The use of a nitrification inhibitor (DCn™) to reduce nitrate leaching under a winter-grazed forage crop in the Central Plateau

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Abstract

Grazing of brassica winter forage crops returns large amounts of excreted nitrogen (N) back to the paddock during winter when risk of leaching is high. This experiment measured nitrate-N leaching below 60 cm of 132 and 173 kg N/ha following June grazing by dairy cows of swede/kale crops in 2008 and 2009. Application of DCD immediately after grazing plus 6 weeks later decreased leaching by 20–27% (significant at $P<0.05$). The retained N was measurable in the soil (0–60 cm) at the end of drainage. We conclude that: grazing of winter forage crops can leach large amounts of N; DCD is one tool to decrease leaching; retained N needs to be utilised by the following crop or pasture and represents a valuable resource on the farm.

Key words: Winter forage, nitrogen, leaching, DCD

Introduction

Over-wintering cattle on forage crops is an increasingly common management option, but there has been little research into the fate of urine-N post-grazing and the management strategies for decreasing leaching. The limited amount of New Zealand research reported to date suggests there is a risk of significant N leaching. Monaghan *et al*. (2007) reported that the wintering component of dairy systems made a disproportionately large contribution to annual N leaching (*ca.* 60%), despite representing a relatively small area of the farming system (<15%). Smith *et al.* (2008) made an assessment of the winter grazing system using hydrologically isolated experimental plots and simulated grazing. Use of the nitrification inhibitor dicyandiamide (DCD) after grazing halved N leaching post-grazing. It also benefitted other aspects of the N cycle by decreasing emissions of nitrous oxide.

Whilst these results are encouraging, it is worth noting that the work to date has focused on experiment plots. The aim of the experiment reported here was to test the effectiveness of DCD in decreasing nitrate leaching from paddocks of grazed forage crop on a commercial farm.

Methods

Field experiments were undertaken in the winters of 2008 and 2009 in separate paddocks on a farm property in central North Island, which uses winter brassicas to meet feed shortages during the winter. The property is on rolling land on a freely draining Taupo pumice soil (Immature Orthic Pumice Soil). On the farm, pasture was sprayed off, grazed, cultivated and then drilled with a swede/kale mix in November or December. Basal fertiliser was applied pre-cultivation and N fertiliser applications of *ca.* 200 kg N/ha were split over 2–3 applications. The block of winter crop is typically grazed in June and July, supplemented with silage *in situ.*

For the experiment, a suitable paddock was identified in May and 20 large plots (each 324 m^2) were marked out in the growing kale/swede crop. Different paddocks were used in 2008 and 2009. The paddocks were strip grazed in mid-June, and the mob of >300 cows generally cleared the experiment site of forage within 4 days. In the first experiment year (2008), the region experienced a severe summer drought so that there was no silage supplement available in winter. The mob was managed by alternating between the brassica crop (18 hours per day) and an adjacent pasture paddock (6 hours per day).

DCD was applied to half the plots within 2 days of grazing (12 kg a.i./ha), and was re-applied 6 weeks later in July. The DCD was granular (DCn™ – sourced from Ballance Agri-Nutrients) and was spread by hand. Treatments were allocated to the plots such that there were 10 replicate blocks, each containing plots with and without DCD. The soil was left fallow after grazing until it was cultivated and drilled with triticale (2008) or chicory (2009) in late August.

Ten porous cups (Webster *et al.* 1993) were installed down the centre of each plot at an angle of 45 degrees to the vertical, approximately 2 m apart, to a vertical depth of 60 cm. Sampling of porous cups started in May/June before grazing of the crop started. The porous cups were sampled generally every 30–50 mm rain until the end of

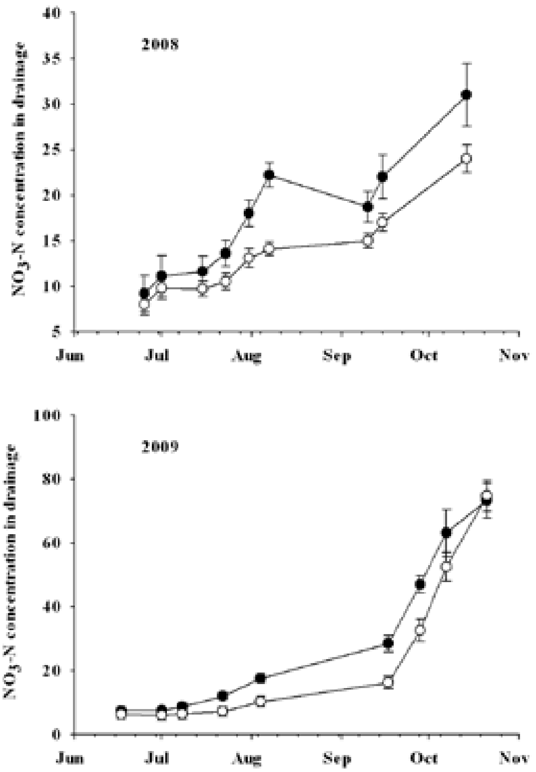

Figure 1. Measured nitrate-N concentrations in drainage measured by porous ceramic cups at 60 cm depth (mg N/L). Closed circles = no DCD, open circles = DCD applied after grazing. Standard error of the mean is shown.

drainage in spring. The leachate from the individual porous cups was analysed for nitrate nitrogen (NO_3-N) and ammonium nitrogen (NH_4-N). The porous cups were removed to allow soil cultivation in August and were reinserted into the soil after the following crop was drilled. Soils were sampled for NH_4-N and NO_3-N to 60 cm before grazing in May, in July/August ("mid-winter") and in November/December (at the end of drainage).

Each year, a single, ungrazed observational plot was also set up separate from the main experiment but in the same paddock. The forage crop was manually removed at the same time that the main experimental area was grazed. Livestock were excluded throughout the winter, so that effects on soil NH_4-N and NO_3-N (Nmin) could be measured in the absence of grazing.

Results

The Waikato region was exceptionally dry and warm during summer 2008 (45 mm rainfall at the site January to March: Table 1, data based on NIWA's virtual climate network). Consequently, the crop accumulated only 7 t DM/ha when assessed in May, below the farm's target of 10 t/ha. In contrast, growing conditions were better in 2009 and a yield of 11 t DM/ha was achieved. Drainage amount was calculated using a water balance model (Woodward *et al*. 2001). Both winters were wet, with 798 mm and 672 mm drainage calculated in winters 2008 and 2009, respectively (Table 2). Drainage started in May 2008 after a very wet April; in the second experiment, drainage started in June 2009.

Soil mineral N, autumn

The sum of soil Nmin in autumn prior to grazing the forage crop indicated the amount of N potentially available for leaching before there had been any contribution from excreta deposited during the winter. Amounts of Nmin were 39 and 27 kg N/ha to 60 cm in 2008 and 2009, respectively, with >90% of this present as NO_3-N. The larger amount of Nmin in 2008 might be a reflection of the lower yielding crop in that year.

Nitrate-N leaching below 60 cm

Ammonium-N levels in the sampled drainage water were generally at or below the analytical limit of detection and so reported N leaching is as NO_3-N. Concentrations in the drainage under the grazed forage crop are shown in Figure 1. Nitrogen concentrations were measured before grazing in 2008 because drainage started earlier in that year. The mean NO_3-N concentrations were larger in the treatment without DCD at the start of the experiment despite the complete randomisation of the

Table 1. Monthly rainfall totals (mm) for the experiment years and the 10-year average (2000-2009) for comparison

Month	2008	2009	10 year average
Jan	13	65	78
Feb	20	130	92
Mar	12	36	68
Apr	223	69	101
May	96	105	119
Jun	137	114	134
Jul	267	187	143
Aug	257	189	143
Sep	81	161	112
Oct	145	157	136
Nov	53	32	89
Dec	133	91	133
Total	1436	1335	1348

experiment. Pre-grazing N concentrations in drainage were therefore used as a covariate in analysis of the data. This was not required in the second experiment. Concentrations of NO_3-N in drainage increased quickly in the late winter/early spring, presumably as the June-deposited urine N was leached to the porous cup sampling depth. Concentrations of NO_3-N reached 31 mg N/L (2008) and 73 mg N/L (2009) at 60 cm depth at the end of drainage in spring each year.

Nitrate-N leaching below 60 cm is reported for the entire winter drainage period (Table 2). In both years, NO_3-N leaching was large from the grazed forage crop, and was larger in the second experiment; 132 and 173 kg N/ha, for 2008 and 2009, respectively. This gives average NO_3-N concentrations in the drainage of 17 and 26 mg N/L. The DCD applications significantly decreased NO_3-N leaching in both years (Table 2). Reductions in leached N were 27 kg N/ha ($P<0.05$) in 2008 and 47 kg N/ha ($P<0.01$) in 2009. This represented reductions of 20–27%.

Soil mineral N, end of drainage

In both years, a large amount of Nmin remained in the soil at the end of drainage after the grazed forage crop, though amounts were larger in the second experiment (Table 3). Plots receiving DCD had significantly more soil Nmin at the end of drainage in 2009. There was less soil Nmin at the end of drainage in 2008, although this DCD effect did not reach significance ($P=0.17$).

On plots where the forage was removed manually without grazing, measured soil Nmin in mid-winter was *ca.* 120 kg N/ha less in both years than on plots that were grazed. This confirmed that a large proportion of the Nmin was derived from grazing and excretal deposition.

Discussion

Soil Nmin at the start of the winter and before the forage crop had been grazed was 30–40 kg N/ha, and was greater in the first year when the crop was affected by drought. It is particularly important to manage the cultivation and fertiliser policy of a brassica crop to ensure soil organic N mineralised after cultivation and any fertiliser N applied subsequently are used as efficiently as possible to minimise the amount of soil Nmin remaining in the autumn.

Amounts of N leaching from grazed forage crops

Amounts of 130–170 kg N/ha measured as NO_3-N leached below 60 cm are large per unit area compared with leaching from grazed pasture, and confirm the results of Monaghan *et al*. (2007) of the disproportionately large contribution of these crops to the overall farm N loss. That measured leaching was large is not surprising given that a 12 t DM/ha swede/kale crop would typically provide *ca*. 250 kg N/ha (Beare *et al*. 2006), and N intake would normally be supplemented with other feed. Most of the consumed N will be excreted as urine and dung, and a crop (that could act as a sink for some of the N) is not sown until spring. Measurements on the ungrazed observational plots confirm that most of the Nmin is derived from excretion. Losses below 60 cm were larger in the second year, and treatment effects were more demonstrable although there was less drainage. This was probably due to: larger forage crop in 2009 (more N consumed); silage fed *in situ* in 2009 (more N consumed); animals moved to pasture paddocks for some of the time in 2008 (less excreta in the forage paddock).

Table 2. Summary of N leaching losses (kg N/ha) post-grazing of the forage crops and pasture treatments

Experiment Year	Drainage Period	Drainage (mm)	NO_3-N leached -DCD	+DCD	LSD	P value
2008	May-Oct	798 mm	132	105	30.0	<0.05
2009	Jun-Oct	672 mm	173	126	22.3	<0.01

Table 3. Summary of soil mineral N at the end of drainage under the grazed forage crop (kg N/ha)

Experiment year	Sample depth	Soil mineral N			
		-DCD	+DCD	LSD	P value
2008	0-30 cm	12	16	3.6	0.02
	30-60 cm	28	32	11.3	ns
	Total	39	48	11.5	ns
2009	0-30 cm	13	27	10.5	0.01
	30-60 cm	45	67	18.1	0.02
	Total	58	94	23.0	0.006

The experiment was set up to measure the largest expected losses; i.e. an early June grazing followed by a prolonged period of bare soil over the winter when most winter rain will cause urinary N to be leached. In practice on farms, the forage crop block tends to be grazed through June and July; it is probable that early grazing will be prone to greater losses because more rain (and drainage) will occur after the start of June grazing compared with an end of July grazing.

DCD application

The results showed that DCD can decrease NO_3-N leaching post-grazing. Results were consistent between years for the two forage crops with a reduction of 27–47 kg N/ha each year (20–27%). The retained N was measurable in the soil at the end of drainage, particularly in 2009. DCD was applied at 12 kg a.i./ha twice, based on the standard recommendations for application to pasture at the time. This was able to be applied to the experimental area by hand. Although this experiment has demonstrated the principle that DCD can be effective, there are practical aspects of application to consider at the farm scale. This includes rate and frequency of DCD application given that it is subject to microbial degradation (Kelliher *et al*. 2008). It is also mobile in soil (Shepherd *et al*. 2012) so that it can become physically separated from ammonium-N. However, the main challenge will be time of application after grazing. Forage crops tend to be managed by break feeding, so it might be necessary to apply to small areas frequently, which might be impractical. Another option would be to apply the DCD to the standing crop before grazing. This would have the further advantage of DCD being present as soon as the urine hits the soil. Further work is required on these practical aspects.

Carry-over effects after spring

Soil Nmin measurements at the end of drainage (Table 2) confirm (a) large amounts of N remaining in the soil at the end of drainage and (b) a measurable increase where DCD was applied, due to decreased leaching. We did not focus on measuring additional yield response in the following spring, but would expect some benefit from the DCD given that it retained an extra *ca*. 40 kg N/ha in the profile.

The distribution of this Nmin down the soil profile also has to be considered, and we would also expect later grazing to result in more Nmin being retained in the soil by the end of drainage. However, it is also important that the following crops/pastures are able to exploit this extra N. Table 2 shows that a significant proportion of the total Nmin is below 30 cm; this N will only be of value if it can be exploited by a crop with a suitable rooting habit. If it is not taken up during the growing season then it will be leached in the following winter, adding to the 130–170 kg N/ha already leached. Thus, the cropping sequence after the grazed forage crop could determine the overall N efficiency of the system.

Conclusions

Large amounts of N leaching were measured after a June grazed forage crop. This is therefore an important part of the rotation to focus mitigation strategies on: any retained N could potentially benefit the next crop. Indications are that DCD can decrease N leaching losses (*ca.*30%). Further work on best application rates and timings is required to determine if even more of the N can be retained. It is important to utilise any soil Nmin retained in the soil, otherwise it will contribute to leaching in the following winter. We suggest that leaching losses would be less from later grazing, and DCD strategies might differ for later grazing.

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