard *et al*. 1999; Di & Cameron 2002a, 2002b).

One approach, in order to try to overcome these problems, is to use lysimeters to measure the leaching losses from stratified samples representing urine patch and inter-urine patch areas and to 'scale-up' the results to the paddock scale by using information about the percent area coverage of urine patches.

Materials and Methods
Lysimeter experiment
A typical grazed pasture site was identified on Landcorp's 'Waihora' farm, in the Lake Taupo district. The soil type is a free-draining yellow brown pumice soil, with soil fertility levels of pH 5.9, Olsen P 22 µg P/mL and Sulphate-S 20 µg S/g. The pasture was a mixture of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). The stocking rate was typical of this class of hill country in this region with 13 ssu (standard stock units) per hectare.

Twenty lysimeters (300 mm diameter x 500 mm deep) were collected from the site in April 2003. Obvious urine and dung patch areas were avoided and the lysimeters were collected by placing a PVC cylinder on the soil surface, digging around the casing, making sure to minimise disturbance to the soil structure inside, and gradually pushing the casing down by small increments (Cameron *et al*. 1992). Once the casing had reached the desired depth (500 mm) the soil monolith was cut at the base with a cutting plate, secured on the lysimeter casing and lifted out of the collection site. The gap between the soil core and the casing was sealed using petroleum jelly to stop edge-flow effects.

The lysimeters were then installed in field facilities where the lysimeters were placed on either side of a trench with the soil surface of the lysimeters at the same level as the surrounding paddock. The space outside the lysimeter casings was backfilled with soil to the same level as the surface of the lysimeters and the surrounding paddock. The lysimeters were thus exposed to the same climatic conditions as the soil and pasture in the surrounding paddock.

Four treatments, each with five replicates, were allocated to the lysimeters in a randomised design: (i) urine alone (equivalent to 700 kg N/ha/yr in May); (ii) urine (May) plus *eco-n* (10 kg/ha in both May and August); (iii) no urine; and (iv) no urine plus *eco-n* (10 kg/ha in both May and August). The application rate of 700 kg N/ha was equivalent to the typical N loading rate under a beef cattle urine patch (Haynes & Williams 1993). The DCD was applied at the rate of 10 kg active ingredient per ha as a fine particle suspension on to the surface of the lysimeters following the urine application on the same day. The DCD treatment was repeated in early August in line with recommended use of the *eco-n* product. Pasture cover at the time of DCD application was short (equivalent to c. 1200 kg dry matter/ha) to simulate conditions after grazing and to ensure that the DCD treatment reached the soil surface. The herbage on each lysimeter was cut periodically to simulate typical grazing practice. Because animal urine deposition is unlikely to occur on the same spot each year, subsequent urine application treatments were made onto the 'no urine' treatment lysimeters of the previous year.

The total amount of water draining from the lysimeters over each entire year was measured on a weekly basis (or more frequently if heavy rain persisted during any one week) and a sub-sample of 100 mL was collected for analysis. The concentration of nitrate-N in the leachate was determined by standard FIA analysis (Tecator Inc., Sweden) and the amount of nitrate-N leached was calculated from the NO_3^- concentration and the drainage volume collected from each lysimeter on each occasion. Analysis of variance was performed using Genstat (Version 9, Lawes Agricultural Trust) and least significant differences (LSD) calculated.

GPS/GIS measurement of urine patch coverage

A new method, using global positioning system (GPS) and geographic information system (GIS) technology, was used to quantify the spatial distribution and area coverage of urine patches deposited by grazing animals (Moir *et al*. 2006). Six 10 x 10 m (100 m^2) plots were marked out on typical areas of the Waihora farm. Three plots were located on flat areas (0-3% slope), while the remaining three were located on easy rolling to medium hill slopes (3-7% slope). Urine and dung patches inside each plot were recorded using survey-grade differential GPS at regular time intervals through the year. Real-time kinematic (rtk) GPS was used to enable the exact location of the centre of each urine and dung patch to be recorded. Grazing information was recorded in order to relate area coverage data to stocking rate and total grazing days.

The radius of each patch was measured with a measurement arm attached to the base of the GPS pole and was also recorded (in cm) in the data logger to enable area to be calculated. Patches were identified either by pasture growth response to urine, or dung, or by any obvious fresh dung deposition. Measurements were generally made 2-3 weeks after the paddock had been grazed so that pasture growth response areas to urine and dung could be easily observed. The sampling time interval was set at a minimum of 3 months.

Results and Discussion

Lysimeter results

The results for year one show that animal urine patches were the main source of nitrate leaching (>95% of the total annual loss) in this Taupo pumice soil (Fig. 1). The results also show that the application of the nitrification inhibitor *eco-n* significantly ($P<0.05$) reduced nitrate leaching losses from urine patch areas. In 2003-4 the amount of NO_3^- leached from urine treated lysimeters was reduced from 306 to 213 kg N/ha/yr with *eco-n* (representing a 30% reduction), in 2004-5 the reduction was from 289 to 195 kg N/ha/yr (33% reduction), and in 2005-6 the reduction was from 133 to 81 kg N/ha/yr (39% reduction). The variation in amount of nitrate-N leached each year appears to be related to the amount of rainfall received, with the greatest nitrate-N loss occurring in year 1 when the greatest amount of drainage occurred (635 mm), compared to year 2 (563 mm) and year 3 (486 mm) when lower nitrate-N losses occurred.

These results relate to leaching losses of urine-N deposited in May. Losses from urine-N deposited at other times of the winter/ early spring drainage period may be different. Unfortunately, there are no other data available to compare these losses against and it is therefore difficult to speculate about what the losses would be at other

Figure 1 Amount of nitrate-N leached in drainage water from the Taupo lysimeters as affected by urine treatments and *eco-n* nitrification inhibitor over the 3 year period of the study.

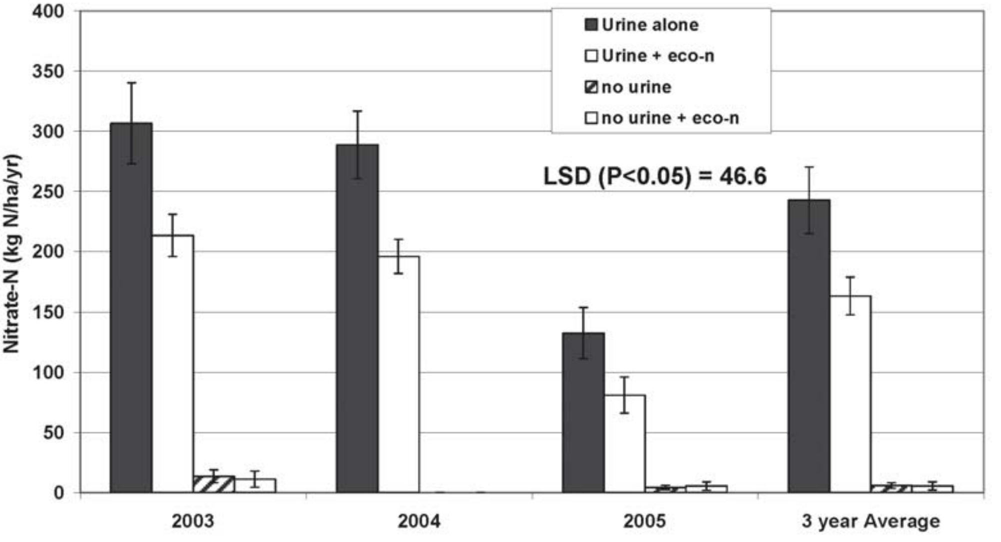

Table 1 Average annual cumulative urine patch coverage.

	Total plot area covered (%)	SE
Flat area	19.3	1.4
Hill slope	14.3	1.7

Table 2 Slope classes and percentage of the Waihora farm area.

Slope Class	Slope (%)	Percentage of total area	Area (ha)
1	0 - 3.0	56.8	1956
2	3.1 - 7.0	38.9	1338
3	7.1 - 15	4.4	150
Total area			3,444

times. However, it is worth noting that other work has shown that at winter soil temperatures typical of the Taupo district (<8ºC) the effect of the *eco-n* inhibitor can last for 2 to 3 months (Di & Cameron 2004b). In addition, work involving a 2.5 week delay in animal urine deposition relative to inhibitor treatment has shown that nitrous oxide gas emissions were reduced by 73%; indicating that the inhibitor was still effective after this time period (Di *et al*. 2007). Therefore it is likely that an application of the inhibitor in May still has the potential to reduce nitrate-N leaching losses from urine that is deposited during winter.

Although the percentage reductions in nitrate leaching reported here are less than previously reported (e.g. 75% in Di & Cameron 2004a) they still represent a statistically significant ($P<0.05$) reduction in nitrate leaching loss (Fig. 1). The reasons for the lower percentage reductions are unclear at this stage but may be due to differences in soil type and/or climatic conditions. Current work indicates that the actual percentage reduction is not necessarily related to the urine application rate and that reductions of over 50% can still be achieved in sheep urine patches where the N loading rate is equivalent to around 300 kg N/ha/yr.

Urine patch coverage results

The average annual cumulative coverage of urine patches on the flat areas was 19.3% and on hill slopes the average annual urine patch coverage was 14.3% (Table 1). Dung patches were excluded from data analysis.

The annual cumulative urine patch coverage for the different slope classes calculated from the research plots, situated on the respective slopes, was then used to calculate the annual urine patch coverage for the full Waihora farm. The different land slope class distributions on the Waihora farm are shown in Figure 2 and areas of each slope class are given in Table 2.

In total, 18.0% (569 ha) of the Waihora farm would be covered by urine depositions each year (Table 3).

Paddock scale nitrate leaching losses

The GPS/GIS urine patch spatial data and the lysimeter trial data were combined together to calculate the nitrate leaching losses at the paddock scale using the following equation (Di & Cameron 2000):

$$N_L = N_{L1} \text{ x } A_1 + N_{L2} \text{ x } A_2$$

Where N_{L1} and N_{L2} are the N leaching losses from the

Figure 2 Slope class distribution on the Waihora farm.

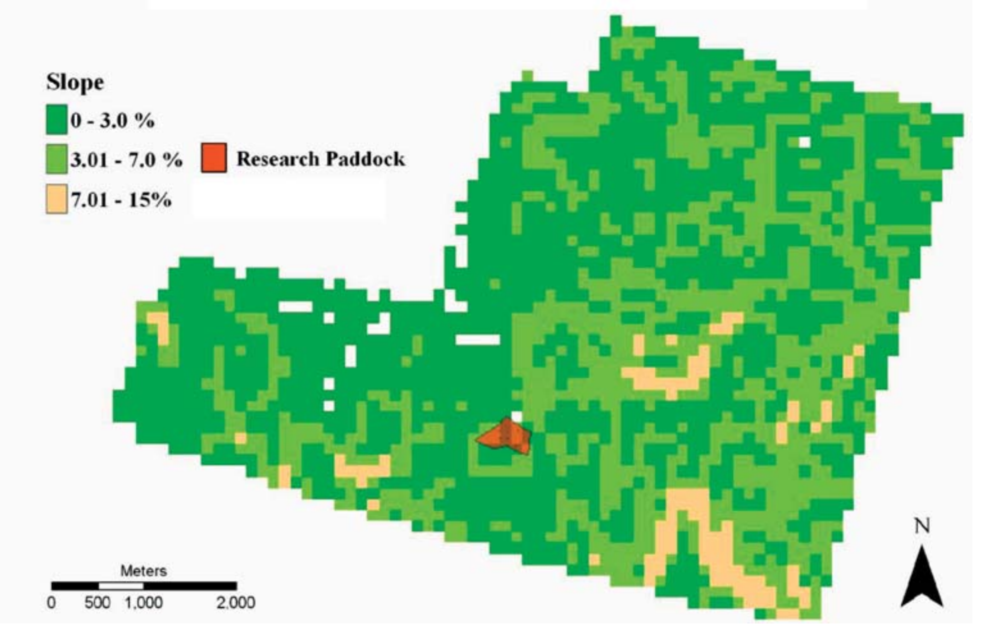

Table 3 Farm area annually covered by urine patches according to slope class.

Slope class	Slope (%)	% of total area covered by urine patches	Total area covered by urine patches (ha)
Flat Areas	0 - 3.0	11.5	377
Hill Slopes	3.1 - 7	6.5	213
Total area		18.0	590

Table 4 Estimate of the effect of *eco-n* on the annual amount of NO_3-N leached from the Waihora farm in the 2003-4 and 2005-06 seasons.

	2003-4 kgN/ha/yr	2004-5 kgN/ha/yr	2005-06 kgN/ha/yr
No *eco-n*	39.9	25.9	15.9
Plus *eco-n*	29.4	17.6	12.2
eco-n reduction (%)	26	32	23

urine patch area (A_1) and the non-urine patch area (A_2), respectively.

Based on the drainage results from the lysimeters and the 25 year average climate data from NIWA, it was found that drainage (and thus nitrate leaching) predominately occurs from urine deposited on this farm during May to October. Therefore the 6-month urine patch area (A_1) prone to leaching is approximately 9% (i.e. 50% of the total value given in Table 3 above) with the remainder of the area being inter-urine patch areas.

The results (Table 4) show that the use of *eco-n* nitrification inhibitor technology has the potential to reduce nitrate leaching losses from the Waihora farm by between 23 and 32%, with an average reduction of 27%. This reduction in nitrate leaching is greater than the 20% target set by Environment Waikato, making this a viable mitigation strategy for use in the Taupo catchment.

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