ASSESSING THE EFFECTIVENESS OF APPLYING NITRIFICATION INHIBITOR IN STOCKCAMPS FOR MITIGATING NITROGEN LOSS FROM GRAZED PASTURES

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Abstract

Application of the nitrification inhibitor DCD is a promising technology for reducing N loss from grazed pastures, but its application over the whole farm may not be economically justified, especially on hills that require aerial application. Critical source areas (CSAs), such as stock camps, represent the areas of highest urinary-N deposition, highest N loss risk, and potential highest efficacy of DCD application in mitigating N loss. However, holding urinary N as ammonium for a period of time following DCD application may not reduce N leaching because the plants' potential to uptake N from CSA soils may have been exceeded. We used agro-ecosystem models, corroborated by available knowledge and experimental results, to assess efficacy of DCD applied to stock campsites to mitigate N leaching.

Observation of GIS-tracked cattle grazing hill pastures indicates that 50% of urination events may be deposited on 6-16% of pasture areas (campsites). Our modelling showed that the intensity of urinary N aggregation within campsites will determine the soil mineral N status, N-leaching risk and the efficacy of DCD. With increasing urinary N aggregation, total N leached averaged over the whole pasture increased exponentially. DCD efficacy at reducing N leaching (kg N/ha, or %) was highest on campsites of 'moderate urinary N aggregation', and the cost-effectiveness (reduction of N leached (kg N/ha/$ spent on DCD) was highest on campsites of high urinary-N aggregation. Our analyses suggest that applying DCD on campsites is a relatively cost-effective N mitigation strategy, but accurate evaluation of the efficiency using this framework is still challenging, requiring assessment of the urinary-N aggregation intensity and a more robust function describing the DCD effects.

Key words: campsites, nitrate, leaching, nutrient transfer and aggregation

Introduction

Application of the nitrification inhibitor, dicyandiamide (DCD), is a promising technology to reduce nitrogen (N) losses from grazed pastures. A large number of experiments demonstrate its high efficacy in reducing N leaching when applied on urine patches (Di & Cameron 2007; Menneer *et al*. 2008; Williamson *et al.* 1998; Monaghan 2009). However, realisation of the high efficacy on commercial pastoral farms provides challenges because no technology is available to precisely apply DCD only on urine patches. Its application over the whole farm has not been economically efficient, and its application on the hill country pasture is considered economically infeasible (Betteridge *et al.* 2011). Critical source areas (CSAs), such as campsites and strip-grazed areas, represent areas of high risk of N loss and, conversely, possible areas giving a high efficacy of a mitigation strategy. To improve the economic feasibility of applying a DCD mitigation strategy, the targeted application on these

CSAs has been proposed (Betteridge *et al.* 2011). But it is unclear if these targeted DCD applications on CSAs are more efficient. This is, because the major function of nitrification inhibitors is to slow down the nitrification process, that is, to hold N in the less-leachable ammonium form longer so that it can be taken up by plants before being lost from the root zone. This retained ammonium N following DCD application may not result in more plant N uptake on these CSAs, as plant N uptake potential is likely to have been exceeded in soils which have history of high aggregation of urine and faecal N.

The objective of this paper was to assess the efficacy of applying DCD to stock camps to mitigate N leaching from hill country pastures. For this purpose, we first quantified the effects of animal camping behaviour on N-leaching from pastures and then assessed the mitigation efficacy of DCD application to campsites. This analysis should support the design of an effective DCD application strategy.

Materials and methods

Measuring N leaching losses from various pasture areas (main grazing area *vs*. campsites of varying urinary N aggregation intensities) with or without DCD application is expensive. We used agro-ecosystem models, corroborated by the available knowledge from experimental studies, to investigate the efficacy of DCD application on campsites to mitigate N leaching. We first estimated the N leached from pastures with no clear campsites (named below as 'baseline N leaching'). In this case, animal urine was deemed to have been deposited randomly over the paddock. Then we estimated the N leaching from pastures with campsites by explicitly dividing the pasture area into campsites and the main grazing area, and estimated the animal transfer of nutrients from the main grazing area to campsites and the N leaching from these two areas separately. Finally, we added the DCD effects on the campsite area and assessed its efficacy in reducing N leaching. A cattle grazing system on ryegrass/clover pasture on a pumice soil (Oruanui) in the Lake Taupo catchment was used in this analysis (Li *et al.* 2010).

1) Grazing system and N-leaching from urine patches

The grazing system was constructed using the APSIM model (Keating *et al*. 2003). The model system include the module AgPasture (Li *et al.* 2011) for pasture growth and N uptake, SoilN and SWIM (Verburg *et al*. 1996) for soil nitrogen and water dynamics, and Manager module (Keating *et al*. 2003) for specifying animal grazing and excreta return. The N leaching from the urine patches in this modelling setup have been validated against experimental observations across many soils (Cichota *et al.* 2010a). The virtual climate station data (1975-2005) (Tait *et al.*, 2006) from the northwest part of the Lake Taupo catchment (38.525S, 75.825E) was used. The Oruanui soil is described according to New Zealand Soil Database (Wilde, 2003). Soil qualities in campsites are specified with a slightly higher soil organic matter, pH, CEC, soil porosity and soil water holding capacity than in the main grazing area, based on experimental measurements (Haynes and Williams 1999; Cayley *et al.* 2002). Pasture was rotationally grazed nine times a year, more frequently in faster growing seasons than in winter.

Two types of simulations were run to (1) predict N leaching according to N deposition rate by simulating N dynamics following deposition of urination events of varying urinary N loads; and (2) assess the effects of urine patch overlapping by tracing N dynamics following deposition of two urination events over different intervals between depositions of each patch. The N leached under each urine patch was simulated for three years, and the average annual N leaching was calculated.

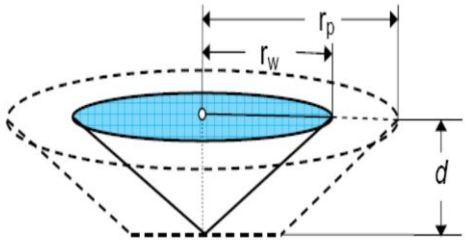
2) *Baseline N leaching*

Without apparent transfer and aggregation of urinary-N by grazing animals (assuming a random distribution of urine patches), N leaching loss from a pasture paddock *($L_{paddock}$)* is calculated as the product of the N leached from an average urine patch (L_U) and the urine deposition density (D_U) on the pasture. D_U is the percentage of total urine patch areas against total land area, calculated according to average pasture response area to a urine deposition and total number of urination events. The average pasture response area was estimated according to urine volume and soil properties using an inverse cone shape (Fig. 1); and total number of urination events was calculated according to pasture production and utilisation (% of pasture on offer), animal daily pasture intake, and average number of urinations per animal per day (McGechan and Topp 2004). The pasture response area, instead of the urine wetted area, was used because plant N uptake was from response area.

The proportion of pasture covered by more than one urine patch was calculated using a negative binomial function (Peterson *et al.* 1956; Pakrou and Dillon 2004) and their effect on increasing N leaching was assessed.

3) *Effects of animal camping behaviour on N leaching*

Cattle congregate on heterogeneous pastures, such as hill country pasture, to form clear campsites (Haynes and Williams, 1999). Monitoring of the activities of GPS-tracked cattle grazing hill pastures showed that 50% urination events may be deposited within 6-16% of the paddock area (Betteridge *et al.* 2010; 2011). The N transfer from the main grazing area to campsites will result in different urine deposition densities (D_U) between these two areas. The N leaching losses from these two areas were estimated separately, then scaled up to the whole paddock.



r_w - *radius of urine patch wetted area*
r_p - *radius of pasture response area*
d - *infiltration depth*

Figure 1 *Representation of a urine patch and pasture response area*

Effect of stock camping on N leaching was assessed by comparing whole-paddock leaching losses from pastures with campsites to those without (baseline N leaching). N leaching from campsites of varying urinary N aggregation intensity was estimated. Whereas urine patches may be considered to be circular within stock camps, as these are generally flat areas, there are no data describing patch shapes on slopes so we have assumed that urine patches are circular generally.

4) *Efficacy of DCD application*

Stock camps have a high urine deposition density, so the proportion of DCD applied to urine patch areas should be much higher when applied on campsites than when applied to urine patches on the main grazing areas. The DCD has high efficacy when applied at the same time as urine is deposited and only on urine patches. Also, it degrades, being effective only 4-6 weeks after application in cool weather and is much less effective in warm weather. In our modelling assessment we used the current DCD application approach recommended by industry, i.e., to apply DCD twice, each at 10 kg/ha, six weeks apart during winter.

We assumed that each double DCD application reduced N leaching by 30% when applied within a few days before or after urine deposition, and had the effects on urine patches deposited during two grazing rotations. This percentage reduction in leached N induced by DCD application was estimated based on the results of field experimental and modelling research (Cichota et al. 2010b). The actual efficacy varies due to many factors. This analysis focused on the relative efficacy of DCD applied on campsites of varying urinary-N aggregation against blanket application.

The efficacy of DCD at reducing N leaching may not be realised on campsites with high urinary N aggregation because soil mineral N always far exceeds the needs of plants for N, and ammonium not taken up by plants will eventually be nitrified and potentially lost as nitrate. Therefore, DCD efficacy on overlapping urine patch areas within campsites, should decrease with the increase of urinary-N aggregation. We assumed that DCD-induced N-leaching mitigation effect at a specific site decreased linearly with the increase of N load (or number of overlapping urine patches) due to the limited plant N uptake potential. Our preliminary modelling analysis showed that if one specific site received six or more urine depositions within one year (Table 1), the DCD effect was negligible, in terms of both additional plant N uptake and mitigation of N leaching.

Campsites were composed of areas covered by different numbers of urine patches. The efficacy of DCD at mitigating N leaching from areas with and without DCD application were calculated and averaged over all campsite areas, then up-scaled to the whole paddock by including the N leached from the main grazing area.

Results and discussion

1) Baseline N-leaching

The estimated average urine patch area was 0.76 m^2, and the estimated N leaching from the paddock was 43 kg N/ha/yr for the modelled grazing system (Table 1, column A). This baseline N-leaching did not include the small effects of urine patch overlapping. Urine patch overlap during the assumed nine grazing events per year and the induced relative increase in N leaching (*i.e.,* percentage increase in N leaching from two fully overlapping urine patches against that from two separate patches) was only 1 kg N/ha/yr or 2.4% in the studied system, due to the low probability of overlapping within a short period. The overlapping effects on increased N leaching were important only when the overlapping interval was less than four months in the studied grazing system (Fig. 2).

Table 1 *N leaching from pastures without campsites (A: Baseline), and from pasture with campsites with high urinary N aggregation (B: assuming that 30% of animal urination events were deposited on 3% of the paddock area).*

Study case in Lake Taupo region	**(A) whole paddock**	**(B) separate areas ⟹**		
		camp	**non-camp**	**paddock**
Pasture and animals:		***Area partition %***		
Harvested herbage (kg/ha/yr)	**12500**	**3**	**97**	**100**
Eaten herbage (kg/ha/yr)	**10625**			
Animal requirement (kg DM /ha/day)	**15**			
Grazing capacity (cow/ha/year)	**708**			
Urination:		***Urination partition %***		
Number of urinations/cow/day	**12**	**30**	**70**	**100**
Number of urinations/ha/yr	**8500**			
Urine Volume (L/urination)	**2.5**			
Urine deposition (volume, L)	**21250**			
Urine patches				
Pasture response area (Ap, m²)	**0.76**			
Urine deposition density (*Du)**	**0.65**	**6.49**	**0.47**	**0.65**
N deposition:				
N deposition rate (kg/ha patch area)	**246**			
Urine N deposition (kg/ha/yr)	**159**	**1594**	**115**	**159**
N-leaching (kg N/ha)	**43**	**951**	**31**	**59**

**** Du*** **= ratio of the total urine patch areas deposited within one year to land area**

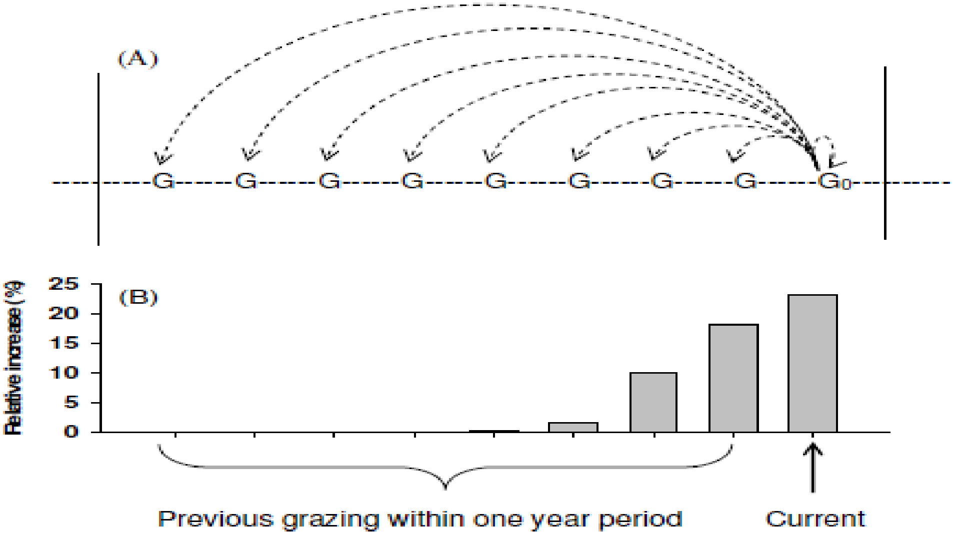


Figure 2 *Urine patch overlapping and its effects on N leaching for modelled grazing system. (A) A urine patch deposited in the current grazing rotation (G_0) may overlap with a patch deposited in current and previous grazing rotations within a one year period (assuming 9 grazings per year). The urine patch is deemed to have completely faded out after one year from its deposition. (B) The overlapping effects, i.e., the relative increase of N leaching from two overlapped patches against the total leaching from two separate patches was seen only when two patches were deposited within four successive rotations.*

2) *Effects of animal camping behaviour on N leaching*

Animal transfer and aggregation of urinary-N to campsites increased N-leaching loss from pastures. The urine deposition density was much higher in the campsites than in the main grazing areas. For a campsite of high urinary N aggregation assuming 30% of urination events on the pasture were deposited within campsites (only 3% of the paddock area), a significant portion of the camp area received multiple urine depositions during a one-year period (Table 2). N-leaching from the small campsite area with high urinary N aggregation may reach 951 kg N/ha/yr, 22 times of that from the main grazing areas; N leaching from main grazing area reduced due to the transfer of the urinary N to campsites. As a result, the total N leached at the whole paddock scale was 37% higher (59 *vs.* 43 kg N/ha/yr) with campsites effects compared to baseline (no campsites) (Table 1). Also, N-leached from campsites was 48% of the leaching from whole paddock area, in this case.

Table 2 *Percentage of paddock component areas covered by different number of urine patches (on an annual basis): A. No aggregation of urination events (baseline); B. with explicit camp & non-camp area, and assuming 30% urination events on the pasture were deposited in camp areas occupying 3% of the paddock.*

Numer of Patches	**(A) whole paddock**	**(B) separate areas** **camp**	 **non-camp**
*Du**	0.65	6.45	0.47
U0	54	1	64
U1	32	4	28
U2	11	7	7
U3	3	10	1
U4	1	11	0.2
U5	0.1	12	0
U6	0	12	0
U7	0	10	0
U8	0	9	0
U9	0	7	0
U10	0	5	0

Du is urine deposition density
U0-U10 is % of area receiving 0-10 urine patches during one year period

3) *Effectiveness of DCD application on N leaching*

The modelling results showed that at any specific point within a campsite, N-leaching increased exponentially with the N deposition rate (higher urinary N concentration, or overlapping patches) (Fig 3A). The assumed decrease in DCD efficacy in reducing N-leaching with the increase of urine N deposition rate (i.e., number of urine patches) at a given site within campsite area is shown in Fig 3B. N leaching from campsites with and without DCD application were calculated and averaged over the total campsite area (Fig 3C), and then up-scaled to whole paddock (Fig 3D) by including N leaching from the main grazing area.

The effects of DCD application at campsites with varying levels of urinary N aggregation are summarised in Table 3. It indicates that nitrogen leaching from campsites or the whole paddock increases with the increase of urinary-N aggregation intensity on campsites, but the reduction of N-leaching through DCD application (kg N/ha or %) was the highest in campsites with "moderate" urinary N aggregation. The low proportion of the DCD applied on urine patches is attributable to the low efficacy of DCD application on campsites of low urinary N aggregation, while the low DCD effect in enhancing plant N uptake is attributable to the low efficacy of DCD application on campsites of high urinary N aggregation. However, the cost-effectiveness of DCD application (reduction in kg N leached/ha/$) remains high on the campsites of high urinary-N aggregation in this case study because of the very low cost of DCD application on these small campsite areas.

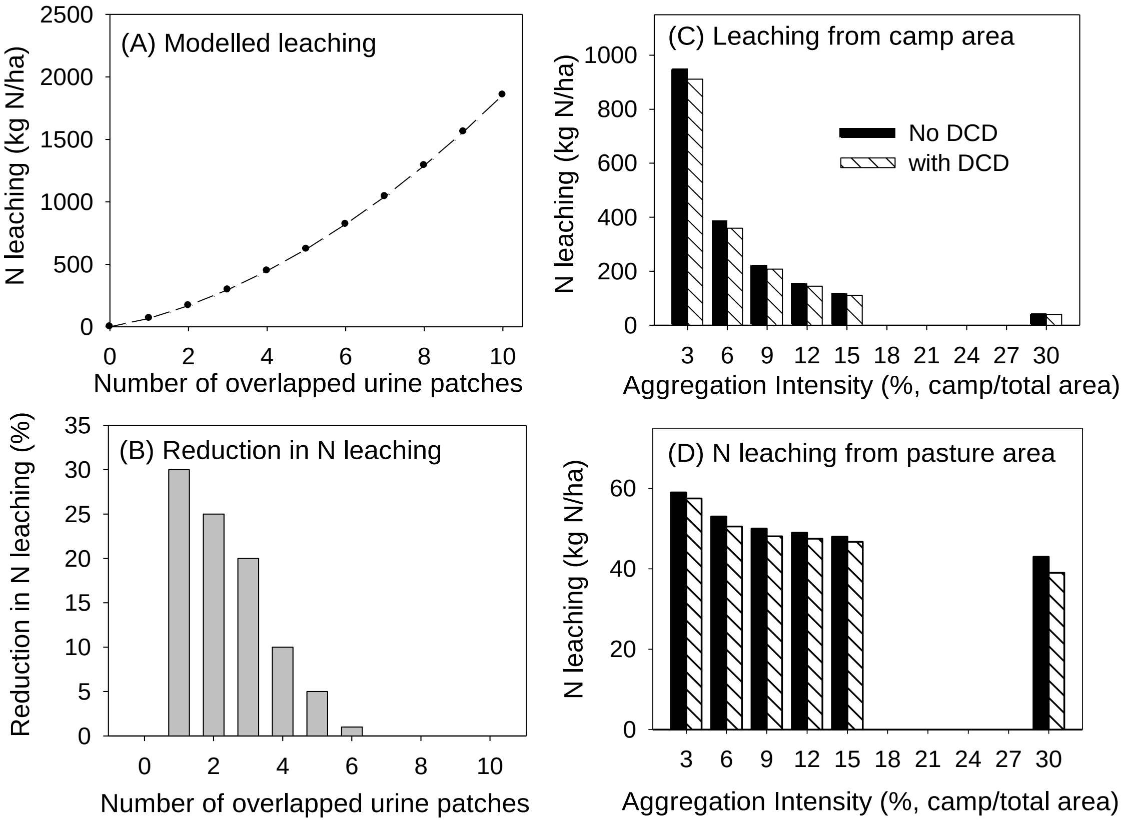


Figure 3 *(A) N-leaching at a specific site increases exponentially with the N deposition rate, expressed as the number of urine depositions (overlapping patches) received during a one year period; (B) DCD-induced reduction in N leaching is deemed to decrease linearly with the increasing number of overlapping urine patches at a site because the inhibition of nitrification does not lead to a greater plant N uptake; (C) Effects of DCD application on N leaching from varying campsites assuming a double application of DCD was applied to urine patches deposited during two winter grazing rotations; (D) DCD-induced mitigation of N leaching at the paddock scale where DCD was applied twice on campsites (blanket application if no campsites, i.e., when aggregation intensity is 30%) . Aggregation intensity is the percentage of the total paddock area on which 30% of all urine is deposited.*

It is important to note that while DCD efficacy is assumed to be 30%, as this is applied to cover only two of the nine annual grazing events in late autumn and early winter, the cumulative impact of DCD on annual basis and at the whole paddock scale is small (Fig 3C and D). The risk of urinary N leaching, represented as the fraction of urinary N leached from a urine deposition, varies with season, was higher in autumn and winter than in spring and summer, for the studied pasture. Simulated N leaching from the urine patches deposited in late autumn and early winter, affected by the DCD application, accounts for 22% of the urine patches but 31% of the total N leached on an annual basis.

Compared to Monaghan et al (2009), our modelled annual reduction in N leaching of 9.4% (mean of 30 years) following a double DCD application was low. Their measured mean DCD efficacy over four years of between 21 and 56% reduction in leached N, was in a grazing trial in southern New Zealand, where leachate from a mole-tile drain system from hydraulically isolated experimental plots was collected and quantified. However, they measured 12.9 kg N leached/ha/yr from control plots whereas we modelled a 43 kg N/ha/yr loss from a Taupo pumice soil. While N leaching, its seasonality and DCD efficacy varies with climate, soil and animal (urine N load) type, the relative change of DCD efficacy with the changes in the level of campsite N aggregation found in this study should stand.

As urine patches on slopes are likely to be long and narrow, rather than circular, the response area relative to the wet area may be much greater. If true, the amount of N leached will be somewhat smaller than we have assumed in this report. This would likely have only a small impact on our analysis on the efficacy of DCD, since the majority of urinary N leached was from campsites rather than slopes. This knowledge gap needs to be addressed to improve estimates of N leaching from hill pastures.

Table 3 *Modelled N leaching and the effects of a double DCD application on grazed pasture when applied to campsites of varying levels of urinary N aggregation. The urinary N aggregation intensity is the percentage of the paddock (camp site area) that receives 30% of all urination events.*

Urinary N aggregation intensity	3	6	9	12	15	No camp
N leaching (kg N/ha/yr) from						
Campsites	951	387	223	154	117	n/a
Main grazing areas	31	32	33	34	36	n/a
Pasture over all	59	53	50	49	48	43
DCD effects: Reduction in N leaching from						
(a) Urinary N deposited during two grazing rotations upon which DCD were applied						
Camp area (kg N/ha)	179	126	69	42	27	n/a
Pasture area (kg N/ha)	5	8	6	5	4	13
Pasture area (% of total N leaching)	9	14	12	10	9	30
(b) Urinary N deposited within one year period (31% reduction in total N leaching through DCD effects						
on 22%	of urine patches)					
Pasture area (kg N/ha)	1.6	2.5	1.9	1.6	1.2	4.0
(% of total N leaching)	2.6	4.7	3.7	3.2	2.6	9.4
Cost effectiveness						
Relative cost against blanket application on whole paddock	0.03	0.06	0.09	0.12	0.15	1
Cost effectiveness (N leaching mitigated/$DCD applied)	40	28	15	9	6	3

Our analysis suggests that applying DCD on campsites is a relatively cost-effective strategy in mitigating N leaching loss, though the reduction of N leaching induced by this double application in later autumn and winter on campsites only, is small. More accurate evaluation of the efficiency requires further assessment of the urinary-N aggregation intensity on campsites on hill country farms to provide more robust functions describing the DCD effects on mitigating N leaching loss. Pasture system modelling, corroborated by experimental results from a wide range of pasture environment, is expected to improve this assessment.

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