THE IMPACT OF CLIMATE ON THE EFFICIENCY OF DCD IN REDUCING N LEACHING

Iris Vogeler, Rogerio Cichota, Val Snow and Ross Monaghan

AgResearch Grasslands, Private Bag 11008, Palmerston North, New Zealand
AgResearch Lincoln, Private Bag 4749, Lincoln, New Zealand
AgResearch Invermay, Private Bag 50034, Invermay, New Zealand
Iris.vogeler@agresearch.co.nz

Abstract

We used the APSIM (Agricultural Production Systems SIMulator) model to investigate the influence of rainfall and temperature on the efficiency of DCD to reduce nitrogen leaching from urine patches. This modelling tool incorporated a recently developed module accounting for nitrification inhibition by DCD. Simulations were run for key dairy regions of NZ (Southland, Canterbury, Manawatu, Waikato and Northland), with three different soil types (clay loam, silt loam, and sand), with and without irrigation and from 1973 to 2005. Deposition of a urine patch was simulated by applying an equivalent of 750 kg N/ha, and these depositions were, in separate simulation runs, done for every month and year of application. The total amount of N leached was summed over the three years following the urine deposition.

Of the 750 kg N/ha applied, on average over all years and deposition months, between 50 and 500 kg N/ha leached. In general, leaching was lowest in Southland and increased with locations further north. DCD decreased N leaching on average by 4-30%, and for a specific location and time by up to 60%. DCD was most effective in Southland, with decreasing efficiency further north. For the irrigated sites, rainfall amount and pattern explained 15% of the variation in DCD efficiency. When considering temperature as well, the variation explained increased to 25%. The influence of rainfall and temperature on DCD efficiency varied across application month and with soil type. These modelling results are an initial step to understand the environmental factors influencing the efficiency of DCD in reducing N leaching.

Introduction

Leaching of nitrogen (N) is a major pressing environmental issue for NZ agriculture. Urine patches are known as hot-spots for nitrate leaching from grazed pastures. The use of nitrification inhibitors, such as dicyandiamide (DCD) has been shown to reduce such N leaching losses. However, its effectiveness has been observed to vary considerably with location and month of application (Di and Cameron, 2007, Di et al., 2007, Menneer et al., 2008, Williamson et al., 1998, Monaghan et al., 2009). Developing guidelines for a widespread use of DCD as a mitigation tool requires better quantitative understanding of the influence of environmental variables on the effectiveness of DCD. The effectiveness is dependent on the residence time of DCD in the soil, which in turn is influenced by DCD leaching and degradation, and thus ultimately by rainfall and temperature (Monaghan et al., 2009).

Better understanding of the environmental conditions affecting the effectiveness of DCD in reducing N leaching could help farmers to choose application times when the efficacy of DCD is maximised.

Materials and methods

APSIM- DCD model testing

The APSIM model (Keating et al., 2003), utilises SWIM (Verburg et al., 1996) as the soil module and AgPasture (Li and Snow, 2011) as the pasture module. A newly developed module for nitrification inhibition was based on the principles of DCD degradation described by a first-order decay process, which is driven by the soil water content, soil temperature, pH, and carbon content (Di, 2004; Singh, 2008). The module is described in more detail in Cichota et al. (2010). APSIM, with the DCD module, was tested against data from a lysimeter experiment (Shepherd et al., 2009). In short, the experiments, with 4 replicates, started in May 2008 and consisted of a low and high irrigation treatment (targeting water inputs of 1100 and 2000 mm /yr). Urine was applied at a rate of 1000 kg N/ha both without and with DCD at a rate of 10 kg /ha, applied immediately following urine deposition and repeated 70 days later. The pasture was cut regularly with urea being applied as fertiliser at a rate of 25 kgN/ ha every month from August until May.

APSIM model simulations

APSIM was then used to determine the impact of climate conditions on the effectiveness of DCD in reducing N leaching from urine patches. This was done by simulating leaching from a urine patch with and without DCD added each month over a 33 year period at 5 different locations using 3 different generic soils. Climate data from 5 locations (Northland, Waikato, Manawatu, Canterbury, and Southland) from the Virtual Climate Station database of NIWA (Tait and Turner, 2005; www.cliflo.niwa.co.nz) were used. Simulations were done with and without irrigation for Canterbury, Manawatu and Waikato, and without irrigation for Northland and Southland, from 1973 to 2005. Deposition of a urine patch was simulated by applying an equivalent of 750 kg N/ha, without or without of DCD, at a rate of 10 kg/ha. Nitrogen leaching data was generated using multiple runs with a complete factorial combination of these five climate stations, three different generic soils (clay loam, silt loam, and sand), N deposition with or without DCD, and 12 separate application dates (once every month). In the simulations nitrogen fertiliser was applied at a rate of 20 kg N/ha/month from September to June, and the pasture was managed under a cut and carry system.

The efficiency of DCD in reducing N leaching over 3 years following deposition was related to climate conditions, including average annual rainfall, rainfall pattern and average annual temperature. To identify climate conditions that influence the efficiency of DCD, the JMP statistical package was used (www.JMP.com) with stepwise regression and correlation analysis.

Results and discussion

APSIM- DCD testing

Comparison with experimental data shows good model performance as drainage (not shown) and NO_3 leaching data were within the range of measured values (Figure 1), especially for the low irrigation treatment.

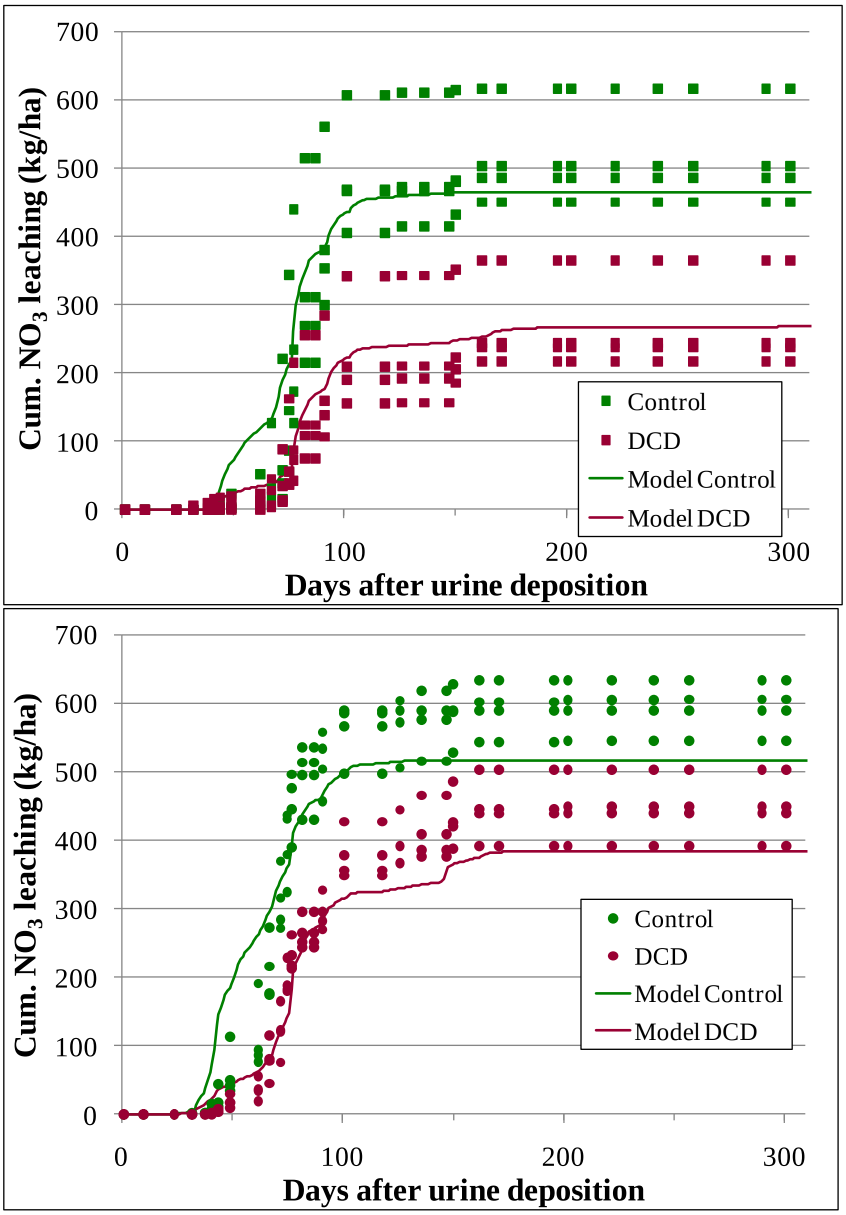

Figure 1. *Measured (symbols) and predicted (lines) cumulative* NO_3 *leaching without (closed symbols and solid lines) and with DCD (open symbols and broken line) from selected lysimeter experiments on Horotiu soil with 4 replicates and for low irrigation (top) and high irrigation (bottom) treatment (Shepherd et al., 2009)*

APSIM model simulations

APSIM was then used to determine the effect of climate variables on the efficiency and effectiveness of DCD in reducing N leaching by using the simulations runs with the 5 climates, three soil types, with and without irrigation over 33 years. Efficiency is defined as the percentage change in N leaching due to DCD application, whereas effectiveness is here defined as the absolute change in N leaching [kg/ha/3yrs].

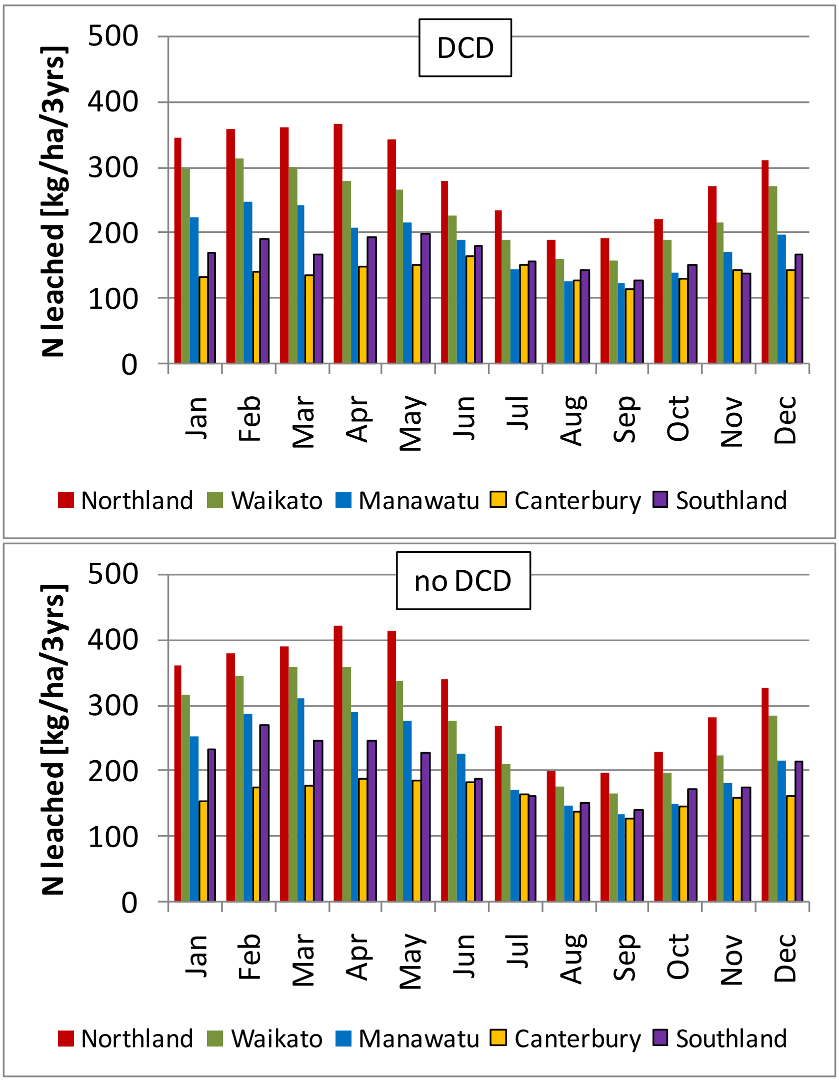

Figure 2. Average N leaching for the different regions with and without DCD.

Average simulated nitrogen leaching from the 750 kg N /ha of urine deposited on the three different soil types over the 33 years (Figure 2) ranged from about 125 to 420 kg N /ha depending on the month of deposition and the region. In general, simulated leaching was highest in Northland and lowest in Southland and Canterbury. In line with experimental and other simulation results, N leaching was higher from urine depostion in the summer and autumn period compared to winter months (Vogeler et al., 2010, Shepherd et al., 2011, Snow et al., 2011). Average DCD efficiency was 4 to 30 % depending on region and month of deposition (Figure 2). Averaged over all months and 33 years of simulation the efficiency was highest in Southland (19%) and decreased further north (Figure 3).

The efficiency of DCD in reducing N leaching was dependent on the month of deposition and the region as shown in Figure 4 for the irrigated sites only and the silt loam. Whereas the efficiency of DCD in Canterbury was highest from January to May, ranging from 22-35%, DCD efficiency in the Manawatu was highest from February to July (22-48%), and in Waikato from March to June (25-45%). The effectiveness of DCD in reducing N leaching (kg N/ha), was highest from March to May in Manawatu and Waikato and February to April in Canterbury (Figure 4).

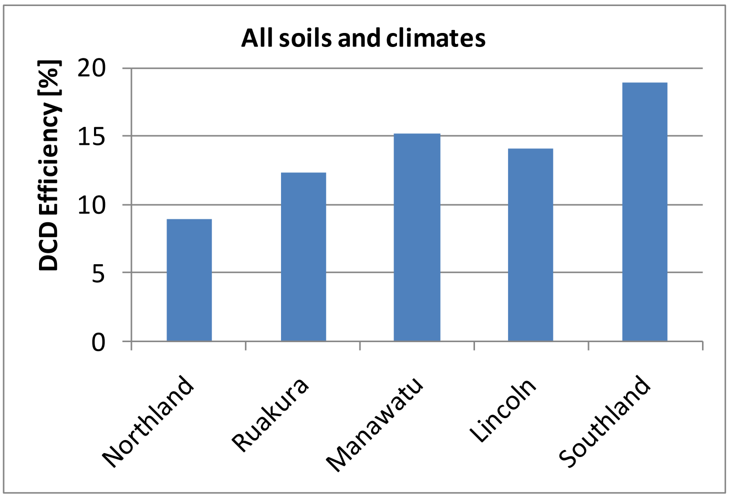

Figure 3. Average simulated DCD efficiency in the different regions for all months and 33 years of simulation.

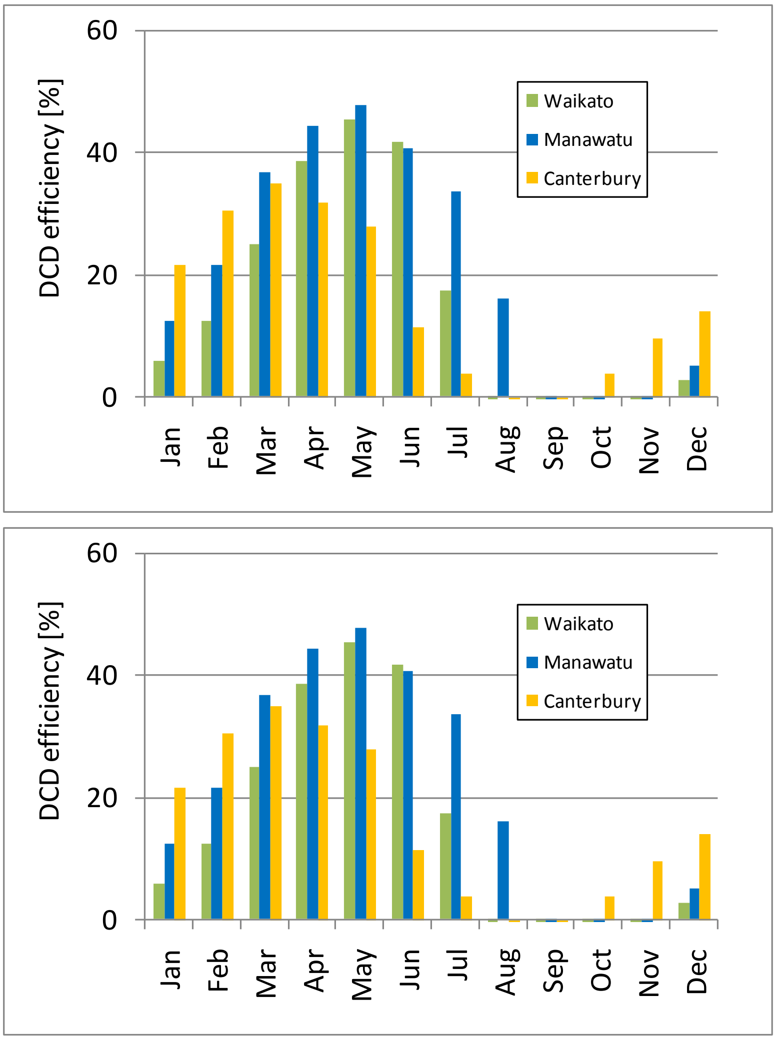

Figure 4. Average simulated DCD efficiency (top) and DCD effectiveness (bottom) following DCD application to the silt loam soil under irrigation.

The efficiency of DCD in is not only dependent on the month of deposition but is also variable between years as shown in Figure 5 for May depositions over the 33 years on a silt loam in Canterbury. DCD reduced N leaching by up to 60%, but in some years slightly increased leaching losses, with the efficiency not being related to the total amount of N leached. N leaching was also highly variable, ranging from almost no leaching to 175 kg N/ha.

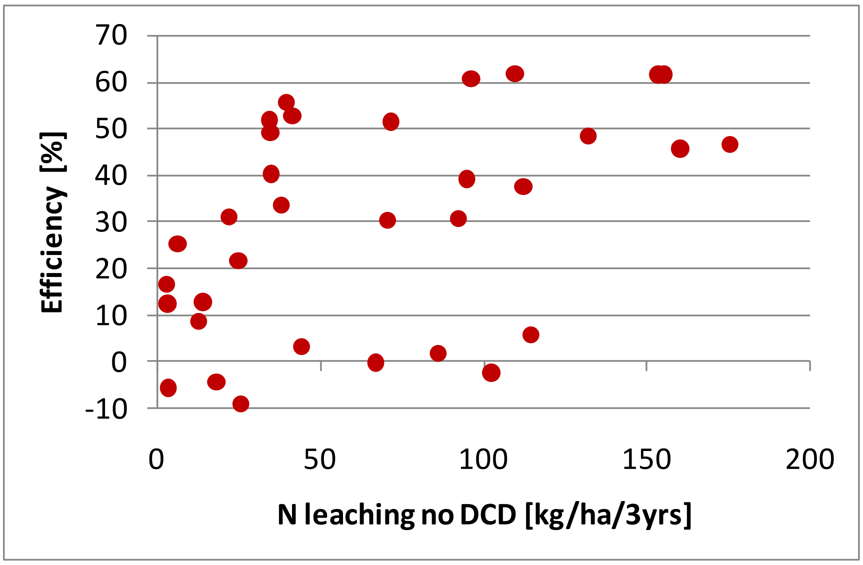

Figure 5. Modelled reductions in N leaching [%] following DCD application to a urine patch deposition of 750 kg N/ha in May on a silt loam soil in Canterbury over 33 years of simulations.

To elucidate the climatic factors that drive DCD efficiency, only the simulations that resulted in N leaching > 50 kg N /ha /3 yrs were considered. Correlation analysis showed very weak relationships between climatic factors and DCD efficiency when all months, soils and irrigated regions were used (Table 1). A stronger correlation was found by splitting the analysis into months and soil type or location, as shown in Table 1 for a few selected months and the silt loam and Canterbury. A strong correlation existed between the rainfall in the year following the urine and DCD deposition and the DCD efficiency. Shorter term rainfall showed a weaker (negative) correlation for the selected sites and months of deposition. In some cases a reasonable correlation was observed between the occurrence of heavy rainfall (> 10 or 20 mm) within two weeks following DCD application. The average temperature in the year following application and DCD efficiency also showed a good correlation for some of the months, and improved when further split by soil. Splitting by location reduced the correlation, as for example the correlation between DCD efficiency and rainfall within the year following the deposition in February in Canterbury (0.04) compared to the correlation for all irrigated sites (-0.74).

Table 1. Correlation coefficients between DCD efficiency and several climatic factors for three irrigate regions (Canterbury, Manawatu, and Waikato), and three soils types (clay loam, silt loam and sand) where ZL = silt loam, Cant = Canterbury. Light shading shows correlation > 0.5 and dark shading > 0.7.

Met-irrigated		all	all	all	all	all	all	all	Cant	Cant	Cant
Soils		all	all	all	all	ZL	ZL	ZL	ZL	ZL	ZL
Month		all	Feb	Apr	Jun	Feb	Apr	Jun	Feb	Apr	Jun
Factor	Time Period										
Rainfall	2 weeks	-0.05	-0.36	-0.05	0.06	-0.29	0.06	0.13	-0.24	0.09	-0.11
Rainfall	1 month	-0.02	-0.39	-0.09	0.17	-0.33	-0.10	0.27	-0.39	0.15	0.39
Rainfall	1 year	0.02	-0.57	0.04	0.35	-0.74	-0.20	0.51	0.04	0.57	0.57
Rainfall + Irrigation	2 weeks	-0.06	-0.33	-0.09	0.07	-0.25	0.04	0.13	-0.18	0.06	-0.11
Rainfall + Irrigation	1 month	-0.07	-0.36	-0.13	0.17	-0.26	-0.12	0.27	-0.32	0.12	0.39
Rainfall + Irrigation	1 year	-0.16	-0.65	-0.18	0.16	-0.75	-0.25	0.43	0.03	0.56	0.35
Rainfall >10 mm	2 weeks	-0.02	-0.34	-0.03	0.06	-0.28	0.06	0.09	-0.16	0.09	-0.06
Rainfall >10 mm	1 month	0.01	-0.37	-0.07	0.15	-0.33	-0.10	0.19	-0.33	0.15	0.42
Rainfall > 20 mm	2 weeks	-0.02	-0.34	-0.03	0.06	-0.29	-0.01	0.07	-0.02	0.06	-0.08
Rainfall > 20 mm	1 month	0.00	-0.36	-0.10	0.14	-0.33	-0.15	0.12	-0.22	0.17	0.16
Temp-average min	2 weeks	0.09	-0.33	0.05	0.25	-0.43	0.04	0.45	-0.41	0.32	-0.03
Temp-average	2 weeks	0.10	-0.31	0.04	0.24	-0.47	-0.05	0.36	-0.46	0.25	-0.31
Temp-average max	2 weeks	0.11	-0.23	0.02	0.20	-0.42	-0.13	0.21	-0.37	0.13	-0.45
Temp-average min	1 month	0.01	-0.35	0.03	0.27	-0.49	-0.03	0.44	-0.45	0.18	0.04
Temp-average	1 month	0.02	-0.35	0.01	0.27	-0.56	-0.12	0.39	-0.48	0.10	-0.24
Temp-average max	1 month	0.03	-0.31	-0.01	0.23	-0.55	-0.20	0.26	-0.38	-0.01	-0.46
Temp-average min	1 year	-0.03	-0.52	-0.02	0.28	-0.73	-0.23	0.34	-0.46	-0.17	-0.36
Temp-average	1 year	-0.05	-0.53	-0.07	0.22	-0.72	-0.30	0.22	-0.57	-0.34	-0.50
Temp-average max	1 year	-0.06	-0.48	-0.10	0.16	-0.64	-0.31	0.11	-0.57	-0.40	-0.54

These results suggest that rainfall and temperature in the year following urine and DCD application were, in some months, key drivers influencing the DCD efficiency. Stepwise regression analysis shows that for the irrigated locations on a silt loam soil, depending on the month, rainfall alone explained between 4 and 55% of the variation in simulated DCD efficiency; this is shown in Table 2 for a selected months. Including the average temperature within one year after deposition increased the percentage of the variation explained up to 65% for February. Including even more climatic factors increased the percentage explained to 69%. Other factors that were important were rainfall in the 2 weeks following deposition, rainfall events larger than 10 and 20 mm within the 2 weeks following deposition, and minimum average temperature in the following 2 weeks. For some other months (April, May, August and September), assuming a linear response to the climatic factors considered could not explain the variation in DCD efficiency simulated. This suggests that either not all key driving factors for DCD efficiency were considered, or there was a nonlinear response between some of the climatic factors and DCD efficiency. This was not however, considered here due to lack of data.

Table 2. Correlation coefficients (R^2) for various factors and DCD efficiency, with RF_1y = rainfall in the year following application, T_1y = average temperature in year following application.

Month	RF_1y	RF_1y + T_1y	Multiple factors
February	0.55	0.65	0.69
April	0.04	0.09	0.21
June	0.26	0.27	0.34

The linear regression coefficients were also used to predict the DCD efficiency. Using only the rainfall within a year following urine and DCD application resulted in a reasonably good relationship between predicted and APSIM-simulated DCD efficiency for a silt loam at the irrigated locations, with an R^2 value of 0.55. Including temperature increased the R^2 to 0.65 (Figure 6).

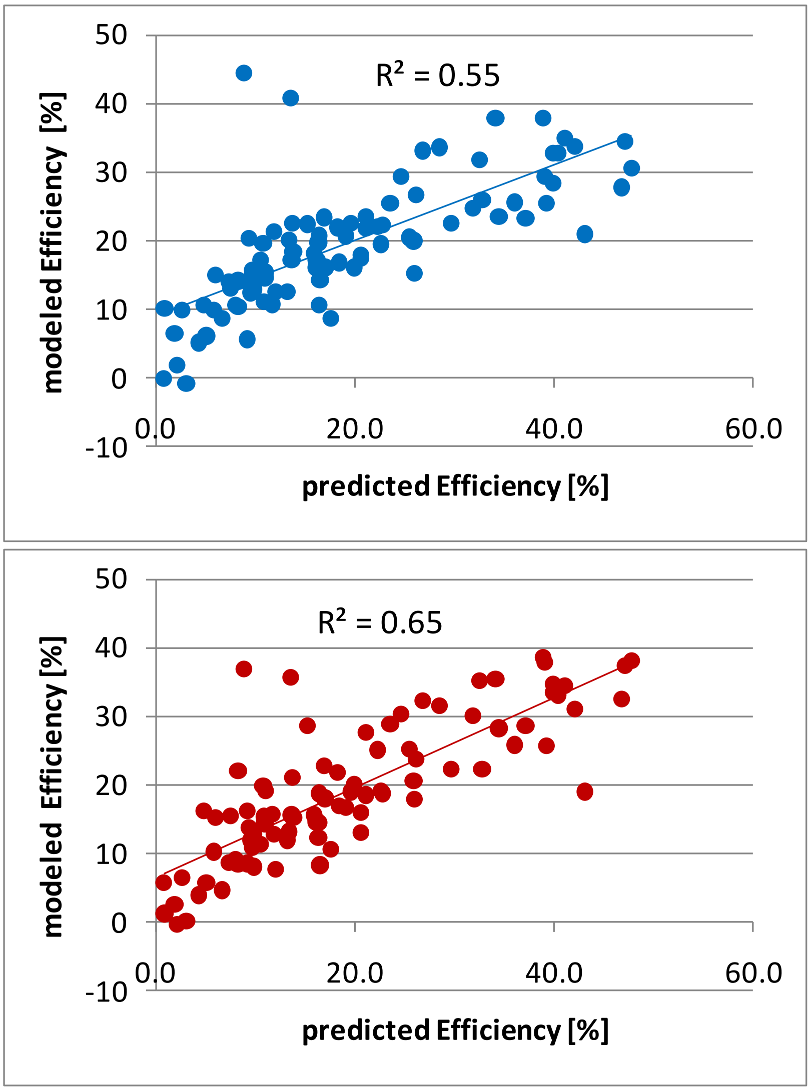

Figure 6. Relationship between APSIM-simulated DCD efficiency (reduction in N leaching) and predicted efficiency based on rainfall within the year following deposition (top) and rainfall and average temperature in the following year (bottom) for a silt loam and irrigated sites Waikato, Manawatu and Canterbury.

Conclusions

APSIM was used to explore the environmental variables that drive the efficiency (percent reduction) and effectiveness (amount of reduction) of DCD in reducing N leaching from urine patches . Simulations were made for key dairy regions in New Zealand (Northland, Waikato, Manawatu, Canterbury and Southland), and three different soil types (clay loam, silt loam and sand). APSIM simulations suggest that DCD efficiency was up to 70% depending on location, year, and soil type. DCD efficiency was largest in Southland, with decreasing efficiency observed further north. There was a high variability in DCD efficiency between years.

Statistical analysis showed that rainfall within the year following application was an important driver of DCD efficiency. For a silt loam soil at the irrigated sites (Waikato, Manawatu and Canterbury), rainfall explained 55 % of the variation in efficiency. Including the average temperature in the year following DCD applicationincreased this to 65%, and including even more climatic factors to 69%. Assuming a linear response between climatic factors and DCD efficiency was not good for all months, suggesting that either a nonlinear response needs to be considered or there are other driving factors not accounted for in the model.

These results are an initial step in identifying the climatic factors that determine the efficiency of DCD in reducing N leaching from urine patches. Further experimental data and more model testing with different soils and multiple DCD applications are however needed to fully understand the determinants of DCD efficiency.

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