PASTURE DRY-MATTER RESPONSES TO THE USE OF A NITRIFICATION INHIBITOR: A SUMMARY OF A NATIONAL SERIES OF NEW ZEALAND FARM TRIALS

P. L. Carey[1], S. Jiang[1] and A.H. Roberts[2]

[1] Land Research Services Ltd, Arts Workshop, PO Box 84, Lincoln University, Lincoln 7647
[2] Ravensdown Fertiliser, PO Box 608, PUKEKOHE 2340
Email: peter@lrss.co.nz

Abstract

The use of a nitrification inhibitor, such as eco-nTM, to reduce nitrate leaching and nitrous oxide emissions in grazed pastures has become increasingly commonplace, especially on NZ dairy farms. Reducing these types of N losses has a potential benefit to boost dry-matter production but results have varied. We collated pasture response data from a national series of farm trials conducted in 132 paddocks on 37 farms in the North (NI) and South (SI) Islands of New Zealand where paddocks were randomly split into two halves and one half treated with eco-n whilst the other half was not. Measurements were made using pasture plate meters and conformed to a strict protocol.

There was a highly significant overall DM response to eco-n use of 19% across all trials (14% NI; 21% SI) although full year responses were more variable between NI regions (4-27%) than SI regions (12-31%). Generally, DM responses were greater than those demonstrated by previous small-scale experimental trials and this may indicate the influence of a farm-system effect. We speculate several reasons for this effect but further research is required to identify the factors involved.

Keywords: dicyandiamide, grazing, N cycle efficiency, farm system, grassland, eco-n

Introduction

The use of nitrification inhibitors such as dicyandiamide (DCD) has become increasingly common in New Zealand (NZ) pastoral farming, especially within the dairy industry. Published research in 2002 first showed its potential effectiveness in Canterbury to reduce nitrate leaching and nitrous oxide emissions within urine patches (Di & Cameron 2002; Di & Cameron 2005). It was also noted that in reducing losses of urine-N to both processes, there is an increased potential for the retained N to increase dry-matter (DM) production and reduce N fertiliser application, thereby increasing farming efficiency and productivity.

Commercialisation of this technology by Ravensdown first occurred in 2004 and the resulting product, eco-n™, a fine-particle suspension of dicyandiamide (DCD), is applied through a contractor-based spray application system. There has been increasing use of eco-n™ throughout NZ since its introduction to both reduce nitrate leaching and boost pasture growth but its efficacy in relation to pasture growth has been subject to enquiry recently in regions outside Canterbury (Edmeades 2010; Vogeler et al. 2011). Whilst there are a number of soil and climatic variables that might affect the performance of nitrification inhibitors, there has not to date been a national series of farm trials analysed to evaluate how effective eco-n is in increasing DM production in differing regions of NZ. Published results of eco-n trials have also largely been experimentally-based to date, using small plots, and there has been limited reporting of actual farm-scale data on working dairy farms.

This paper presents a summary of a national series of on-farm trials coordinated by Ravensdown where DM response data for eco-n and non-eco-n split-treated paddocks has been recorded by a range of third parties in various regions throughout NZ.

Materials and Methods

Farm and paddock selection

Farms were selected by Ravensdown within each region and trials were established on the basis of the farmer's willingness to participate and to follow the criteria outlined in the protocol for the rising plate measurements. Trials were distributed between South (SI) and North (NI) Island regions and on average, 4-5 paddocks were selected per farm but the actual range was from 1-16. Paddock numbers were greater overall for the NI trials but the SI had more farms so that overall, paddock numbers were similar (Table 1). Not all major milk producing regions were represented in the trial program but those that were, covered a wide range in rainfall and temperature (Table 1). The trials were conducted between 2006 and 2011.

Paddock selection was based on the following criteria:

1. Likely to be grazed in the autumn during April/May;
2. Uniform in contour, pasture species, grazing management, fertility and water distribution (no border-dykes);
3. Not effluent blocks unless effluent was to be applied to the whole farm evenly.

Trial and measurement procedure

All trial paddocks were set up as two half-paddocks with one half chosen randomly to receive eco-n at the standard rate (10 kg DCD/ha) while the other half received nil. This was to try and ensure that soils, fertiliser application, stock management, pasture species, pasture age and fertility were as similar as possible. Paddocks also had to provide transects of minimum length of 50 m, and preferably longer. The DCD was applied once by a commercial spray contractor during May to June (NI) or April to June (SI), and again in either July-August (NI) or July-September (SI) and usually within seven days of grazing. Grazing generally occurred on both sides of the paddocks simultaneously. No attempt was made to impose uniform management between farms so datasets covered a range of individual farm management variation.

At least 60 rising pasture plate measurements were taken on each half-paddock area, pre- and post-grazing, but followed the same path each time, avoiding water troughs, gateways and other non-uniform areas. Ideally, these were taken within two days of actual grazing and readings were converted to kg DM/ha using the appropriate calibrated formula. Pasture growth measurements were made by contracted research individuals or organisations, contracted technicians, Ravensdown staff or, in a few instances, farmers.

Pasture mass data was recorded from the time of DCD application but DM responses largely occurred from July/August onwards and if measurements finished prior to the late-December/mid-January period then this was considered a "spring" trial while measurements finishing after this time, from late-February-to-mid-April, were considered "full-year trials". Total spring and full-year DM production figures were constructed from this data for each island, and where data was reasonably consistent from month-to-month allowed DM response rate figures to be interpolated for each month. A total of nine NI farms were used for these monthly calculations with all regions from the main data pool represented by at least one farm whilst eight farms represented SI regions, mainly from the Southland, Otago and Canterbury regions. Monthly DM means were transformed (log) to help satisfy the assumption of equal variances ("homogeneity of variances") and smooth the effects of varying numbers of means for the beginning and end of each 12 month period. The mean values were then back-transformed to give the 'geometric means'.

Table 1. Trial locations and paddock numbers, mean annual rainfall, air temperature and soil temperatures for trial regions.

Trial locations	*Total farms*	*Total paddocks*	[a] *Ann. RF (mm)*	*Av. air temp (°C)*	[b] *Av. soil temp (°C)*	[c] *Soil class.*	[d] *Drain class.*	*Stock. Rate (cows/ha)*
North Island								
Northland	4	10	1490	15.5	14.9	O,G,U,B	2-5	2.3-2.6
Taranaki	4	25	1900	12.9	13.3	A	5	2.3-3.8
Waikato	2	26	1190	13.7	13.3	A	5	3.0-3.5
Taupo	1	3	1102	13.0	11.5	M	5	2.7
Wairarapa	2	4	970	13.3	12.7	A,P	3-5	2.3-2.8
NI total	13	68						
South Island								
Marlb-Nelson	1	5	970	12.8	11.5	R	4	2.8
West Coast	2	5	2300	11.7	11.3	R	3-5	1.4-3.2
Nth-Cant	5	11	[e] 750	12.4	11.0	P,B	3-5	2.6-4.4
Sth-Cant	7	16	[e] 570	11.3	10.4	P,B	3-5	2.6-4.4
Otago	7	16	[e] 810	11.1	9.6	R,P,G	2,3,5	2.6-3.0
Southland	2	11	1100	9.9	9.0	R,G	2,5	2.5-3.0
SI total	24	64						
NZ Total	37	132						

[a] Annual rainfall; [b] 0-10 cm; climate data from long-term NIWA climate summaries (NIWA 2011); [c] NZ revised soil classification (Hewitt 1993) A- Allophanic; B- Brown; G- Gley; O- Oxidic; M- Pumice; P- Pallic; S- Sedimentary; R- Recent; U- Ultic; [d] Drainage class: 2- poor; 3- imperfect; 4- moderate; 5- good (Leathwick et al. 2002); [e] Rainfall was generally augmented by irrigation from late October-to-April for these regions to an approximate total of 1100 mm i.e. ~500 mm irrigation).

Statistical analysis

Most major milk producing regions were represented in the range of trials undertaken (but not all) although total numbers of trials and paddocks were not necessarily evenly distributed across them.

The data for as many trials was included as possible, regardless of the significance of results, and excluded only for the following reasons:

1. Too many grazing measurements were missed such that it seriously affected the dataset's integrity.
2. DM responses were compromised by poor soil or pasture management within the paddock.

Data for a total of 132 paddocks (split into halves) from 37 trials (13 NI, 24 SI) met the criteria for inclusion in the analysis and this was considered sufficient to conduct an adequate statistical test of the data and for predictions within each region to be reasonably accurate based on current farm practice and performance. Data for 32 paddocks from five farms was excluded based on the above criteria.

Data was analysed as 37 pairs using a simple paired t-test comparison in the statistical analysis module of Microsoft Excel. Each pair represented the mean production for both treatments from however many paddocks were monitored; anything from 1-16. Data was analysed this way in order to remove the potential conflict to the independence of the t-test values for paddocks under similar management within farms but we also measured it as individual paddock pairs. Least significant differences (LSD) and tests for significance (p values) were calculated from the t-test values for each set of comparisons. Means across all paddocks are included for comparison.

Results

Mean pasture DM values for eco-n and nil treated split paddocks and percentage increase in DM responses (eco-n over nil treated areas) for spring and full year trials for both islands are shown in Figures 1 and 2, respectively. For spring trials there was an overall increase in DM response of 12% for NI trials and 21% for SI trials, whilst for full year trials the mean increase was approximately 20% and 22% for North and South Island trials, respectively. The response for eco-n over nil treated paddocks for all trials was 19% (CI 95% 15-23%), averaging 14% and 21% for North and South Island farms, respectively (Figure 2). Differences between the two treatments were highly significant overall with p values for the spring trials for both Islands and NI full-year trials ranging between $p<0.01 – 0.001$ (1%-0.1% level) whilst for the SI full-year trials the p value was <0.05 (5% level). Least significant differences between the treatments were therefore, correspondingly small for most comparisons except the SI full year trials where the total number of farms was only four (Figure 1). When data was analysed by paired split-paddocks (132 pairs) rather than paired trials, the data was broadly similar with an overall mean in DM response for the eco-n over nil treatment of 18% (Table 2).

Whilst DM responses were positive overall for the effects of eco-n over nil-treated areas, responses varied considerably between regions and individual paddocks (Table 2). Responses for the Waikato were lowest overall, ranging from 4-7% but conversely responses for the Taranaki trials were some of the highest at 23-27%. South Island trials ranged similarly from 6-31% but paddocks at the lower end of this spectrum comprised a small minority. As the DM frequency response graph shows in Figure 3, the mid-range response rate was similar to the mean response rate at around 17% and the response distribution was basically sigmoidal.

Monthly growth patterns differed between North and South Island trials with the main growth period occurring from September-to-April for NI trials (Figure 4) whilst for the SI trials, growth peaked more sharply over the months of October-to-March (Figure 5).

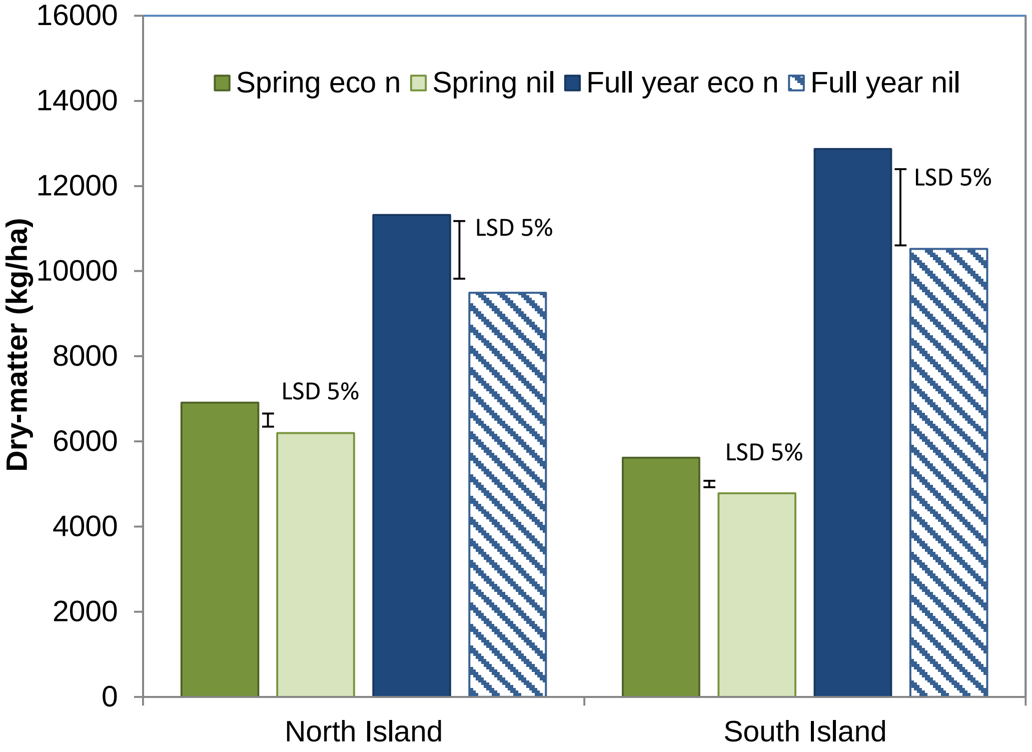

Figure 1. Mean DM production values for eco-n and nil treatment trials for spring (Jul-Jan) and full year (May-Apr) North and South Island trials. LSD (5%) bars shown.

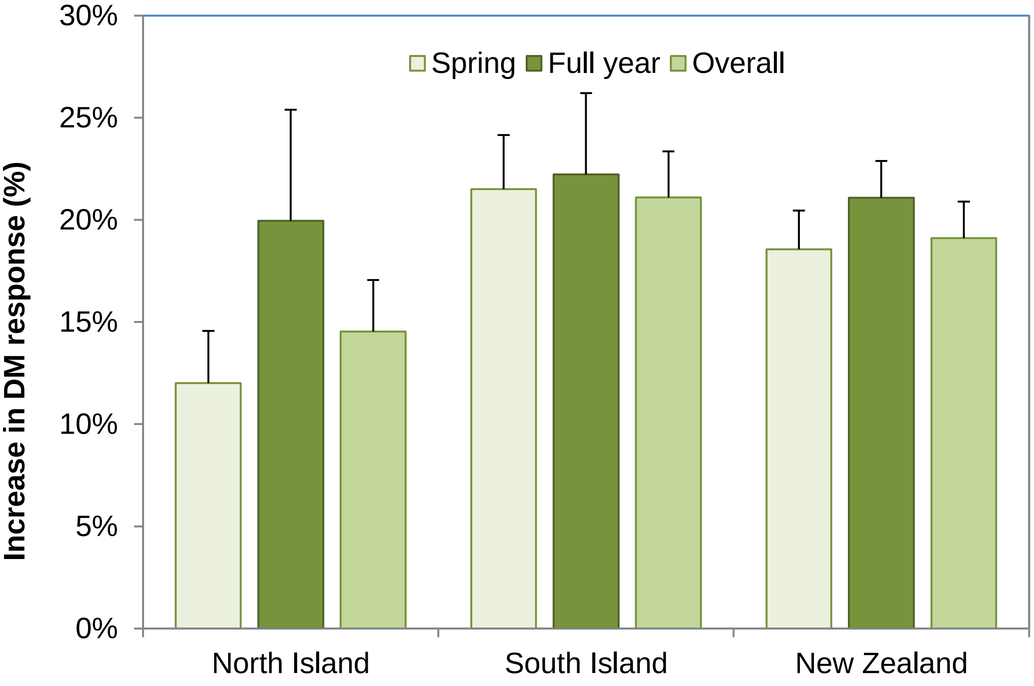

Figure 2. Mean percentage increase in DM response for eco-n over nil treatment trials for spring, full year and overall NI, SI and all trials (NZ). Standard error bars shown.

The percentage response for eco-n-treated NI areas was least over the spring-summer months at around 11-12% but for the same period for the SI trials, responses averaged 19%. During the autumn-winter months DM response rates were similar for both islands at 14-17%. There were, however, fewer data points early or late in the season for both sets of full-year trials so caution is required about making any firm comparisons here.

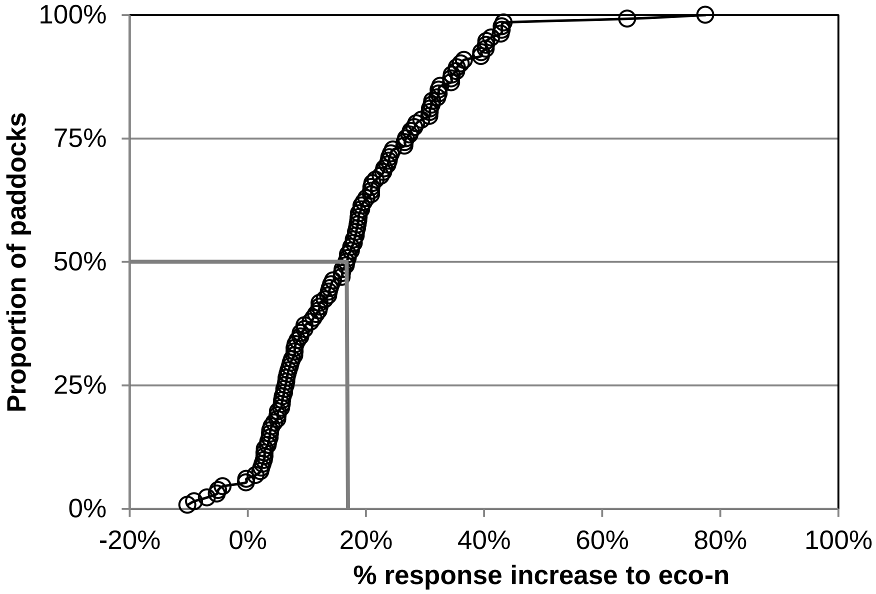

Figure 3. DM frequency response graph for eco-n over nil treatments for all paddocks. Vertical line shows median response.

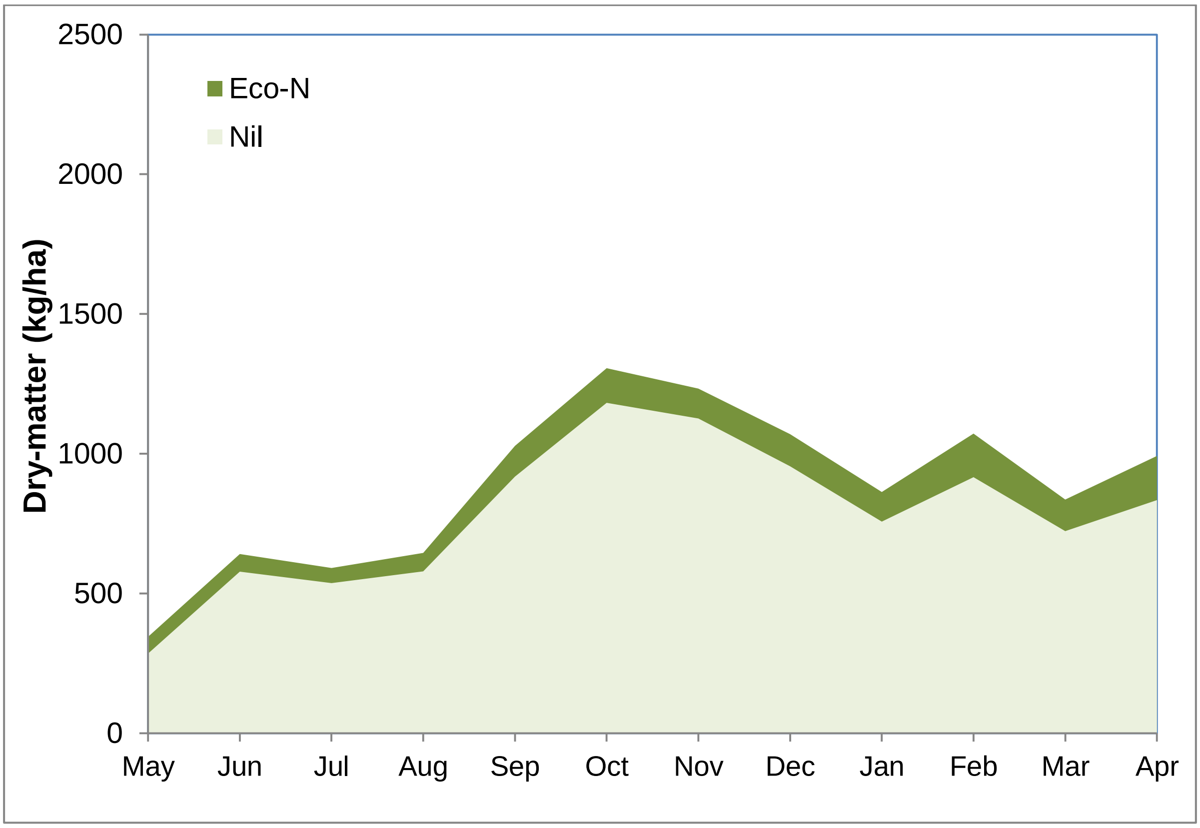

Figure 4. Geometric monthly means for DM production rates for eco-n and nil treated paddocks for nine NI trials.

Table 2. North and South Island spring (July-Jan) and full-year (May-Apr) trial means for eco-n and nil treatments and numbers of paddocks in each region.

Region	**Eco-n**	**nil**	**net diff**	**DM resp %**	**Pdk nos.**
Spring trials					
Northland	8068	7341	727	10%	10
Taranaki	7242	5932	1311	23%	2
Waikato	4794	4514	280	7%	16
Taupo	6698	6536	161	3%	3
Wairarapa	5417	4910	507	10%	2
NI mean	6145	5664	481	9%	33
Marlb-Nelson	6134	5479	655	13%	5
West Coast	8309	7814	495	6%	4
Nth-Cant	4544	3488	1056	32%	7
Sth-Cant	4392	3689	704	23%	15
Otago	4880	4063	817	25%	16
Southland	3803	3364	440	14%	8
SI mean	4911	4188	723	21%	55
Spring mean	5374	4741	633	17%	88
Full year trials					
Taranaki	12138	9628	2510	27%	23
Waikato	10219	9784	436	4%	10
Wairarapa	11090	9215	1875	21%	2
NI mean	11530	9649	1881	20%	35
West Coast	13855	10565	3290	31%	1
Nth-Cant	7205	6621	584	12%	4
Sth-Cant	12678	10481	2197	21%	1
Southland	17746	14414	3332	25%	3
SI mean	12066	10086	1980	19%	9
Full year mean	11639	9738	1901	20%	44
Grand mean	7462	6407	1055	18%	132

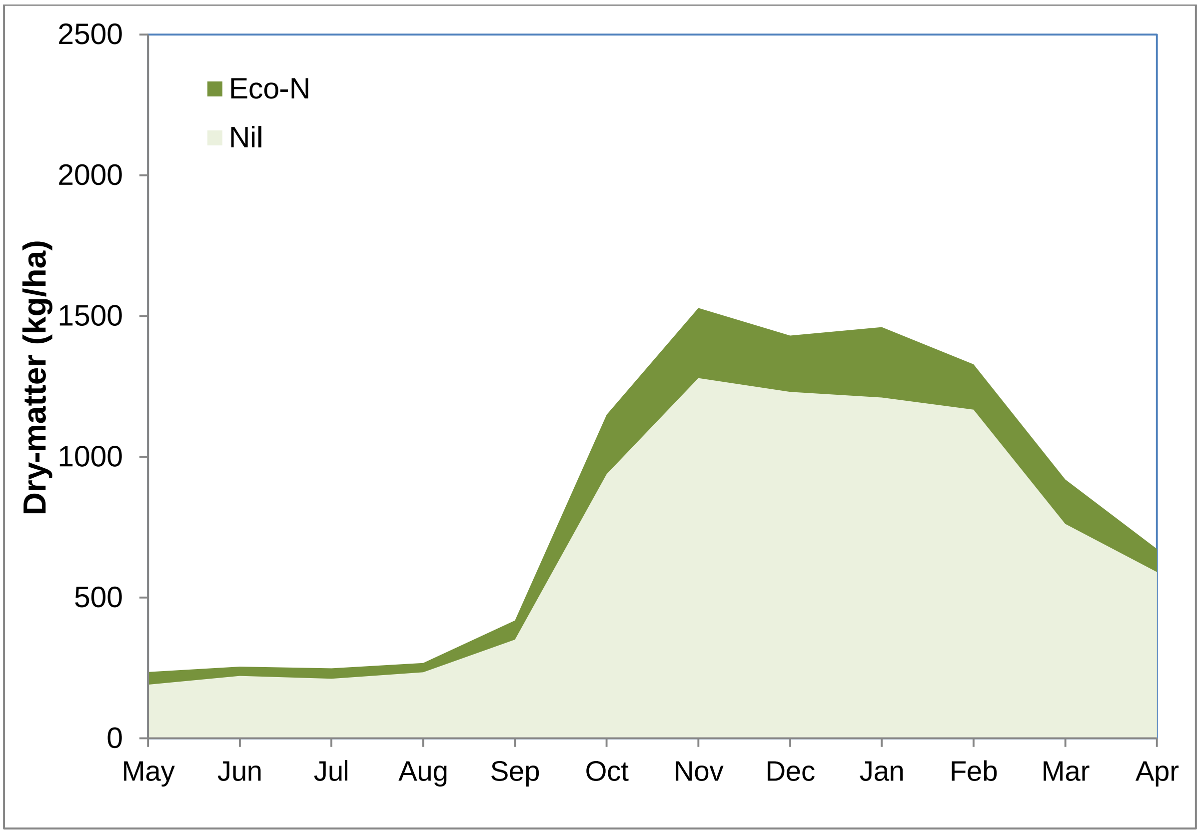

Figure 5. Geometric monthly means for DM production rates for eco-n and nil treated paddocks for eight SI trials.

Discussion

On the balance of the farm trial data there is strong evidence to show that using eco-n is an effective means of increasing DM production. This increase in DM production is likely to have occurred through the reduction in N loss resulting from the application of the DCD nitrification inhibitor in eco-n (Di & Cameron 2002; Di & Cameron 2005; Di & Cameron 2007). Unknown, however, is why it appears less effective in some NI regions, specifically the Waikato, but at the same time is very effective in other NI regions such as Taranaki. Rainfall, and presumably drainage, is higher for the Taranaki farms than the other NI and SI regions so some of the difference may be explained by this but the reality is that pasture response to DCD application will vary depending on farm, climate and soil factors (Table 1). The benefits of this data set is that it covers a wide range of these factors and that significant gains still seem possible in most regions even though the individual factors responsible for differences are unclear at present. Whilst we know that use of DCD has other benefits in reducing, for example, nitrous oxide emissions (Di et al. 2007) there is less evidence to show if DCD improves pasture quality apart from, admittedly, anecdotal observations of less "clumping" due to less uneven pasture growth. However, there is evidence by Moir et al. (2007) to show that pasture quality under high fertility conditions remains similar after DCD use.

Of equal interest is why the results from these farm trials exceed response values for experimentally-based plot trials. Di and Cameron (2007) and Zaman et al. (2010) both used DCD on urine-treated pastures in lysimeter studies on sedimentary soils under SI conditions and measured average DM increases of ~25% and ~10%, respectively, but this is from pasture areas wholly treated with urine. In the North Island, Menneer (2008) also reported a large DM increase (34%) when DCD was applied to urine treated plots. Assuming that only 23% of dairy pasture on average might receive urine in an annual season (Moir et al. 2011) one might expect these increases to be diluted accordingly, for example down to 7% as calculated by Meneer et al. (2008). However, this does not seem to be the case for many of the large-scale field trials reported here. Similarly in small plot trials based in the Manawatu, Zaman et al. (2009) measured DM increases from DCD use (applied with a urease inhibitor) of about 10% but again this data was from plots receiving 100% urine/agrotain areal application and consequently, any increase ought to be diluted over the entire pasture area. Application of DCD to non-urine receiving areas has not shown any increases in DM response over non-DCD, non-urine treated areas in small scale plot trials (Zaman et al. 2009). Canterbury farm trial data has been different, however, with significant increases in DM production in the non-urine areas (20%) of large grazed pasture plots recorded as well as an increase in the urine patch areas (29%) (Moir et al. (2007). This shows that the application of eco-n has clearly improved the N cycle efficiency of the inter-urine spaces as well as the urine patch areas but it’s unclear currently whether any of this is related to DCD use on N applied in fertiliser. Even if this was the case, it would still appear that a greater ‘farm-system’ effect is operating, multiplying benefits across the paddock to more than the area occupied by both urine and DCD.

Obviously there are several mechanisms operating here reducing eco-n effectiveness in the Waikato on the one hand, but increasing its effectiveness elsewhere, and to more than the areas occupied by both urine and DCD. In the former, it may be that the residence time of DCD in the topsoil as a function of both temperature (microbial breakdown) and movement of DCD down the profile, particularly in volcanic ash soils is greater but this would seem somewhat at odds with the Taranaki results. The efficacy of eco-n application is related to the movement of DCD and in free-draining soils there will be movement of DCD in the wetting front away from later applied urine spots. The lower response in the Waikato might also be due to the effects of summer drought conditions that periodically occur (2011) causing the response to be 'lost' during the moisture-limited late summer months. Snow et al. (2011) and Shepherd et al. (2011) have both suggested that the critical period for N leaching in the Waikato is late summer rather than the autumn/winter months and therefore targeting DCD application over this period could be more effective. Snow et al. (2011) have also suggested that N losses will potentially be greater for non-irrigated rather than irrigated pastures. Such an effect was noted by Burgess (2003) where N leaching from applied dairy effluent trials was actually less for irrigated than un-irrigated plots because of the greater utilisation of the applied-N by the pasture. Vogeler et al. (2011) using a newly developed module in APSIM (Agricultural Production Systems SIMulator) to model N leaching losses for Southland, Canterbury, Manawatu, Waikato and Northland dairy farms concluded that rainfall, pattern and temperature explained about 25% of the variation between sites and soils.   There is an obvious parallel that differences in DM production between sites would also be similarly variable and thus, further research is required to identify the causes.

We postulate that the mechanism responsible for the ‘farm-system’ effect maybe in the scaling up of farm or plot trials. Paddocks that may be eight or more hectares in size will, even using break feeding, be considerably greater than any experimental plot. Cows grazing longer in areas where more feed is available means that excreta returns will also likely be greater there. It is hypothesised that the prolonged pasture DM response could be due to the mineralisation of some of this N that was previously immobilised into organic forms earlier in the season and/or retention and release of ammonium ions from soil cation exchange sites. Such factors aren’t tested in the ungrazed small plot trials. The increased N nutrition at critical times in spring and/or autumn, when grasses are setting tillers, may also contribute to increased DM as the greater tiller numbers can then contribute to more overall production on the eco-n treated pastures (Bahmani et al. 2001). DCD use may also reduce N losses from top 5 to 10 cm of soil; which may be the only depth warm enough for active plant root growth and N uptake during the early spring. Questions as to why we continue to see pasture production increases, long after any benefit of applying DCD might be expected to persist, likewise, remain to be answered.

Average increases of 14% DM in NI regions, even if biased to some degree by the Taranaki results, and the average 21% observed in SI regions, would more than account for the costs of application if the increased pasture production is mostly converted into milk solids. If we assume pasture production of 13,000 kg DM/ha/y and an increase in DM production due to eco-n of 10% and 85% utilisation, then this would provide an additional 1100 kg DM/ha/y. If we assume that this extra dry matter is converted into milk solids (MS) at a ratio of 13 kg DM per kg MS (13:1) then this results in an extra 85 kg MS/ha and at $6/kg MS results in a gross income of $510/ha. Subtracting the current cost of eco-n application of $192/ha (2 applications at $96/ha each) then the net profit is $318/ha. This subject and the economics of eco-n use vs. potential benefits to the dairy industry will be discussed in a later paper and confirmation through farm data that these financial gains are actually being achieved would aid this discussion.

Thus, there remains a significant amount of research to be undertaken on how DCD-based nitrification inhibitors perform under varying soil and climatic conditions and how their performance can be optimised. It also appears, however, that many of these questions must be answered on a farm-scale basis where ‘farm-system’ effects are included, not through small-scale pasture production trials.

Summary

Pasture production data for 132 paddocks from 37 farm trials conducted between 2006 and 2011 in the South and North Islands was used to conduct a statistical analysis of the effect of the DCD nitrification inhibitor, eco-n, on treated vs. non-treated half paddocks. Overall increases in DM production of 14% were recorded for NI trials and 21% for SI trials. Some regions such as the Waikato, however, recorded noticeably lower increases than other North and South Island regions and suggest that a number of possible climatic and/or soil factors are affecting responses. Reasons for this might include greater N leaching over non-target periods (e.g. late summer) than initially assumed and/or increased leaching and degradation of DCD. The increase in DM over all trials was 19%, similar to that recorded in experimental trials but only where areal urine coverage of the trial plots was 100%. In a typical farm paddock, urine coverage in a single year is less than 25%; suggesting that a farm-system effect must be operating that enhances the benefits of DCD application to more than the urine-affected area alone.

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