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Improving Nitrogen Cycling Efficiency of Intensively Grazed Pastures Using Nitrification Inhibitors

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Abstract

The predominant land use in New Zealand is grazed pastures where animals graze outdoor pastures all year round. Two of the major nitrogen (N) loss pathways that reduce the N efficiency in intensively grazed pasture systems are nitrate (NO_3^-) leaching and nitrous oxide (N_2O) emissions. Nitrate is a contaminant for surface and groundwater and N_2O is a greenhouse gas (GHG) with a long-term global warming potential of about 310 times that of carbon dioxide (CO_2). Agricultural soils are a major source of both NO_3^- leaching and N_2O emissions. In New Zealand, agriculture accounted for about 50% of total greenhouse gas emissions in 2005, of which one third is N_2O . In intensively grazed pastures, most of the NO_3^- leached and N_2O emitted are contributed by N returns in animal excreta, particularly in animal urine. As animals graze outdoor pastures, between 70-90% of the N ingested is returned to the pasture in the urine and dung. The N loading rate under a dairy cow urine patch, for instance, can be as high as $1000 \text{ kg N ha}^{-1}$. This N loading rate is well in excess of that which can be used by the pasture plants and the surplus N is prone to leaching and gaseous emission losses.

A new soil treatment method has recently been developed to reduce both NO_3^- leaching and N_2O emissions from intensively grazed pasture soils. This new technology involves treating grazed pasture soils with a nitrification inhibitor (e.g. dicyandiamide, DCD) to slow down the conversion of ammonium (NH_4^+) to NO_3^- . The inhibitor works by deactivating the enzyme responsible for this conversion, ammonia mono-oxygenase (AMO). Studies under a range of soil and environmental conditions have shown that this new soil treatment method can decrease NO_3^- leaching by about 60% and decrease N_2O emissions by about 70% from treated animal urine patches. The reduction in these N losses increases the N use efficiency and thus results in higher pasture yield. This paper describes the theory behind this nitrification inhibitor technology as used in intensively grazed pastures, the benefits of using it, and recommendations aimed at maximising the effectiveness.

Keywords: Intensively grazed pastures, nitrate leaching, nitrous oxide emissions, nitrification inhibitors, soil treatment method.

Introduction

The predominant agricultural land-use in New Zealand is grazed pastures where animals graze outdoor pastures all year round. Pastoral agriculture is also a major land use in a number of other countries, including Australia. In New Zealand one of the major land use changes during the past decade has been that of intensification – the replacement of sheep and cropping with dairy farming, largely driven by world agricultural commodity prices.

Currently New Zealand has more than 1.4 million ha of dairy pasture land carrying about 5 million dairy cattle, and these numbers are projected to increase further in the next few years. Most of the dairy pastures in New Zealand are mixtures of perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). In such pasture systems, the main inputs of nitrogen (N) are nitrogen fixation from white clover and N fertiliser, predominantly in the form of urea. The land use change from sheep to dairy farming in recent years has resulted in increased use of N fertilisers.

There has been rising public concern of adverse impacts of dairy expansion on the environment, particularly nitrate (NO_3^-) leaching and water contamination. This issue was highlighted by a Parliamentary Commissioner for the Environment report in 2004 (PCE, 2004), and more recently by a State of the Environment report in 2007 (MFE, 2007b). However, contrary to common public perception, only a small amount of NO_3^- leached in intensively grazed pastures is derived directly from N fertilisers applied. Most of the NO_3^- leached is in fact derived from N returned in animal excreta, particularly in the urine (Di and Cameron, 2002a; 2002b). As animals graze outdoor pastures, between 70-90% of N ingested is returned to the pasture in the urine and dung (Haynes and Williams, 1993; Jarvis *et al.*, 1995). The proportion of N returned in the urine varies depending on the pasture quality and N content. For example, in a good pasture with 4% N content 70-80% of excreta N is returned in the urine, mostly in the form of urea. The N loading rate under dairy cow urine patches, for example, can be $1000 \text{ kg N ha}^{-1}$. However, the N loading rate in the urine patch areas can vary between different animal grazing systems (e.g. sheep, beef cattle and dairy cattle) due to variations in animal size and pasture quality. The urine-N loading rate usually increases from sheep, to beef cattle and to dairy cattle systems.

Another major N loss pathway in intensively grazed pasture systems which also has a negative environmental impact is nitrous oxide (N_2O) emissions. N_2O is a greenhouse gas (GHG) with a long-term global warming potential of about 310 times that of carbon dioxide (CO_2). As with NO_3^- leaching most of the N_2O emitted from grazed pastures is also derived from N deposited in animal excreta; particularly in the urine patch areas (MFE, 2007a). In New Zealand, about 50% of the total greenhouse gases emitted in 2005 was from agriculture, and of this, about one third was N_2O (MFE, 2007). (The remaining amount of agricultural emissions was mainly methane (CH_4) from enteric fermentation.) More than 80% of the N_2O emitted was derived from animal excreta.

Nitrate leaching and N_2O emissions from grazed pasture systems, in particular, from urine patch areas, not only result in reduced efficiency of N, but also have serious environmental consequences. Therefore, major efforts have been devoted to developing N management strategies and technologies that can reduce NO_3^- leaching and N_2O emissions from grazed pastures. One of the new soil treatment methods that have been shown to be effective in reducing both NO_3^- leaching and N_2O emissions from intensively grazed pastures is the use of nitrification inhibitors. In this paper, we outline the theory behind the nitrification inhibitor technology to reduce NO_3^- leaching and N_2O emissions from grazed pastures, the benefits, and the conditions to optimize its effectiveness.

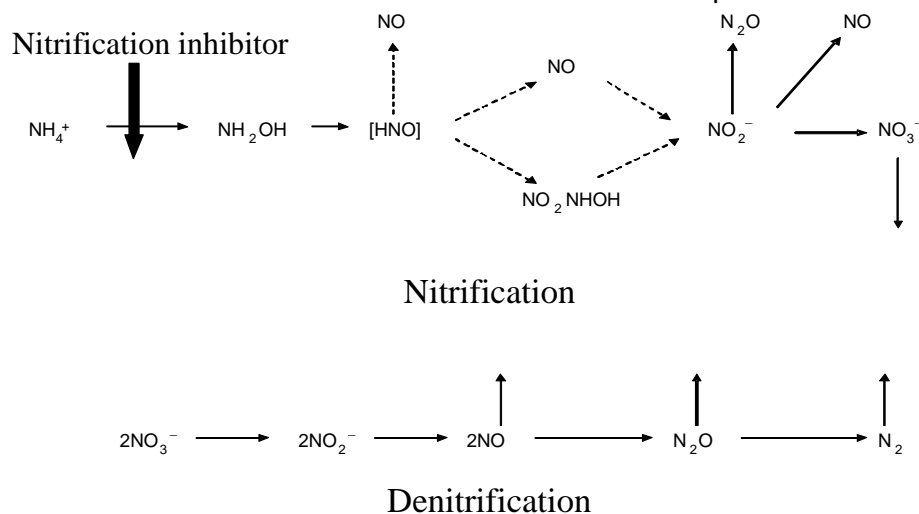
Theory behind the nitrification inhibitor technology

Because of the random distribution of cow urine patches in a grazed field and the fact that urine is returned after each grazing rotation at different times of the year, it is rather difficult to reduce NO_3^- leaching from animal urine patch areas in grazed pastures. However, over the past few years, Di and Cameron have reported a series of studies showing that by treating grazed pasture soil with a nitrification inhibitor, such as dicyandiamide (DCD), the NO_3^- leaching and N_2O emissions from animal urine patches can be significantly decreased (Di and Cameron, 2002c, 2003, 2004a, 2004b, 2005, 2006, 2007, 2008, Di *et al.*, 2007).

The nitrification inhibitor slows down the rate of first step of the nitrification process, the conversion of ammonium (NH_4^+) to nitrite (NO_2^-) and thus to NO_3^- (Figure 1) (Amberger 1989). The inhibitor works by deactivating the enzyme responsible for this conversion, ammonia mono-oxygenase (AMO). Because most soils in temperate regions of the world have a net negative charge, NH_4^+ is adsorbed onto the soil exchange surfaces, giving a greater opportunity for it to be taken up by plants, immobilised into soil organic matter, or fixed into 2:1 type clay mineral interlayers, rather than being leached. However, NO_3^- is easily leached from the soil because it has a negative charge and is thus not held by the negative charged sites on the clay and organic matter. Therefore reducing the rate of conversion from NH_4^+ to NO_3^- can help to retain more nitrogen in the soil for plant use.

N_2O is produced from both nitrification and from denitrification; by slowing down the production of NO_3^- in the soil, nitrification inhibitors help reduce N_2O emissions from both processes (Di and Cameron, 2008).

Figure 1. Nitrification inhibitors slow down the rate of the first step of the nitrification process.



Nitrification inhibitors, such as DCD and, lately, DMPP (3,4-dimethylpyrazole phosphate), have been used to increase the efficiency of N supply from fertilizers or manures (e.g. Amberger, 1989; Zerulla *et al.*, 2001). However, until recently the potential to use nitrification inhibitors to reduce NO_3^- leaching losses and N_2O emissions from grazed pasture systems was unknown.

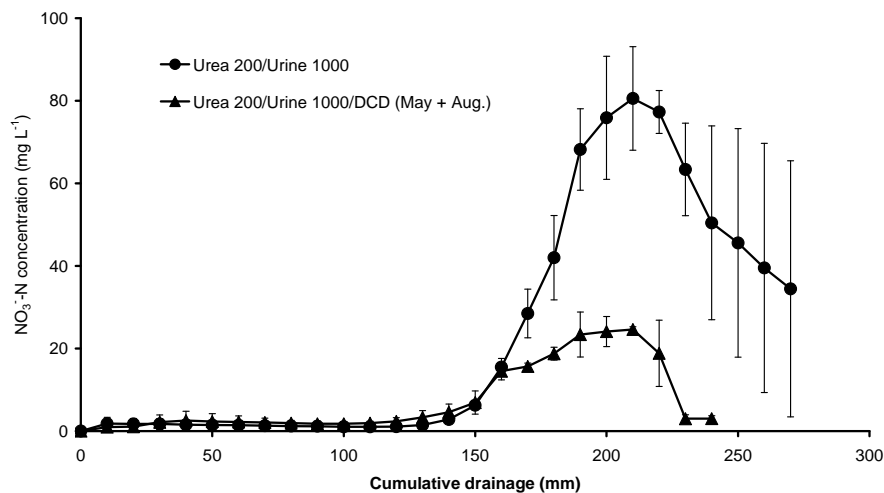
Because urine from grazing animals is deposited at random during grazing and ammonium oxidizing microbes are present everywhere in the soil, it is important to treat the entire soil surface with the inhibitor. One way of achieving this is by applying the nitrification inhibitor in a liquid or fine particle spray form (commercially marketed as 'eco-n' in New Zealand) so that as much of the soil surface as possible is covered by the inhibitor. Therefore wherever the urine is deposited following a grazing rotation, the soil is already treated and the nitrification process is inhibited.

Benefits of the nitrification inhibitor technology in grazed pastures

Reduction of nitrate leaching

One of the key benefits in using nitrification inhibitors to treat grazed pasture soils is a reduction in NO_3^- leaching losses. Di and Cameron (2002c) tested the potential of DCD to reduce NO_3^- leaching from dairy cow urine patches using Lismore stony silt loam monolith lysimeters (50 cm diameter and 70 cm deep) in Canterbury, New Zealand. The results showed that NO_3^- leaching could be reduced by an average of about 69% for dairy cow urine applied in the autumn or spring. These early results were later confirmed by subsequent studies using deeper Templeton sandy soil lysimeters (80 cm diameter and 120 cm deep) which showed that DCD could reduce NO_3^- leaching from cow urine-N patches by 68-76% (Di and Cameron, 2004a; 2005) (Figure 2).

Figure 2. Nitrate-N concentration in the drainage water from Templeton soil lysimeters which received dairy cow urine with and without DCD (Di and Cameron, 2004a).

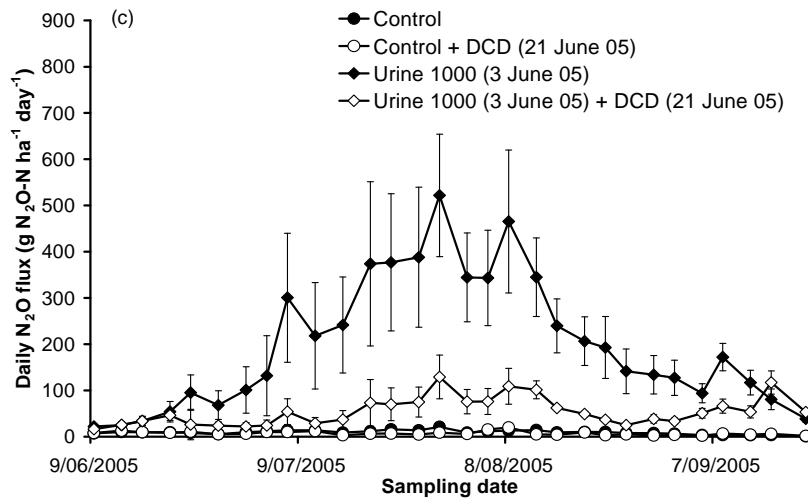


In a subsequent study on a shallow stony Lismore soil, Di and Cameron (2007) studied NO_3^- leaching from animal urine-N applied at four different rates, 0, 300, 700 and 1000 kg N ha⁻¹ to represent N inputs from control, sheep, beef cattle and dairy cattle urine-N returns, respectively, with and without DCD. They showed that DCD gave an average NO_3^- leaching reduction of 63% from these N sources, showing the potential of this technology in not only dairy but also in sheep and beef cattle pastures.

Reduction of nitrous oxide emissions

Research has shown that N_2O emissions from urine patches are also reduced by the use of nitrification inhibitors. By treating the soil with DCD, N_2O emissions from a Lismore stony soil was reduced by 76% following urine application in the autumn (from 26.7 kg N_2O -N ha⁻¹ without DCD to an average of 6.4 kg N_2O -N ha⁻¹ with DCD) (Di and Cameron, 2003). The N_2O flux was decreased by 78% following urine application in the spring (from 18 without DCD to 3.9 kg N_2O -N ha⁻¹ with the application of DCD). These results have been confirmed on a Templeton sandy soil where similar reductions were achieved (Di and Cameron, 2006). In a separate study, N_2O emissions were determined on four different soils, including the Lismore and Templeton soils in Canterbury in the South Island, and Taupo pumice soil near Lake Taupo and Horotiu soil near Hamilton in the North Island. The application of DCD reduced N_2O emissions by an average of 70% across all soils from the urine-N applied (Di *et al.*, 2007) (Figure 3).

Figure 3. N₂O emissions from a Templeton sandy soil, from the Control, Control plus DCD, Urine and Urine plus DCD. Note that DCD was applied 18 days after the urine application (Di *et al.*, 2007).

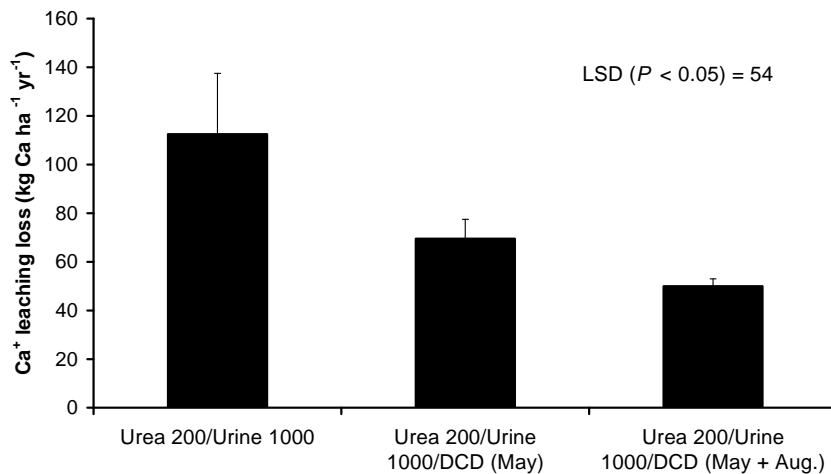


The New Zealand Ministry of Agriculture and Forestry responsible for compiling the agricultural greenhouse gas emissions inventory is currently undertaking preparatory work for the 2009 inventory which, as a world first, includes a calculation to offset N₂O emissions from grazed dairy pastures resulting from nitrification inhibitor use.

Reduction in cation leaching

An additional benefit with the use of DCD in grazed pastures is the reduction of cation leaching losses associated with the reduction of NO₃⁻ leaching. Because NO₃⁻ is negatively charged, it takes cations, usually Ca²⁺, Mg²⁺ and K⁺, as counter ions when leached through the soil profile, therefore, a reduction in NO₃⁻ leaching with the use of DCD can lead to a reduction in the leaching losses of these cations (Di and Cameron, 2004a, 2004c, 2005) (Figure 4).

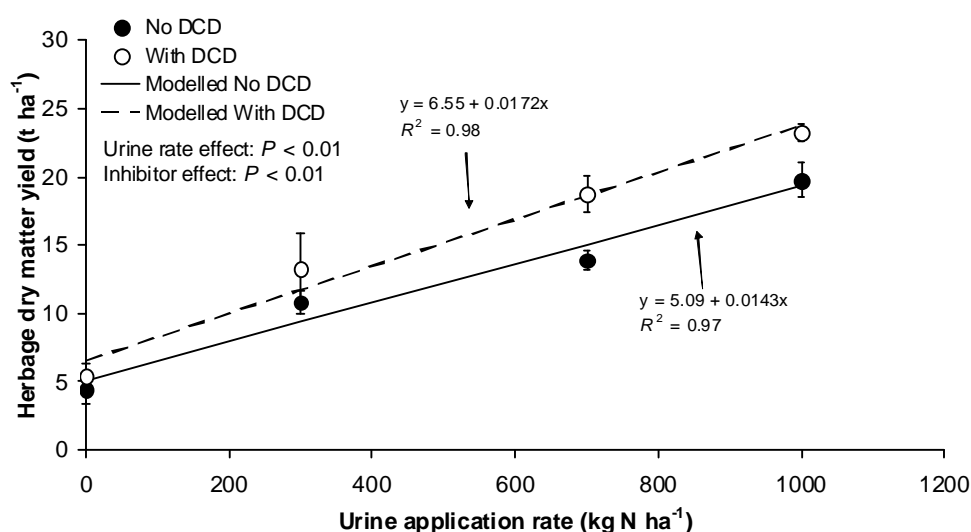
Figure 4. Reduction in calcium (Ca²⁺) leaching from urine applied in the autumn, and DCD applied in the autumn once or DCD applied in autumn and spring in a Templeton sandy soil (Di and Cameron, 2004a).



Increase in nitrogen efficiency and pasture production

Because nitrification inhibitors can help retain more nutrients, particularly N, in the top layer of the soil, this makes more N available for pasture uptake over a longer period, the use of nitrification inhibitors can result in increased pasture production. Pasture yield in urine patch areas have been shown to be increased by more than 30% with the use of DCD (Di and Cameron, 2004a, 2005). When urine-N was applied at different rates to simulate urine-N inputs from sheep, beef cattle and dairy cattle, the N use efficiency was increased by an average of 32% and pasture yield increased by an average of 25% with DCD (Di and Cameron, 2007) (Figure 5). On a grazed paddock scale, pasture increases were recorded in both the urine and inter-urine patch areas (Moir *et al.*, 2007).

Figure 5. Herbage dry matter yields (\pm SE) as affected by urine rate and DCD application in a stony soil (Di and Cameron, 2007).



Optimising the efficiency of nitrification inhibitors

In New Zealand, most of the NO_3^- leaching occurs during the late autumn – winter – early spring period (May to September for the Southern Hemisphere), when the temperatures are low and drainage is high. Therefore, nitrification inhibitors are recommended for use during this high risk period to reduce NO_3^- leaching. During the summer period when temperatures are high, most of the water is lost to the atmosphere by evapotranspiration and also plants are actively growing to use the N in the soil, therefore there is little NO_3^- leaching during this period. Nitrification inhibitors are thus not needed during this period.

Once the nitrification inhibitor is in the soil, it is gradually broken down by soil microbes, thus diminishing its effectiveness. The degradation rate of DCD is affected by temperature (Irigoyen *et al.*, 2003; Di and Cameron, 2004b). During the period when the inhibitor is recommended for use (autumn – winter – spring), the temperatures are generally low in most parts of New Zealand (often below 12 °C), and therefore the degradation rate of DCD is also relatively low. It is thus recommended that DCD should be applied twice over this high risk period, one in late autumn (e.g. May) and one in late winter/early spring (July/August) (Di and Cameron, 2004a, 2005). The current recommended rate for DCD is 10 kg DCD ha⁻¹ per application (Di and Cameron, 2005).

Nitrous oxide emissions are also the highest during the wet period from late autumn to winter to early spring, the application of nitrification inhibitors during this period will therefore also have a major impact on N_2O emissions.

To maximise the effectiveness of nitrification inhibitors to reduce NO_3^- leaching and N_2O emissions from grazed pastures, it is best to apply the inhibitors shortly after grazing before the urine-N is converted to NO_3^- . Once the urine-N has been converted to NO_3^- , then the inhibitor will not be effective anymore to provide the environmental and agronomic benefits. The application of nitrification inhibitors therefore requires a well planned and coordinated approach between the farmer and applicator.

This technology is best suited to grazed pasture systems in the temperate part of the world, e.g. New Zealand, southern Victoria, New South Wales and Tasmania of Australia, parts of South and North America, Northern Europe, and parts of North Asia. In the warmer parts of the world, the degradation rate of most nitrification inhibitors is more rapid and this would shorten their effective period and thus necessitate more frequent applications (Irigoyen *et al.*, 2003; Di and Cameron, 2004b).

Conclusions

In intensively grazed pastures, such as dairy pastures, the major N loss pathways, e.g. NO_3^- leaching and N_2O emissions, not only result in low N use efficiencies, but also contribute to adverse environmental impacts. In intensively grazed pastures, the most important N source for both NO_3^- leaching and N_2O emissions is the N deposited in the animal urine patch areas as the animals graze the field. Direct losses from the fertilizer N applied are relatively small in comparison. However, both NO_3^- leaching and N_2O emissions can be significantly decreased by strategic treatment of the grazed pasture soil with a nitrification inhibitor. The nitrification inhibitor slows down the rate of nitrification, i.e. the conversion of ammonium (NH_4^+) to nitrite (NO_2^-) by deactivating the enzyme responsible for this conversion, ammonia mono-oxygenase (AMO). A series of studies reported by Di and Cameron over the past few years show a reduction of about 60% in NO_3^- leaching, 70% in N_2O emissions and an increase of more than 20% in pasture yield can be achieved. Modelling work is currently underway in calculating annualised effects of nitrification inhibitors on NO_3^- leaching and N_2O emissions in grazed pastures based on recommended use as described in this paper. The modelled annualised effects on N_2O emissions will also be used to offset N_2O emissions for the 2009 inventory.

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References

- Amberger A (1989) Research on dicyandiamide as a nitrification inhibitor and future outlook. *Commun Soil Sci Plant Anal* 20: 1933-1955.
- Di HJ, Cameron KC (2002a) Nitrate leaching in temperate agroecosystems: sources, factors and mitigating strategies. *Nutr. Cycl. Agroecosys.* 64: 237-256.
- Di HJ, Cameron KC (2002b) Nitrate leaching and pasture production from different nitrogen sources on a shallow stony soil under flood irrigated dairy pasture. *Aust J Soil Res* 40: 317-334.

Di HJ, Cameron KC (2002c) The use of a nitrification inhibitor, dicyandiamide (DCD), to reduce nitrate leaching from cow urine patches in a grazed dairy pasture under irrigation. *Soil Use Manage* 18: 395-403.

Di HJ, Cameron KC (2003) Mitigation of nitrous oxide emissions in spray-irrigated grazed grassland by treating the soil with dicyandiamide, a nitrification inhibitor. *Soil Use Manage* 19: 284-290.

Di HJ, Cameron KC (2004a) Treating grazed pasture soil with a nitrification inhibitor, 'eco-nTM', to decrease nitrate leaching in a deep sandy soil under spray irrigation – a lysimeter study. *N Z J Agric Res* 47: 351-361.

Di HJ, Cameron KC (2004b) Effects of temperature and application rate of a nitrification inhibitor, dicyandiamide (DCD) on nitrification rate and microbial biomass in a grazed pasture soil. *Aust J Soil Res* 42: 927-932.

Di HJ, Cameron KC (2004c) Effects of the nitrification inhibitor, dicyandiamide on potassium, magnesium and calcium leaching in grazed grassland. *Soil Use Manage* 20: 2-7.

Di HJ, Cameron KC (2005) Reducing environmental impacts of agriculture by using a fine particle suspension nitrification inhibitor to decrease nitrate leaching from grazed pastures. *Agric Ecosyst Environ* 109: 202-212.

Di HJ, Cameron KC (2006) Nitrous oxide emissions from two dairy pasture soils as affected by different rates of a fine particle suspension nitrification inhibitor, dicyandiamide (DCD). *Biol Fert Soils* 42: 472-480.

Di HJ, Cameron KC (2007) Nitrate leaching losses and pasture yields as affected by different rates of animal urine nitrogen returns and application of a nitrification inhibitor – a lysimeter study. *Nutr Cycling Agroecosys* 79: 281-290.

Di HJ, Cameron KC (2008) Sources of nitrous oxide from ¹⁵N-labelled animal urine and urea fertilizer with and without a nitrification inhibitor, dicyandiamide (DCD). *Aust J Soil Res* 46: 76-82.

Di HJ, Cameron KC, RR Sherlock (2007) Comparison of the effectiveness of a nitrification inhibitor, dicyandiamide (DCD), in reducing nitrous oxide emissions in four different soils under different climatic and management conditions. *Soil Use Manag* 23: 1-9.

Haynes RJ, Williams PH (1993) Nutrient cycling and soil fertility in the grazed pasture ecosystem. *Adv Agron* 49: 119-199.

Irigoyen I, Muro J, Azpilikueta M, Aparicio-Tejo A, Lamsfus C (2003) Ammonium oxidation kinetics in the presence of nitrification inhibitors DCD and DMPP at various temperatures. *Aust J Soil Res* 41, 1177-1183.

Jarvis SC, Scholefield D, Pain B (1995) Nitrogen cycling in grazing systems. In: Bacon, P.E. (ed), *Nitrogen Fertilization in the Environment*. Marcel Dekker, New York. pp381-419.

MFE (2007a) *New Zealand's Greenhouse Gas Inventory 1990-2005*. Ministry for the Environment, Wellington, New Zealand.

MFE (2007b) *Environment New Zealand 2007*. Ministry for the Environment, Wellington, New Zealand.

Moir J, 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. *Soil Use Manag* 23: 111-120.

PCE (2004) *Growing for Good*. Parliamentary Commissioner for the Environment, Wellington, New Zealand.

Zerulla W, Barth T, Dressel KE, von Locquenghien KH, Wissemeier AH (2001) 3,4-Dimethylpyrazole phosphate (DMPP) – a new nitrification inhibitor for agriculture and horticulture. *Biol Fert Soils* 34: 79-84.