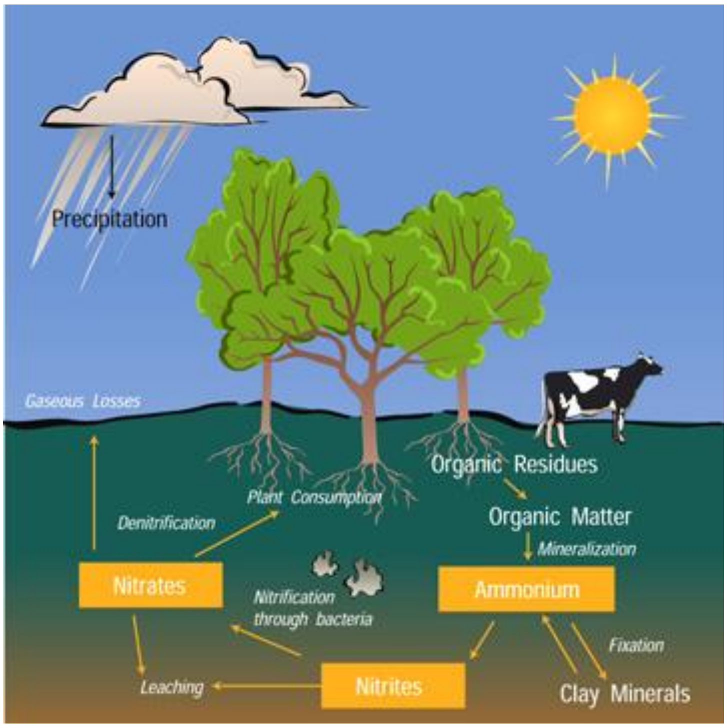
Nitrification Inhibitors: A Climate Change Mitigation Tool for the Tasmanian Dairy Industry

Do they work and will they give an economic return to dairy farmers?



A Summary Report on the Investigation of the Efficacy of Nitrification Inhibitors in Reducing Nitrogen Losses from the Soil Profile

Tasmanian Institute of Agricultural Research

November 2010

Rob La Grange and Richard Rawnsley

Funded by Dairy Australia and your Regional Development Program

Introduction

Nitrous oxide (N_2O) is a potent greenhouse gas emitted by the agricultural sector worldwide. In Australia, N_2O emissions from the agricultural sector are estimated to constitute about 5% of total greenhouse gas emissions from all sectors. Different strategies have been suggested that will reduce N_2O emissions on farm and one promising approach is the use of nitrification inhibitors. Nitrification inhibitors reduce the activities of aerobic soil microorganisms that convert soil ammonium to soil nitrate. Depending on soil conditions, some of the soil nitrate will be converted into gaseous nitrogen products including N_2O. By reducing the amount of soil nitrogen being converted to nitrate there are reduced nitrogen losses as leached nitrate and gaseous N_2O. Some nitrogen fertiliser products are coated with nitrification inhibitors to potentially reduce losses of nitrogen from the fertiliser and research has shown varying responses to the use of these coated products. One promising use of nitrification inhibitors is the sprayed application of Dicyandiamide (DCD) onto intensively grazed pastures where its action targets soil nitrogen more broadly, in particular the large quantities of nitrogen released from urine deposits. The current field study undertaken in Tasmania investigated the effects of using coated urea products and a soil applied nitrification inhibitor on soil nitrogen losses and pasture growth rates.

Dairy farms are significant contributor to climate change through the global warming effects of the greenhouse gasses, methane (CH_4) and nitrous oxide (N_2O). Methane is produced in the rumen of the dairy cow through the fermentation digestion of food by microorganisms living in the rumen and is released into the atmosphere through eructation. Nitrous oxide is released from the soil into the atmosphere as a breakdown product of soil nitrogen.

The Tasmanian Institute of Agricultural Research (TIAR) has developed a DGAS calculator that calculates greenhouse gas emissions from farms and the impact that mitigation strategies might have on these emissions. The DGAS report for the trial farm is shown in Figure 1. Many factors influence the rate of N_2O emissions from a dairy farm. Cold wet conditions combined with low soil temperatures and poor draining soils can contribute to elevated soil nitrate levels and increased losses of nitrogen as gaseous N_2O. The assumption made in the abatement strategy using nitrification inhibitors coated onto fertiliser is that an average annual reduction in N_2O emissions of 40% could be achieved from the coated fertilisers. This would equate to a reduction in N_2O emissions from 1.1 tonnes CO_2 equivalent per tonne of milk solids down to 0.6 tonnes CO_2 equivalent per tonne of milk solids. The indirect N_2O losses from the volatilisation and leaching/runoff of nitrogen fertiliser could also potentially be reduced by 19% from 2.6 to 2.1 tonnes CO_2 equivalent per tonne of milk solids. The overall estimated change in farm emissions (CH_4 and N_2O emissions) would be a 6.2% reduction. The assumption made with respect to applying a nitrification inhibitor as a spray treatment onto paddocks being grazed through winter and early spring is that a similar average annual reduction in urinary nitrogen of 40% could be achieved. The calculator indicates that based on this assumption, direct N_2O losses would be reduced from 1.3 to 1.0 tonnes CO_2 equivalent per tonne of milk solids, equivalent to a 17.6% reduction and indirect N_2O losses would be reduced from 2.6 to 2.3 tonnes CO_2 equivalent per tonne of milk solids, equivalent to a 12.3% reduction. The overall estimated change in farm emissions (CH_4 and N_2O emissions) would be a 3.7% reduction.

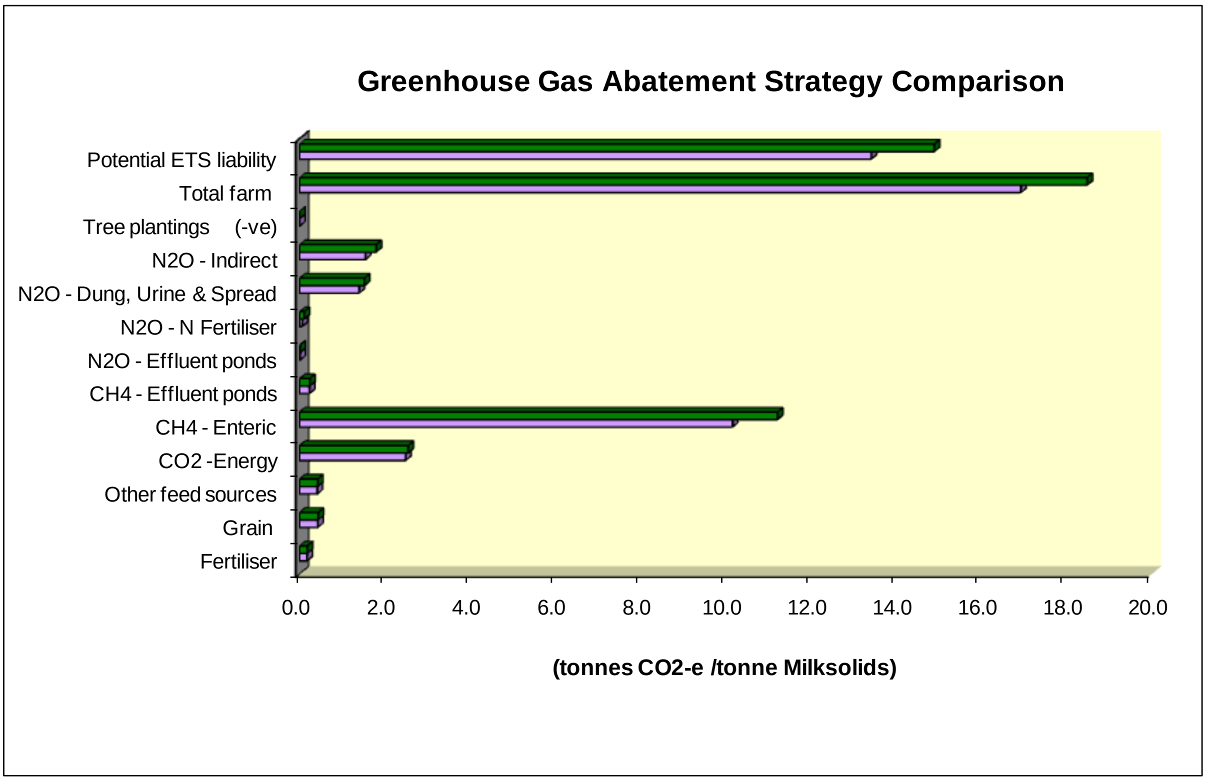


Figure 1. DGAS report for the dairy farm involved in the trial

Trial Design and Treatments

The study was established in a paddock on a commercial dairy farm in central north Tasmania. There were two main plot treatments, these were with and without the soil applied nitrification inhibitor dicyandiamide (DCD). The DCD applications where undertaken in April 2010 and August 2010. Four N fertiliser treatments (subplots treatments) were overlayed on the main plot treatments. These were urea coated with the nitrification inhibitor 3.4-Dimethylpyrazole Phosphate (DMPP) marketed as Entec™ ™; urea coated with DCD as well as a urease inhibitor marketed as Guardian™ ™, straight urea and a zero N treatment. All N treatments were applied at a rate of 46 kg N/ha and were applied in November 2009, February 2010, April 2010 and August 2010. Pasture growth rates across all plots were determined using a rising plate meter and soil nitrogen status (inorganic N and organic N) was determined through soil analysis of soil cores taken at a depth of 0-10cm across the plots. These cores were assayed for nitrate nitrogen (mg/kg), ammonium nitrogen (mg/kg) and total nitrogen (%).

Results and Discussion

The expectation from using nitrification inhibitors is that less soil nitrogen is lost either as leached nitrate or gaseous nitrogen products. The consequence of this is more soil nitrogen being available for plant uptake and therefore increased pasture growth. Recent trials in New Zealand investigating the impact of DCD on plant growth have demonstrated significant increases in pasture growth and significant economic returns to using DCD as broad paddock spray in autumn and early spring. The effect of the DCD was to reduce the losses of soil nitrogen from urine patches on intensively grazed dairy pasture.

The mean growth pasture growth rate estimated in the initial regrowth cycle following the N fertiliser applications in the current study was 80.0, 75.0, 85.4 and 59.1 kg DM/ha.day for N fertiliser treatments Entec™ , Guardian™ , Urea and nil, respectively. Although not significantly ($P > 0.05$) different there was anecdotal evidence to suggest that all N fertiliser applications resulted in higher growth rates. The lack of significant differences was a function of the high variability associated with the experimental site. Following the April application of the main plot and sub plot treatments it was found that there was no significant ($P > 0.05$) effect of DCD on pasture growth rate, but a significant ($P < 0.05$) N fertiliser treatment effect. The mean pasture growth rate of the DCD applied and non DCD applied plots was 33.9 and 33.1 kg DM/ha.day, respectively. The mean pasture growth rate of the N fertiliser treatment Entec™ , Guardian™ and Urea was 34,4, 35.6 and 40.9 kg DM/ha.day, respectively which were not significantly ($P > 0.05$) different to each other but significantly ($P < 0.05$) greater than the mean growth rate of nil treatment; 23.2 kg DM/ha.day. Similarly to the April application, following the August application of the main plot and sub plot treatments it was found that there was no significant ($P > 0.05$) effect of DCD on pasture growth rate, but a significant ($P < 0.05$) N fertiliser treatment effect. The mean pasture growth rate of the DCD applied and non DCD applied plots was 15.4 and 15.0 kg DM/ha.day, respectively. The mean pasture growth rate of the N fertiliser treatment Entec™ and Guardian™ was 16.8 and 19.3 kg DM/ha.day, respectively which were not significantly ($P > 0.05$) different to each other but significantly ($P < 0.05$) greater than the mean growth rate of Urea and nil treatment; 12.3 and 12.2 kg DM/ha.day, respectively. The results of the Tasmanian trial have shown no significant pasture growth responses to the sprayed soil application of DCD. This is in contrast with the trials in New Zealand. There was a pasture growth response to those treatments receiving nitrogen but there was little indication that there was significant difference in pasture growth response between the N formulations. Only following the August application was there a significant increase in pasture growth by the Entec™ and Guardian formulations over the Urea formulations.

The experimental site was located on heavy black clay soil and as a result of the very wet winter and early spring of 2009 the experimental site became quite badly pugged. Whilst care was taken to avoid uneven areas when using the rising plate meter it is likely that this damage contributed to the high degree of variability in the pasture growth assessment resulting in insignificant findings. Another factor contributing to the high degree of variability was the grazing animal. The farmer treated the paddock as any other paddock in the grazing management applied on the farm. Some plots were ‘camped’ on resulting in these areas not being grazed down and thereby affecting the next reading to some extent. More significant pasture responses might have been observed under an animal free-mechanical cutting and weighing program.

Soil nitrogen assessments included an analysis of soil inorganic N status, the components of the soil inorganic N status (nitrate and ammonium N concentration) and total soil N percentage. Prior to the initial subplot N fertiliser applications on the 2nd February 2010, there was found to be no significant ($P > 0.05$) difference in inorganic N status between the subplot treatments. The mean initial soil inorganic N concentration was 14.4 mg/kg. There was a significant ($P < 0.05$) difference in the soil inorganic N concentration between the subplot treatments at 7 days after application (DAA) of the subplot treatments. The mean total soil inorganic N concentration of the urea treated plots was 37.3mg/kg which was significantly ($P < 0.05$) greater than all other treatments. The mean soil inorganic N of the Guardian™ treatment was 27.7mg/kg which was significantly ($P < 0.05$) higher than the nil treatment but not significantly ($P > 0.05$) different to the Entec™ treatment. The mean soil inorganic N concentration of the Entec™ treatment was 23.1 mg/kg which was not significantly ($P < 0.05$) different to the soil Nil treatment, which had a mean concentration of 17.0 mg/kg. At 17 and 27 DAA of the subplot treatments, there was no significant ($P > 0.05$) difference in the soil inorganic concentrations between treatments.

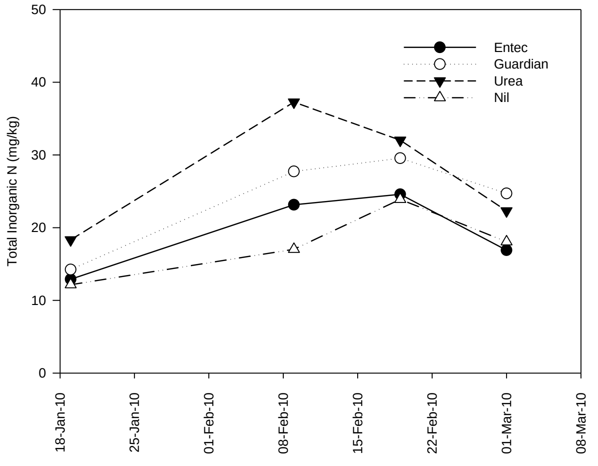


Figure 2 Mean total soil inorganic nitrogen (mg/kg) prior to and following the application of N fertiliser sub plot treatments on the 2nd February 2010.

The mean soil inorganic components (nitrate nitrogen and ammonium nitrogen) and total soil nitrogen at each assessment date for each of the N fertiliser treatments applied in February 2010 are given in Figure 3. There was no significant ($P > 0.05$) effect of any N fertiliser treatment on total nitrogen. At 7 DAA (assessment 2), there was a significant ($P < 0.05$) N fertiliser treatment effect on soil nitrate N, with the urea plots having a significantly ($P < 0.05$) higher soil nitrate N concentration then all other treatments, which were not significantly ($P > 0.05$) different to each other. At 7 DAA the mean soil nitrate N concentration of the N fertiliser treatments was 17.1, 9.2, 8.9, and 5.1 mg/kg for Urea, Guardian™ , Entec™ and Nil, respectively. Similarly at 7 DAA, there was a significant ($P < 0.05$) N fertiliser treatment effect on ammonium N concentration with urea and Guardian™ treated plots having significantly($P < 0.05$) higher ammonium N concentration then the Entec™ and Nil treatments, which were not significantly ($P > 0.05$) different to each other. At 7 DAA, the mean soil ammonium N concentration of the subplots treatments was 20.1, 18.5, 14.2 and 11.9 for Urea, Guardian™ , Entec™ and Nil, respectively. There was no significant ($P > 0.05$) effect of any N fertiliser treatment on the soil ammonium N and soil nitrate N concentration at 17 and 27 DAA (assessment 3 and 4) of the sub plot treatments. The results of this analysis have indicated that the both the Guardian™ and Entec™ formulations where able to ”slow” nitrification resulting in lower amount of soil nitrate N 7 DAA of the N fertiliser treatments..Although this did not result in any observed significant difference in pasture growth response, the soil N analysis has clearly shown the functionality of these formulations. This slowing of the nitrification process is likely to result in lower N losses where environmental conditions are conducive to nitrate losses.

It is assumed that the use of nitrification inhibitors coated onto urea would reduce the amount of ammonium nitrogen converted to nitrate by soil microorganisms but the question to be asked is whether this effect is significant under warm active plant growing conditions. The trial paddock remained wet into summer of 2010 as a result of the very wet 2009 spring and because of the poor draining heavy clay soils. Under these conditions urea coated with a nitrification inhibitor might be expected to result in more soil nitrogen being available for plant growth. The results presented above and in figure 3, graphs a-c show that nitrate nitrogen levels for the plots treated with Entec™ ™ and Guardian™ ™ were significantly lower than for urea and that levels for Entec™ ™ were lower than for Guardian™ ™. These results are before the February 2010 fertiliser treatments were applied. This would suggest that soil nitrogen levels were still influenced by the November 2009 treatments. This would suggest that both DMPP and DCD had a nitrification inhibitory effect still noticeable 62 days following treatment.

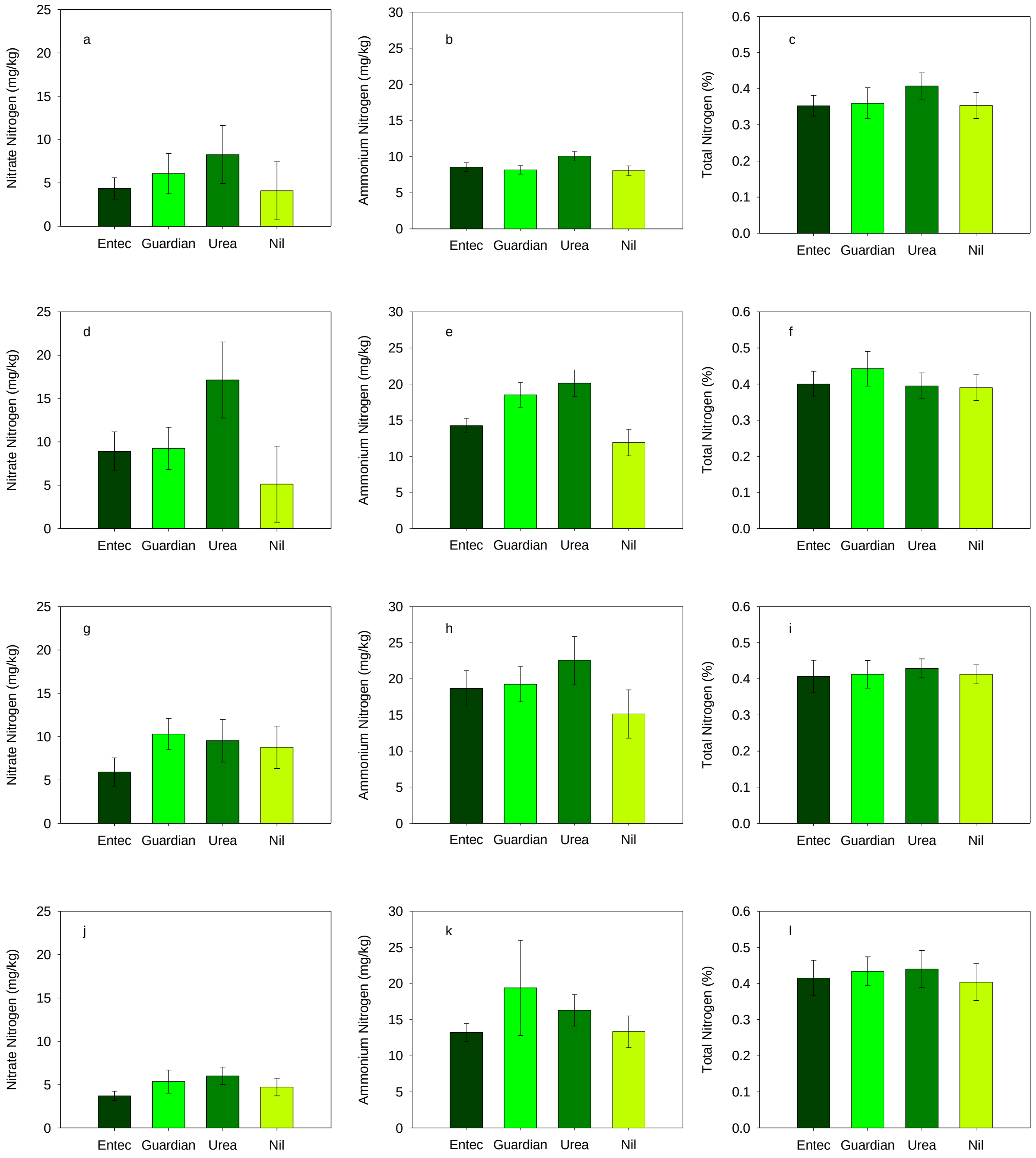


Figure 3 Mean soil nitrate nitrogen (mg/kg), ammonium nitrogen (mg/kg) and total soil nitrogen (%) prior to and following the application of N fertiliser sub plot treatments on the 2nd February 2010. Assessment 1 (a-c), Assessment 2 (d-f), assessment 3 (g-i), assessment 4 (j-l).

Figure 4 shows the change in soil inorganic N for the August 2010 round of treatments where both the N fertiliser treatments (subplots) and the DCD (main plots) as a spray treatment were applied. Soil N analysis undertaken prior to the application of main plot (DCD) and N fertiliser sub plot treatments on the 17th August and 18th August 2010, (assessment5), found that there was no significant (P > 0.05) main plot, sub plot or main plot by subplot treatment interaction on soil inorganic N concentration.

The mean soil inorganic N concentration of all plots was 18.5 mg/kg. At 15 DAA it was found that the sub plot N fertiliser treatment has a significant ($P < 0.05$) effect on soil inorganic N concentration. The mean soil inorganic N concentration of the subplots treatments was 23.6, 20.5, 18.7 and 16.5 mg/kg for Guardian™ , Urea, Entec™ and Nil, respectively. Applications of Guardian™ resulted in a significantly ($P < 0.05$) higher soil inorganic N concentration than the Entec™ and nil treatments but was not significantly ($P > 0.05$) different to Urea. At 15 DAA there was no significant ($P > 0.05$) main plot (DCD treatment) or an interaction between the main plot and subplot on soil inorganic N concentration. The mean soil inorganic N without and with DCD was 20.1 and 19.5 mg/kg, respectively. At 35 DAA there was a significant ($P < 0.05$) interaction between the main plot (with and without DCD) and the subplot N fertiliser treatments on soil inorganic N concentration. The subplot treatments of Entec™ and Guardian™ combined with the DCD applied main plot treatments were found to have a significantly lower soil inorganic N concentration then Entec™ and Guardian™ alone treatments. There was no significant ($P > 0.05$) difference in soil inorganic N status of the urea treated plot with or without with DCD and similarly for the nil subplot treatments. At 48 DAA the mean soil inorganic N without and with DCD was 30.0 and 18.3 mg/kg, respectively.

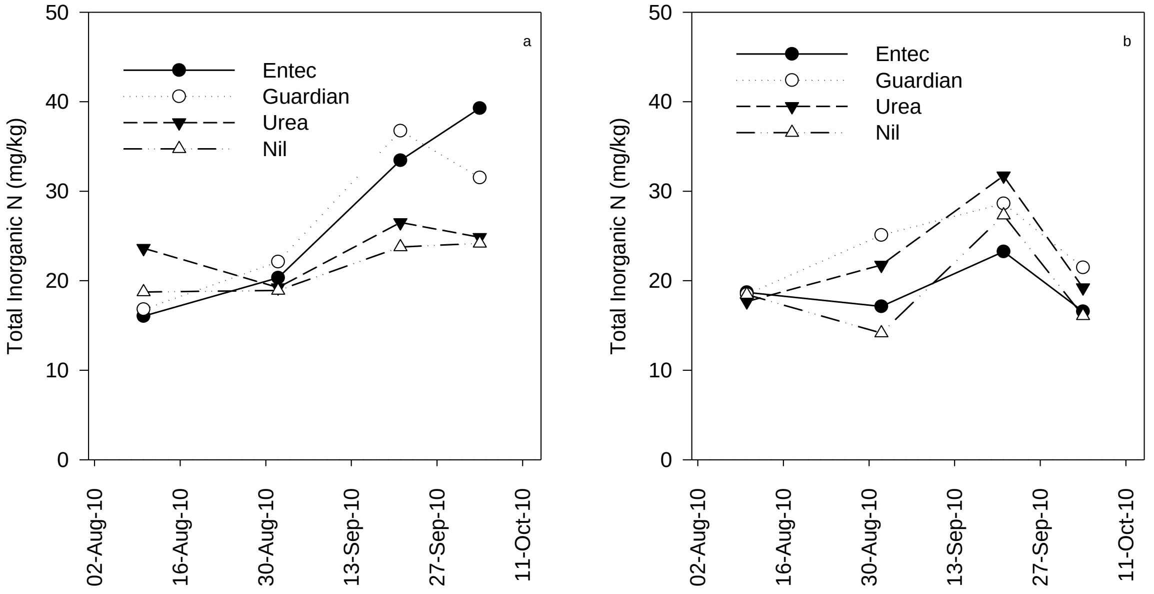


Figure 4 Mean total soil inorganic nitrogen (mg/kg) prior to and following application of main plot (without DCD (a) and with DCD (b)) and N fertiliser sub plot treatments on the 17th August and 18th August 2010, respectively.

Figure 5 shows the levels of the different soil nitrogen fractions for the August 2010 round of treatments where both the N fertiliser treatments (subplots) and the DCD (main plots) as a spray treatment were applied. At 15 DAA (assessment 6) there was a significant ($P < 0.05$) main plot effect on soil nitrate N. The mean soil nitrate N concentration was 2.8 and 4.7 mg/kg for those plots treated with and without DCD, respectively. At assessment 35 DAA (assessment 7) there was a significant (P < 0.05) sub plot effect on soil nitrate N with the urea and Guardian™ treatment plots having significantly (P < 0.05) higher soil nitrate N concentrations then the Entec™ and Nil treatments, which were not significantly (P > 0.05) different to each other. The mean soil nitrate N concentration at 35 DAA was 4.9, 4.7, 3.5 and 3.6 mg/kg for Urea, Guardian™ , Entec™ and Nil plots, respectively. There was no significant (P > 0.05) main plot effect or interaction between the main plot and subplots on soil nitrate N concentration at 34 DAA. At 48 DAA (assessment 8) there was no significant (P > 0.05) effect of subplot treatments (N fertiliser treatments), main plot treatments (with or with DCD) or interactions on soil nitrate N concentration.

At 15 DAA (assessment 6) there was a significant (P < 0.05) N fertiliser treatment effect on soil ammonium N. The mean soil ammonium N concentration at 15 DAA was 16.3, 19.5, 14.7 and 13.6 mg/kg for Urea, Guardian™ , Entec™ and Nil, respectively. At 15 DAA the mean soil ammonium N concentration of the Guardian™ treated plots was significantly (P < 0.05) higher than the Entec™ and Nil treated plots but not significantly (P > 0.05) different to the Urea treated plots. At 35 DAA (assessment 7) there was a significant (P < 0.05) interaction between the main plot (with and without DCD) and the subplot N fertiliser treatments. The subplot treatments of Entec™ and Guardian™ when combined with the DCD applied main plot treatment, were found to have a significantly (P < 0.05) lower soil ammonium N concentration then the Entec™ and Guardian™ alone treatments. In comparison, there was no significant (P > 0.05) difference in soil ammonium N concentration with or without DCD when combined with the Urea and Nil treated plots. At 48 DAA (assessment 8) there was no significant (P > 0.05) effect of subplot treatments (N fertiliser treatments), main plot treatments (with or with DCD) or interactions between the subplot and main plot on soil ammonium N.

The coated urea products did not show any consistent trend in reducing soil nitrate levels compared to straight urea both under DCD or with no DCD applied. In some treatments Entec™ ™ did show a significant reduction in soil nitrate levels compared with other urea fertiliser coated with DCD. However the application of DCD as a plot spray did show significant reductions in soil nitrate levels in most treatments. This was true for soil tested 15 days, 35 days and 48 days post application of DCD as a plot spray treatment. The DCD treated main plots showed a tendency to have lower soil inorganic N (ammonium N and nitrate N) status over the study period. This indicates that more nitrogen was being taken up by plants or immobilised in the soil profile and that it most likely that the DCD soil sprayed treatments is effective in reducing losses of soil nitrogen as nitrate and by argument as N_2O. These results would be consistent with findings from other research trials.

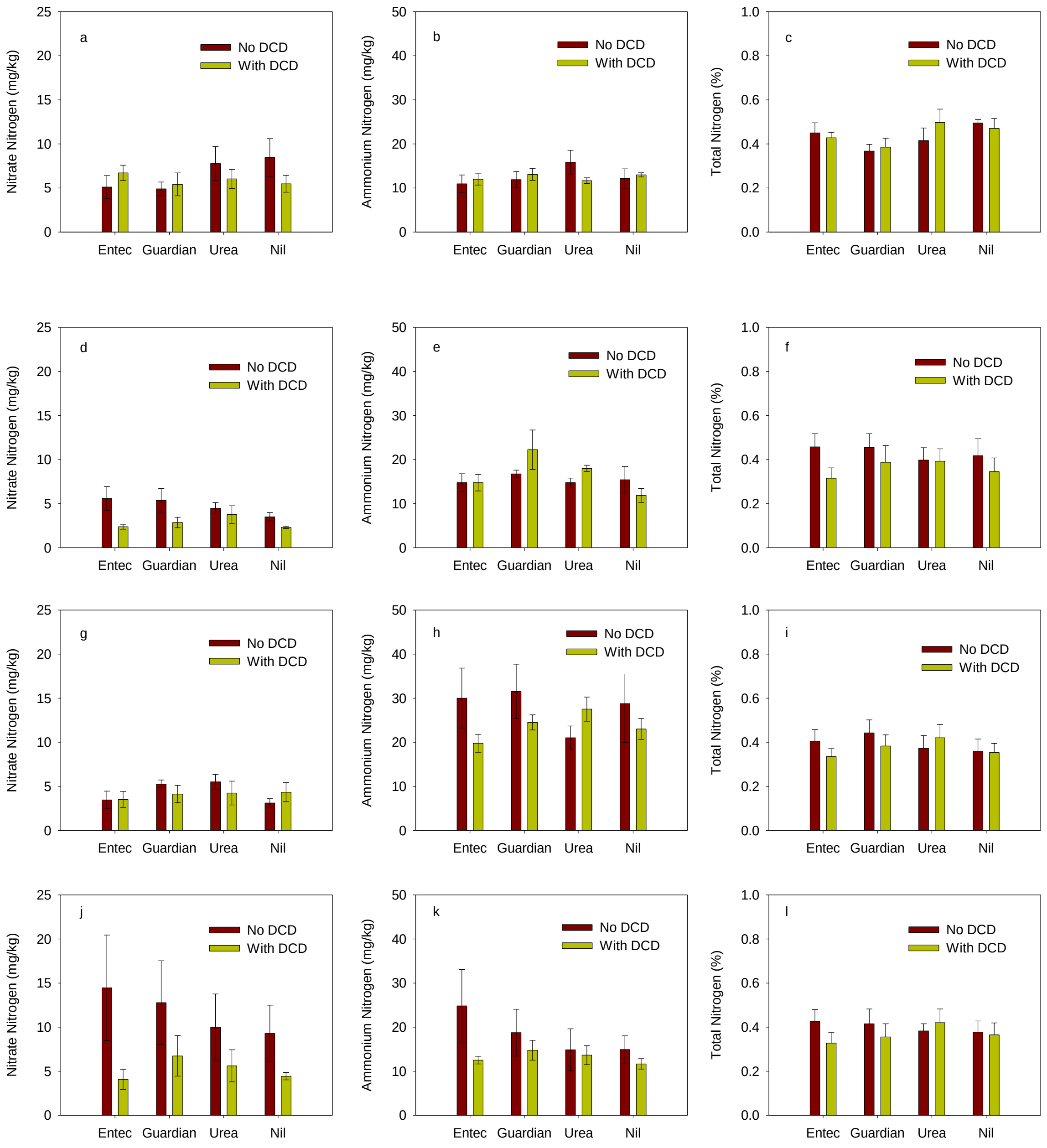


Figure 5. Mean soil nitrate nitrogen (mg/kg), ammonium nitrogen (mg/kg) and total soil nitrogen (%) prior to and following application of main plot (DCD) and N fertiliser sub plot treatments on the 17th August and 18th August 2010, respectively.. Assessments dates 10th August 2010 (a-c), 1st September 2010 (d-f), 21st September 2010 (g-i), and 4th October (j-l).

Conclusion

Despite the limitations of the trial with respect to using expensive technological equipment to monitor nitrate losses through leachate and N_2O losses to the atmosphere, the trial found DCD to be effective as a nitrification inhibitor consistent with findings from other research trials in New Zealand and

Australia. It would be expected that the reduction in soil nitrate levels as a result of using DCD would in turn result in significant increases in pasture growth. Whilst this has been a significant finding of trial work done in New Zealand, the trial in Tasmania did not find any significant changes in pasture growth rates through winter and spring as a result of using DCD as a spray application on pastures. This could well be the result of inherent variability associated with the experimental site and the rising plate meter, the poor physical condition of the paddock surface and other animal factors affecting pasture growth. The trial findings suggest that Tasmanian dairy farmers would reduce N_2O emissions from intensively grazed pastures under those conditions that favour the production of N_2O. Many dairy farms in Tasmania experience conditions that are conducive to N losses.   It would be worthwhile to repeat the trial in Tasmania on a smaller scale with no direct animal factor and more sophisticated equipment to measure soil nitrate and N_2O losses as well as pasture growth responses. This would give Tasmanian dairy farmers more reliable information on the use of DCD nitrification inhibitor as a spray treatment to reduce N_2O emissions coupled with economic modelling to project the economic returns to using DCD as a result of extra pasture dry matter consumed.

Extending the message

The trial demonstrated that both DMPP and DCD coated onto urea have a nitrification inhibitory effect on nitrogen in the soil. Using these products would contribute to reduced N_2O emissions especially under conditions favouring the production of excess nitrate in the soil and under conditions favouring the production of N_2O from nitrate. From a greenhouse gas perspective the use of these products would be an advantage. The trail did not show any significant pasture growth responses in using these coated urea products but the limitation of data collection around pasture responses has been noted above. Farmers are not likely to adopt the use of these products unless compelled to do so or unless some monetary gain can be achieved.

The study has indicated that the use of DCD as a spray on intensively grazed paddocks in winter and early spring in Tasmania has the ability to slow nitrification and the formation of nitrate N. As a result less nitrate is likely to be lost as leached nitrogen or as gaseous N_2O. New Zealand data show a significant increase in pasture production from paddocks sprayed with DCD in two applications; an autumn and an early spring application. It would be of value to have a trial established that would see pasture responses more accurately determined as this could be a strong incentive for Tasmanian dairy farmers to consider using DCD.

The New Zealand results have been extended to some Tasmanian dairy farmers in 2010 as part of a series of seminars highlighting soil nutrient mapping. The results of this trial are planned to be shown to Tasmanian dairy farmers as part of a climate adaptation project in the middle of 2011. Whilst these results will clearly highlight the benefits of using nitrification inhibitors to reduce nitrate and N_2O

losses they cannot directly demonstrate any associative increased pasture growth responses. However the logic of increased pasture growth because more soil nitrogen is retained as plant available nitrogen is powerful and ably demonstrated in the New Zealand trials.

Acknowledgements

The authors wish to thank Peter Chamberlain, Matthew Costello and Susan Walker for technical support in the setting up of the trail paddock, the treatment applications and the soil sampling required**.**

References

Cameron KC, Hong HJ, Moir JL, Christie R, Pellow R (2005). Improved nitrogen management with eco-n nitrification inhibitor – an example of "Growing for Good". *Paper for the large herd's Conference field trip to the Lincoln University dairy farm*.

Earle DF, McGowan AA (1979). Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry* 19, 337–343.

Moir JL, Cameron KC, Di HJ (2007). Effects of the nitrification inhibitor dicyandiamide on soil mineral N, pasture yield, nutrient uptake and pasture quality in a grazed pasture system. In: *Soil Use and Management*, **23**,111-120.

Zerulla W, Barth T, Dressel J, von Locquenghien KEKH, Pasda G, Rädle M, Wissemeier AH (2001). 3,4-Dimethylpyrazole phosphate (DMPP) – a new nitrification inhibitor for agriculture and horticulture. *Biology and Fertility of Soils* **34**, 79-84.