Modelling the role of DCD in mitigating nitrogen losses under grazed pastures

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Abstract
The simulation model APSIM (Agricultural Production Systems SIMulator) with a submodule accounting for nitrification inhibition by DCD was used to investigate the role of DCD on nitrate leaching under grazed pastures. To account for the degradation of DCD two different approaches were used. In the first approach the exponential degradation of DCD was assumed to be driven by soil temperature, soil moisture content and soil pH, similarly to the nitrification process. In the second approach environmental conditions throughout the degradation process were assumed to remain constant, and the temperature effect on degradation was based on an empirical relationship developed by Kelliher *et al.* (Kelliher, 2008). The model was parameterised using lysimeter data and then used to evaluate the effect of various environmental conditions (soil conditions, rainfall pattern, temperature) and management options (timing and rate of DCD application) on the effectiveness of DCD in reducing nitrate leaching under grazed pastures.

Key Words
Nitrate leaching, DCD, APSIM, modelling.

Introduction
Intensification of dairying is widespread in New Zealand, and although economic benefits are potentially large, this can lead to environmental degradation. Intensive dairying with increasing fertiliser input, especially nitrogen (N), biological fixation of N in these legume-based pastures, and very high concentrations of N under urine patches can generate nitrate (NO_3) leaching to the ground water aquifers, and thus create environmental problems. As a solution to mitigate the leaching losses of NO_3^- under dairy pastures, the use of nitrification inhibitors such as dicyandiamide (DCD) has been proposed (Di, 2004; Menneer, 2008; Monaghan, 2009). However, the effectiveness of DCD under grazed pastures has not yet been assessed in detail, and best management practices for the application of DCD have yet to be developed. Modelling is increasingly being recognised as a suitable alternative to measurements for assessing best management options because it can be a cost-effective way of assessing multiple options. The objective of this study was to develop a deterministic module for APSIM that can describe the role of nitrification inhibitors on nitrogen transformations and nitrate leaching under grazed pastures. The model was used to evaluate the effect of various environmental conditions (soil conditions, rainfall pattern and temperature) and management options (timing and rate of DCD application) on the effectiveness of DCD in decreasing nitrate leaching.

Modelling
Simulation models, such as APSIM (Agricultural Production Systems SIMulator) are increasingly being used as a tool for the evaluation of alternative management strategies for improving the economic and environmental performance of agricultural production systems. APSIM is a modelling framework in which a system is configured from component modules, which can be plugged in and pulled out depending on the system considered. For our simulations we combined APSIM with (i) SWIMv2 for describing water movement and nitrate and DCD transport, based on Richards' equation and the convection dispersion equation, (ii) AgPasture for describing the pasture system, and (iii) Micromet for calculating evapotranspiration based on the Penman-Monteith approach. A schematic picture of the configuration of APSIM with the various modules is shown in Figure 1.

Features of the Nitrogen cycle in APSIM relevant to nitrification
The SoilN module describes the dynamics of both carbon and nitrogen in soils. The nitrification of ammonium (NH_4) into nitrate (NO_3) in SoilN is described using a Michaelis-Menton response to available soil NH_4, with the rate of nitrification given by:

$$k = k_{\max}\left(\frac{[NH_4]}{[NH_4]+K_{NH_4}}\right) f_T\, f_w\, f_{pH}$$

[1]\

where $[NH_4]$ is the ammonium concentration in the soil, k_{max} is the potential nitrification rate (mg N/kg soil/ day), k_{NH4} is the NH_4 concentration for half maximum response to ammonium concentration, f_T, f_w and f_{pH} are temperature, water and pH response factors, that lie between 0 and 1. The effect of a change in microbial population on the potential nitrification rate is not considered.

The f_w and f_{pH} are assumed to decrease on either side of an optimum soil moisture and pH range while f_T increases exponential.

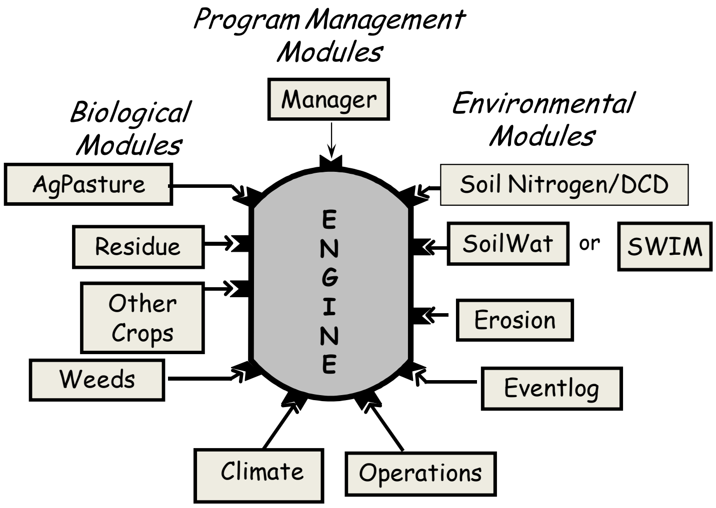

Figure 1. Modular Structure of APSIM

Effect of DCD on nitrification

In soils, DCD is susceptible to biodegradation, which has been shown to be affected by soil temperature, soil moisture content, soil pH, and organic matter content (Di 2004; Singh 2008). We describe the degradation of DCD via a first-order decay process that is affected, in the same way as the process of nitrification, by temperature, water content and pH. Thus, the residual mass of DCD, (M_{DCD}), decreases exponentially with time according to:

$$M_{DCD}(t) = M_{DCDo}\exp\left(-\mu\, f_T\, f_w\, f_{pH}\, t\right) \qquad [3]$$

where M_{DCDo} is the initial mass of DCD, and μ the first order decay rate constant [h^{-1}].

Nitrification (Eq. [1]) is inhibited by DCD according to:

$$k = k_{\max}\left(\frac{[NH_4]}{[NH_4]+K_{NH_4}}\right) f_T\, f_w\, f_{pH}\, f_{DCD}$$

[4]

where f_{DCD} is the factor accounting for the nitrification inhibition by DCD, which is dependent on the concentration on DCD and lies between 0 and 1 at some optimal DCD concentration (M_{DCDopt} [kg/kg soil]), at which all nitrification in the soil is inhibited. The factor f_{DCD} is given by (Vogeler, 2007):

$$f_{DCD}(t) = \left(1 - \frac{M_{DCD}(t)}{M_{DCDopt}}\right) \qquad [5]$$

Alternatively, for a simple model we may assume that the soil temperature is the main factor influencing the degradation of DCD. We can then replace the rate order μ in Eq. [3] by a half life H, where H = ln(2)/μ, and the equation can be written as:

$$M_{DCD}(t) = M_{DCDo} \exp(-0.693\, t / H) \qquad [6]$$

We then can use the relationship between DCD half life (H) and soil temperature (T) developed by Kelliher *et al.* (Kelliher 2008) for soils close to field capacity:

$$H(T) = 168 \exp - 0.084\, T \qquad [7]$$

and use the above two equations to calculate f_{DCD} in Eq. [5]. Note that this approach is based on the assumption that the environmental conditions during the degradation period of DCD remain unchanged, with a simple half life to account for temperature effect and soil moisture close to field capacity. The effect of pH on the degradation of DCD is ignored. In many situations such a simplified description of DCD degradation might, however, be appropriate. In our modelling approach, DCD moves according to the convection dispersion equation through the soil profile.

The above approach within APSIM was parameterised using lysimeter data from Shepherd *et al.* (Shepherd 2009), which showed that DCD reduced nitrate leaching by 25 to 50% depending on the irrigation management (Figure 2). Then it was used to evaluate the effect of various environmental conditions (soil conditions, rainfall pattern, temperature) and management options (timing and rate of DCD application) on the effectiveness of DCD in reducing nitrate leaching under grazed pastures. The effect of DCD on the nitrification process, and consequent leaching of nitrate was simulated based on two different approaches. The first approach accounted for DCD leaching, and DCD degradation driven by temporal soil temperature, moisture content and pH. In the second, more simple, approach a constant half life was used, which was based on a degradation-temperature relationship developed by Kelliher *et al.* (Kelliher, 2008), and an average temperature over the degradation period. The effect of DCD on pasture production, by increasing the residence time of available nitrogen in the rootzone, was also investigated.

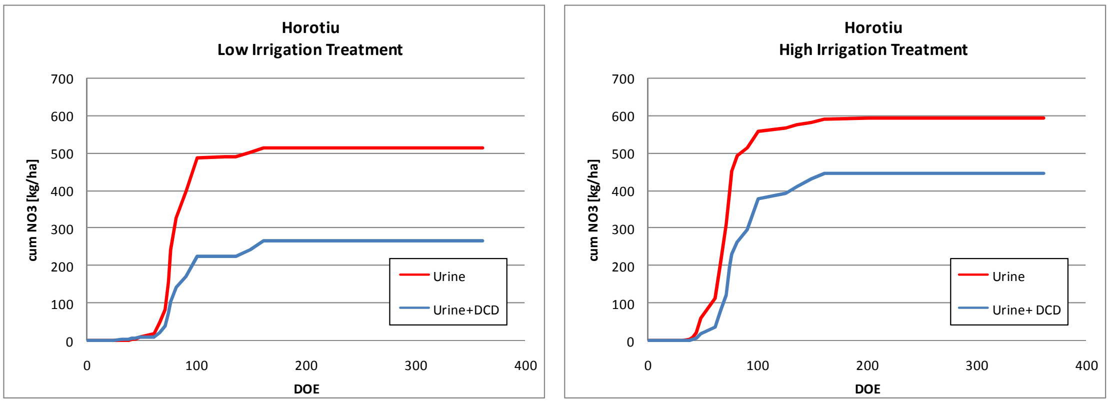

Figure 2. Cumulative leaching of nitrate from a urine patch with and without DCD application under a low and high irrigation regime as a function of time with DOE = Day of Experiment.

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