TARGETING DCD AT CRITICAL SOURCE AREAS AS A NITROGEN LOSS MITIGATION STRATEGY

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Abstract
The nitrogen (N) discharge allowance (NDA) imposed on Taupo farmers prevents on-going increases in stocking rate to cover ever-increasing costs of production unless effective N leaching mitigation tools are found. The nitrification inhibitor DCD applied to pastures over winter will reduce N leaching, but economics are questionable, especially on sheep and beef farms. This research targets DCD at intensively managed areas over the winter months and at stock camp areas on hill paddocks, where a high percentage of urine is excreted during this period. Two farmers in the Lake Taupo catchment applied DCD to pastures from May/June until September. DCD applications were mapped with a TracMap GPS logger and data were downloaded into a database via the internet. Soil samples were taken twice in 2010 and analysed for nitrate-N, ammonium-N and DCD to characterise DCD efficacy at five depths. Six cattle fitted with GPS collars were tracked through several large paddocks over six weeks to determine in which contour class they camped. DCD applications resulted in elevated concentrations of ammonium-N in the upper soil profile and, in most cases, lowered nitrate-N concentrations compared to control areas not receiving DCD. Strip-grazed crops had substantially higher soil concentrations of ammonium-N and nitrate-N than strip-grazed pastures, as crop density (kg DM/ha) was much greater than pasture density, resulting in greater urinary N return. The full-year, whole-farm baseline N leaching was calculated as 32 kg N/ha. It was calculated that targeting DCD to the 23% of the farm where crops and pasture+baleage were intensively managed over winter reduced leaching loss by 9%. This saved 77% of the DCD-related costs had DCD been applied over the whole farm and allowed a 9% higher stocking rate within the farm's NDA, giving a net return of $7200 for the 129 ha farm. GPS-monitored cows on a gentle hill country paddock did not identify campsites suitable for targeted DCD, but camping along a fence line of an adjacent forest block was evident.

Additional keywords: nitrification inhibitor, grazed pasture, cattle

Introduction

The declining quality of the near-pristine waters of Lake Taupo is of concern. Although agricultural land use accounts for only 22% of the catchment area, 95% of manageable N entering the lake comes from this landuse class. Nitrogen (N), predominantly from livestock urine, is the growth limiting nutrient of most aquatic weeds and periphyton in the lake and so is targeted by Environment Waikato as the best means of managing lake water quality into the future (Environment Waikato 2010).

Farmers in the catchment are required to have resource consent to farm their land. This consent is based on a N management plan that details stock numbers, fertiliser use and management practices which determines the amount of N that will leach from the land. This leached N must not exceed the Nutrient Discharge Allowance (NDA) allocated by Environment Waikato to the farm. The NDA effectively prevents farmers from increasing their stocking rate as, in general, more animals result in more N leached. To off-set ever-increasing farm costs, farmers can use N leaching mitigation strategies; produce new products for niche, high-value markets; or have the consumer pay for the true cost of production that includes environmental production costs (viz. pay more/kg product). Mitigation is the most promising short-term solution and a new approach is presented in this paper.

One tool recommended for reducing N leaching is the nitrification inhibitor DCD (Di & Cameron 2007), but this is uneconomic on sheep and beef farms, especially on hill country (R Webby and B Thorrold, pers. comm.).

Betteridge *et al.* (2010a; 2010b) showed that 50% of urination events by cattle grazing steep hill pastures were excreted in stock camp areas covering just 6 to 14% of the paddocks' area. By contrast, sheep on similar land performed 50% of their urination events over 15 and 30% of the paddock area (Betteridge *et al.* 2010a; 2010b). For sheep, these areas were located at higher elevations in the paddock, often on moderately sloping land that is frequently inaccessible to farm vehicles.

For this three-year study we hypothesise that it might be economically feasible to mitigate N leaching losses from break-grazed pastures and crops during winter and from vehicle-accessible stock camps in hill pastures providing that they can be easily identified from contour maps and other landscape features. As there are numerous reports demonstrating the efficacy of DCD for mitigating N leaching from urine patches (Di and Cameron, 2007, Di et al., 2007, Menneer et al., 2008, McDowell and Houlbrooke, 2009, Williamson et al., 1998, Monaghan, 2009), N leaching was not quantified in this study.

Two farmers in the Lake Taupo catchment implemented *Targeted DCD* as a novel N mitigation strategy to: identify management issues that need resolving; enable soil sampling as an indirect measure of DCD efficacy; test the hypothesis that Critical Source Areas (CSAs) in cattle-grazed pastures can be identified from contour maps; and to provide data for modelling the impact of the *Targeted DCD* strategy on the farm's NDA (average allowable amount of N leached/ha/yr).
This paper presents the first year's data and modelled economic assessment of this N mitigation strategy from this study.

Methods and Materials
Two farms on the western side of the Lake Taupo catchment were used for this study. During the trial period pastures were grazed only by cattle. DCD was applied at the recommended rate of 12 g/m^2 a.i.

Farm 1
This is a 290 effective ha farm carrying 2008 sheep and 284 cows, young bulls and heifers. The farm comprises 26% flat, 48% easy and 26% steep land. Cattle were all wintered on the flat and easy areas of the farm. A brassica crop mix of kale and swedes was grown on 5.5 ha

within a pasture renewal programme. Mixed pastures are dominated by ryegrass or tall fescue, and contained white clover. Pastures had all been renewed during the previous 10 years, where contour allowed. The brassica mix was sown in three areas and was strip-grazed as a sole ration by 56 rising one-year-old (R1) heifers, 56 R1 bulls and 20 R2 bulls in their respective mobs, over 80, 91 and 40 days respectively, from late May. From mid June 115 R2 and mixed age (MA) cows strip-grazed pasture. Where pasture mass was about 2000 kg DM/ha two round bales of baleage/day were given as a supplement, but in paddocks with around 2800 kg DM/ha only one bale/day was used. This management lasted about 64 days until calving. All cattle were given a new break of feed daily, without back-fencing. The farmer made all livestock management decisions.

The Ravensdown product ecoN® was applied as a suspension using a Goldacre, single jet spray unit towed behind the farm's quad bike. The suspension was made immediately before application and was maintained as a suspension by the action of the by-pass flow returning to the spray tank. To reduce the farmer's workload, he was permitted to spray pasture up to 7 days before and up to 14 days after a feed-break was grazed, while still ensuring DCD efficacy. To represent a Control treatment, some areas were marked with pegs to indicate where not to apply DCD. Some of these areas had not been grazed whereas others had been grazed before the first soil sampling, but neither received DCD.

To optimise spray application and to provide auditable data, the quad bike was fitted with a TracMap® GPS logging system. Before spraying, a new file was entered into the GPS to show the paddock's boundary fences. The sprayer's bout width was entered so that as the bike moved around the paddock the sprayed area was blacked-out. This ensured that the farmer obtained complete coverage without overlap. Upon completion of spraying, data were transferred to a computer and exported into the TracMap® website for data processing and storage. A summary of each spraying operation (time spent, product applied and area sprayed) was emailed to the farmer for his records. DCD application started on 17 June and finished on 20 August.

Modelling

For the purposes of modelling, Farm 1 was redefined as 129 ha of flat to rolling land grazed only by the cattle groups described above. The pasture system was modelled using the Agricultural Production System Simulator (APSIM, Keating *et al.* 2003). The *AgPasture* module (Li *et al.* 2010) was used to simulate pasture growth rates, animal consumption and associated N uptake (from soil and biological N fixation) and N return through animal dung and urine. The S*WIM* module (Verburg *et al.* 1996) was used to simulate soil N movement and estimate N leaching. Pasture management was simulated based on the grazing system of strip-grazed crops and pasture described for Farm 1, followed by pasture grazing for the remainder of the 12 month period, assuming pasture production of 9500 kg DM/ha/yr. Baleage (1622 kg DM/ha) was made within the system from non-strip grazing areas and was fed to animals when they graze the strip-grazing area in winter. Published standards for urine output by age and gender were used, and urine patch overlap effects on N leaching was assumed within intensively managed areas over winter, only. DCD was assumed to reduce N leaching by 40% (an assumption based on very high urine density) and 25% ((Cichota et al., 2010)Cichota et al., 2010, (Cameron et al., 2007)Cameron et al., 2007) in the crop and strip-grazed pastures respectively, during winter. Twelve-month baseline leaching over the whole farm, without DCD, was compared with the same system where targeted DCD was applied during winter.

Farm 2
This was a large Maori-owned Incorporation with 2,500 ha of developed land which carries sheep, beef and deer on mixed pastures and winter crops. Two large pasture paddocks (480 m asl) of flat to rolling contour, strip-grazed by cows or R1 heifers, were used for *targeted DCD*. Supplementary baleage was provided. Cows with GPS tracking units grazed a third, 67 ha hill paddock with a mean elevation of 820 m asl, to identify campsites. The low areas have an annual rainfall of about 1200 mm whereas the high elevation paddock is much colder in winter and has rainfall in excess of 3000 mm/yr.

The Ballance AgriNutrients DCn® product was applied as a dry prill with a C-Dax fertiliser spinner towed by a quad bike. The TracMap® GPS logger was used to detail the two DCD applications to the lowland paddocks. Grazing of trial areas was from 15 June through until 16 September and DCD was applied from 6 July until 23 August for both MA cows and steers.

Six MA cows were fitted with a GPS collar (Betteridge et al. 2010b) between 11-26 August while grazing the large paddock with a mob of 70 other MA cows. In order to prolong the battery life of the GPS units, they were programmed to record cattle position continuously for 10 min, followed by a 20 min shut-down. Average slope across 25 m2 grid cells overlying this paddock were calculated from a 5 m digital elevation model. Campsites were assumed to be potential CSAs as cows move very little from these areas during the hours of darkness. Slopes of these campsites were assessed to determine if they were suitable for targeted DCD.

Soil sampling and analyses
Sites on both farms were sampled twice, the first sampling on 4th or 9th August and second sampling 14-15 September. Sites were randomly selected and marked with a peg for the second sampling. Soil was sampled at five depth strata, 0-75, 75-150, 150-300, 300-450, 450-600 mm and five replicate samples were collected from each strata at each site, and bulked. At the sampling, the various sites had received no, one or two DCD applications, depending upon the site's position within the grazing programme and the timing of the DCD application. Each pegged site was GPS-registered to accurately locate it on the GIS map. This enabled the matching of grazing and DCD application data in relation to soil sampling dates.

On Farm 1, 34 sites were selected of which; 9 sites were within a brassica crop grazed by R1 bulls, 9 were within a brassica crop grazed by R1 heifers and 16 sites were within 3 paddocks grazed by MA cows. On Farm 2, three DCD-treated sites were sampled in the MA cow-grazed pasture and six DCD-treated sites and four control sites were sampled in the steeper heifer-grazed paddock. Combined results from this farm are presented in this paper.

Bulked soil samples were placed in a plastic bag and stored outside, in the shade, during the collection periods. At the lab, samples were chilled to <5°C and analysed within one week. The five replicate core samples within each depth horizon at a pegged site were thoroughly mixed. A 7 g sample of fresh soil was extracted in 40 ml of 2 M KCl for N assays. Another 15 g fresh weight sample was extracted in 40 ml water for DCD analyses. Extractions were done over 1 h in a rotary shaker. Following centrifugation and filtering the supernatant was assayed for ammonium-N and nitrate-N by flow injection analysis. The method for nitrate+nitrite was according to ISO 13395 and the method for ammonium is according to ISO 11732. The DCD was determined by the method of Schwarzer and Haselwandter (1996) on a Shimadzu LC-6A high performance liquid chromatograph with an Aminex organic acid column HPX-87H 300x7.80 mm. Data were corrected to a soil dry weight basis.

Results and Discussion

Practical issues

DCD applied either as a suspension or in the granular form was found by the two farmers to be easy to apply. However, a good high flow water supply is necessary when making the suspension of ecoN® as filling a 200 l tank with a slow flow supply would be unacceptable. Farmer 1 used a 600 l tank with a 50 mm tap. Allowing the three-week window of time during which to apply the DCD is considered essential for farmer's who wish implement *targeted DCD* using their own equipment, as it would be impractical to spray small strip-grazed areas each day after grazing.

Neither farmer had difficulty in using the TracMap® GPS system after they had used it once. They found the system very useful in achieving complete coverage without overlap and valued the emailed summary showing when and where DCD had been applied. A reminder via email from the central database, or from the farmer's own computer's calendar, would be useful to ensure that the second application of DCD was made at the correct time to the correct strips or paddocks. For Lake Taupo farmers to receive a N credit through use of targeted DCD, it is envisaged that auditable records would need to be available to the regional authority. This would be possible from the TracMap® system, or similar.

Farm1

As this study aimed to identify practical issues for farmers using *targeted DCD*, interpretation of the soil test data which were without an experimental structure (Fig.1) was difficult. For example, the interval between when urine was excreted on a daily feeding break relative to when DCD was applied and, when soil samples were taken, varied greatly. Break-grazing of crops started 3 months before the first soil sampling and had, therefore, received both DCD applications by that time. In this case, some of the earliest urinary N would have leached quite deeply before sampling. By contrast, in the cow grazed-systems, the first grazing, the first urine excretions and the first DCD application were likely to have happened only days before soil sampling. Not having back fences, especially on the crops, would have exacerbated this problem of chronological confounding of activities since fresh urine could have been excreted on soil treated with DCD several weeks earlier. For these reasons statistical analyses were not attempted. However, generalisations upon the efficacy of DCD were still possible by comparing the relative amounts of ammonium-N and nitrate-N in the soil horizons.

R2 and MA cows

<u>*Zero DCD*</u> The three Control sites each showed DCD in the upper two soil horizons in August (Fig. 1A) even though none was applied by the farmer, as confirmed from the TracMap® records. This contamination would have been caused by cows eating DCD that was applied to pasture a couple of days before it was grazed and then excreting it, in urine, on to Control sites the following day. This was possibly at less than the optimum application rate for inhibiting nitrification over the following six weeks. This is supported by findings of S. Ledgard (pers. com.) that >90% of DCD drenched to cattle is excreted in urine. This contamination possibly resulted in similar amounts of ammonium-N and nitrate-N in the top horizon in August, whereas at the September sampling, when the 'accidentally applied' DCD had leached away from the top horizon, nitrate-N was five times more concentrated than ammonium-N in the 0-75 mm zone. In September, DCD was detected only in the 150-600 mm soil horizons of these same Control sites and, as concentrations of ammonium-N were so low, there appears to have been no carryover nitrification inhibitory effect from the first soil sampling.

Single DCD application Ammonium-N and nitrate-N concentrations in the 0-75 mm horizon were of similar magnitude in August. There were no sites with only 1 application in September (Fig. 1 B). As expected, DCD (concentrations are shown as 10x their actual level) was seen in the soil horizons in August and should have caused a lower concentration of nitrate-N, than was found.

Double DCD application Where two application of DCD had been applied prior to the September sampling (Fig. 1C), ammonium-N was the predominant form of N, especially at the first sampling, while at the second sampling there were relatively higher concentrations of nitrate-N and no evidence of DCD in the 0-75 mm horizon.

R1 Bulls and Heifers on crop
Control In control plots (Fig. 1D) high concentrations of both ammonium-N and nitrate-N were detected in the 0-75 mm horizon, at both the first and second samplings. This reflects the recent excretion of urine (urea) which generally elevates ammonium levels in the few days following excretion, before being nitrified to nitrate. As there were no back fences used, these young cattle roamed and urinated randomly over the whole previously-eaten-off areas. As no DCD was able to be applied to the standing crop, as it was with pasture- fed cows, these animals were unable to contaminate the Control sites with DCD. Relative to nitrate-N, very little ammonium-N was detected below the 0-75 mm horizon at either sampling.

Double DCD application Where two applications of DCD had been applied by the August sampling, ammonium-N was four times higher than nitrate-N in the top horizon, which was low and similar amongst all horizons at both sampling dates. Some ammonium-N was seen in the second depth horizon at both soil samplings. Again, DCD had leached to lower horizons, being particularly noticeable in September.

Full-year leaching estimates from grazing studies assume that spring pasture growth will utilise the N protected from loss by leaching by application of DCD. In the winter cropping situation this may not apply since the crop stubble and soil must be worked up and the new pasture or crop sown. This then has to develop an adequate root system capable of capturing soil N. In the Lake Taupo catchment, good spring growth of new pastures is unlikely until late October-November, but we have frequently measured leaching events at 600 mm depth, in October. Therefore, a strategy that captures this nitrate from spring nitrification following cropping, is required.

Farm 2
MA cows and R1 heifers
Zero DCD The un-grazed sites had <10 µg N/g soil (ammonium-N and nitrate-N) at both sampling events at each soil depth (Fig. 2F), with concentrations diminishing with depth, reflecting the long period since these sites had been grazed. In lower strata these concentrations were little different from equivalent Control sites.

Single DCD application Unexpectedly, DCD did not elevate ammonium-N concentrations at the August sampling from the baseline level of 0.43 µg ammonium-N/g soil even though there was DCD detected within the soil profile (Fig. 1G). Perhaps the lower August concentration (0.451 µg DCD/g soil) in the 0-75, compared to 1.8 µg DCD/g soil the 75-150 mm horizon contributed to this finding. In contrast, the 5.2 µg/g dry soil concentration of ammonium-N soil and the higher nitrate-N concentration in September reflected the extra five weeks of grazing in this one paddock, without back fencing.

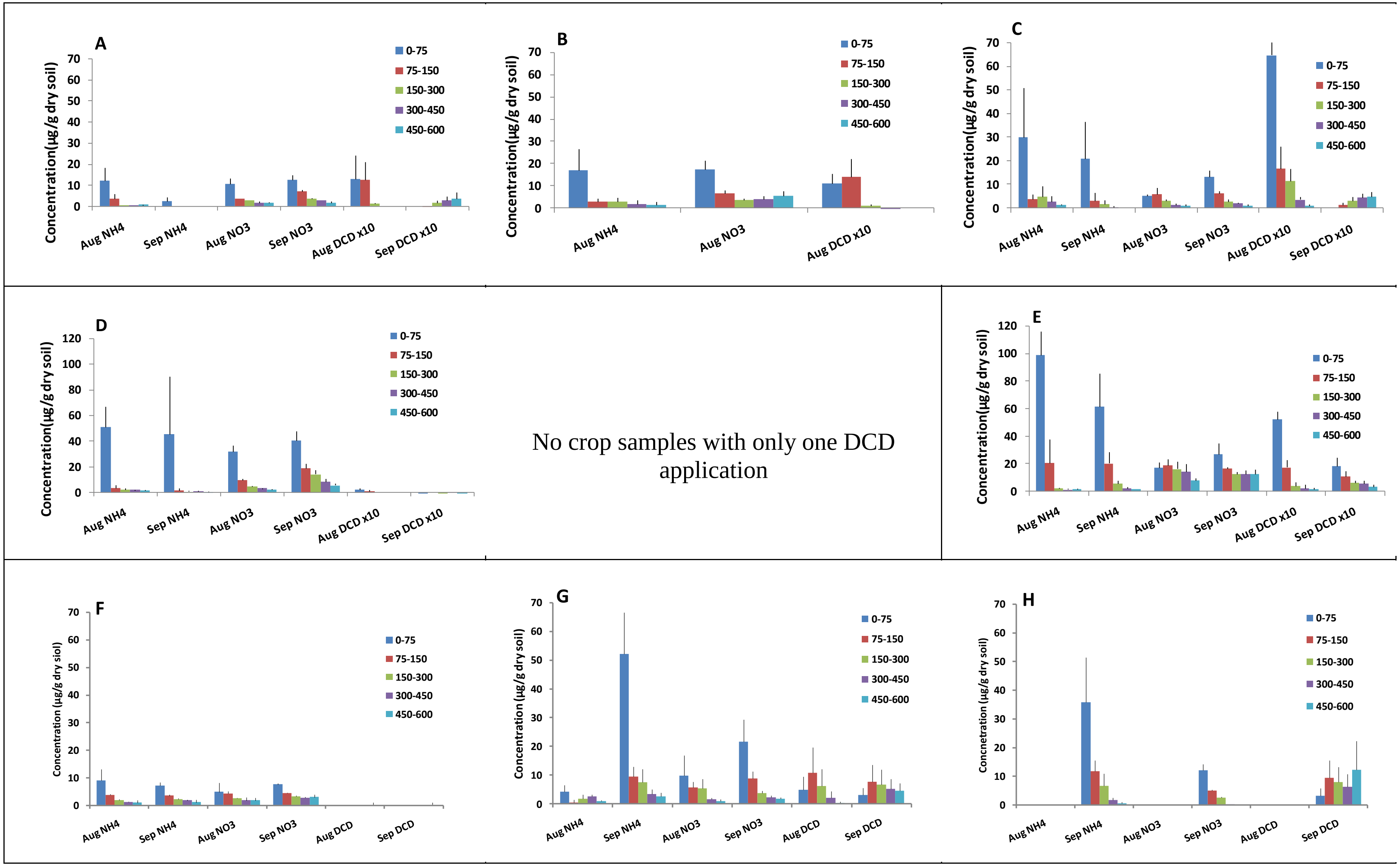

Figure 1 Mean (1/2 SD) soil concentrations of ammonium-N, nitrate-N and DCD (x10) at five soil depths, sampled on 10 August and 16 September, 2010, on two farms in the Lake Taupo catchment. Farm 1: A, B, C – pasture with baleage, D, E - brassicas only; Farm 2: F, G, H - pasture with baleage. Data the left hand column is from Control plots without DCD; centre column two sites that had received only one application of DCD before sampling; right hand column, sites that had received two applications of DCD before sampling.

Double DCD application Where two applications of DCD had been applied before the September soil sampling (Fig. 2H), ammonium-N concentrations were higher than nitrate-N in the upper strata and DCD was detected in each of the soil strata. These results confirmed that the application of DCD to reduce nitrate-N in top soils over winter was effective.

GPS movement of six cows

The slope classification of the grid cells overlaying the 67 ha paddock grazed by cows with GPS collars showed the 5-10˚ class comprised the greatest percentage of the paddock area with similar, though smaller percentages in the 0-5˚ and 10-14˚ classes (Fig. 2). The cows almost totally stopped eating between sunset and sunrise and moved very little from where they first lay down (data not shown), as reported in other studies for both sheep and cows (Betteridge *et al.* 2010a). The average 7.3˚ slope was less steep than we required to properly evaluate the hypothesis that camping in steep hill country takes place on the lowest slope class. This was confirmed by the fact that individual cows rested in many different areas over the 15 days, suggesting there were no clearly evident campsites for targeting DCD (Fig.3).

Although only one third of all animal movement was recorded by the GPS, we believe that this did not compromise our intent of determining where cattle rested, since true rest lasts several hours and this would have provided several consecutive readings at any one site. In this paddock >90% of the land was potentially suited to spreading of DCD by farm vehicle and this failed to meet our hypothesis that DCD could be economically targeted to a small percentage of the land area in hill country to mitigate N leaching from a large percentage of urine patches. Future research must determine the slope class distributions that generate easily defined stock camps that suit this mitigation strategy.

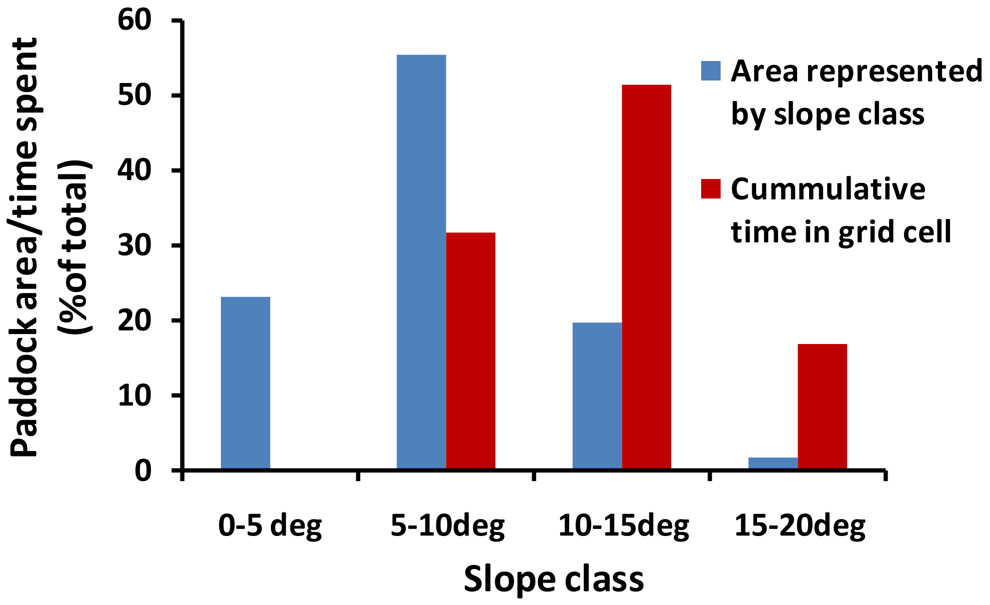

Figure 2 Slope classification of a 67 ha paddock grazed by 6 cows fitted with GPS collars over 15 days. The average paddock slope (7.3˚) was derived from the average slope within each 25 m^2 grid cell overlaying the paddock. Slope classes are classified as a percentage of the total area. GPS collars logged movement for 10 consecutive min in every 30 min. cumulative time is total time spent within each cell by all GPS animals.

Modelled effect of DCD on Farm 1

Without DCD the year-round whole-farm estimate of leached N was 32 kg/ha. Assuming *targeted DCD* gave a 40% reduction in leached N in strip-grazed crops and a 25% reduction in strip-grazed pasture, leached N was estimated to be 29 kg/ha/yr. This equates to an 8.9% reduction due to DCD. As these intensively grazed areas occupied only 23% of the whole farm, this required 77% less DCD than if it had been applied to the whole farm, as is presently recommended for dairy farms. Given that all the urine excreted from May/June through until calving was treated with DCD in this Case Study, the DCD-related costs were 77% lower, without loss in the potential effect of DCD had it been used over the whole farm. The APSIM model shows that the highest annual leaching loss occurs from urine deposited in late summer and early autumn (Volger *et al.* 2010). However, because DCD used in warm seasons has reduced efficacy (Kelliher *et al.* 2008), it should not be applied when the soil temperature exceeds 15˚C. As in the Lake Taupo catchment this state may not be reached until late-April or May, farmers should not start DCD applications before May.

Assuming a 9% reduction in N leaching due to *targeted DCD* allows the farmer to increase the stocking rate by 9%, 168 more sheep stock units (ssu) could be carried in this Case Study. Using a cattle breeding & finishing gross margin of $65/ssu and after deducting the cost of applied-cost of DCD for the 23% of the farmed area grazed during winter, a net return of $7200 was generated without the farm's assumed NDA of 32 kg N/ha/yr being exceeded.

More detailed modelling with the present and the next two years of measured N concentrations in the 450-600 mm depth soil profile, is planned. As the estimated potential for N to leach can be determined from the product of N concentration in the 450-600 mm horizon and drainage volume, these values will be used as a surrogate for measured N leaching, with which to better parameterise APSIM.

Conclusions

With few exceptions, DCD resulted in the expected elevation of ammonium- and reduction in nitrate-N concentrations in the upper strata of the soil at both sampling dates. Compared to strip-grazed pastures, the grazed-crop paddocks had substantially higher concentrations of N in the top soil due to the longer period of time animals spent in these confined areas. Because cropping is invariably performed on vehicle-accessible land, these critical source areas are ideally suited to the *targeted DCD* mitigation strategy. In our Case Study, DCD was required only on the 23% of the farm that was intensively managed between June and mid-August yet provided the same 9% reduction in N leaching that would have been achieved if the whole farm had been treated with DCD. The reduction in the amount N leached would allow this farmer to increase his stock numbers and, therefore, gross margin, while remaining within the farm's NDA. Hill land with an average slope of 7-8˚ is not conducive to establishment of stock camps. Further work is required to define the class of hill country which lends itself to *targeted DCD* so that a farmer can economically use this mitigation opportunity to increase the farm's stock numbers without exceeding the farm's NDA.

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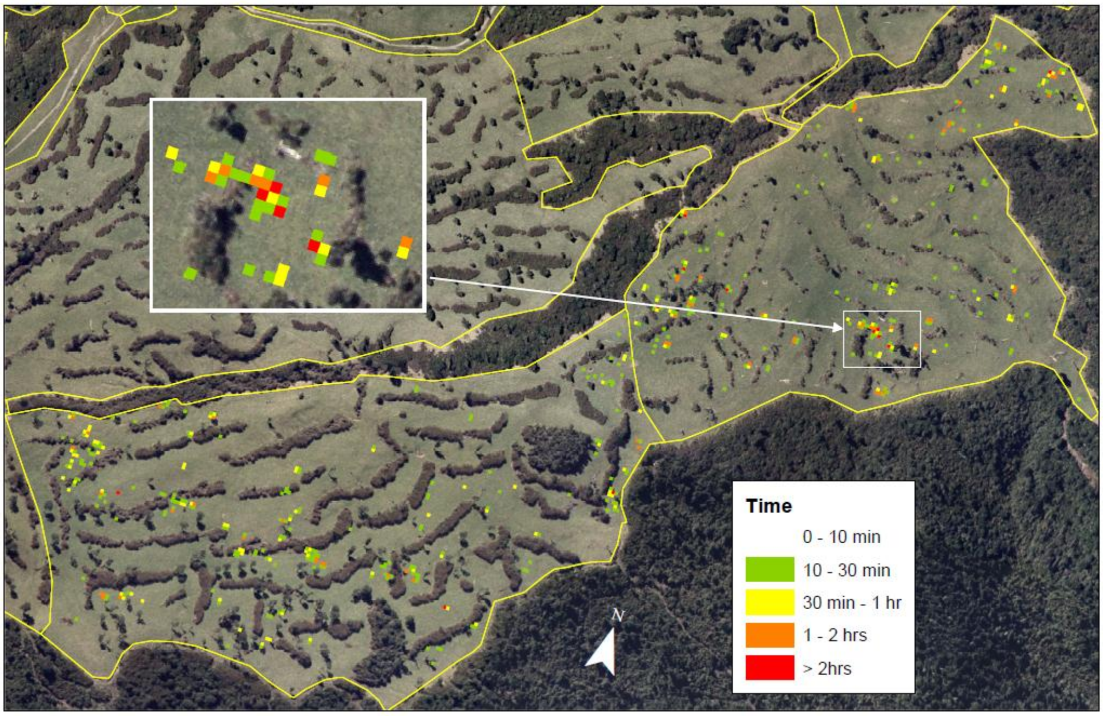

Figure 3 Cumulative time (minutes) spent by six cows with GPS within 25 m^2 grid cells in this 67 ha paddock with average slope 7.3˚.Grazing was between 11 and 16 August 2010. The gate between the two bottom paddocks was open and the paddocks were treated as one. The inset shows more detail of one area. Scattered trees and windrows of trees cleared during land development are easily seen.

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