REVIEWING AND REVISING THE DCD MODEL WITHIN OVERSEER® NUTRIENT BUDGETS

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Summary

The OVERSEER® nutrient budgeting tool (‘*Overseer’*) allows users to assess the impacts of potential farm management changes on the resultant farm nutrient budget and, therefore, the efficiency of nutrient use on the farm. One of these management options is to apply the nitrification inhibitor dicyandiamide (DCD) in autumn and late winter.

The aim of this project was to review the original DCD model that was implemented in *Overseer* v 5.4 in 2007/08, based on published papers and reports. The result of the assessment was that there was insufficient new data for *Overseer* to significantly change its current modelling approach. Because much of the experimental data are based on measurements at the urine patch scale, the challenge for *Overseer* is to scale up these results to the paddock, block and farm. This requires up-scaling of the urine patch principles to a complex farm system with multiple grazing events through the whole year; the DCD effect will be variable on these urine deposits. The conclusion was that the empirical approach to modelling DCD effects is still appropriate, using rainfall/drainage and temperature after application as the main drivers to estimate efficacy. To make further progress, more understanding around the DCD mode of action and the ability to model the process-based effects is required, but this is probably a long-term goal.

Introduction

OVERSEER® Nutrient Budgets (*Overseer*) calculates on-farm nutrient flows, including an estimate of nitrate leaching (NO_3) and nitrous oxide (N_2O) emissions (Wheeler et al., 2008). In 2008, the effect of dicyandiamide (DCD) on these losses was added to the model as a mitigation option (Version 5.4). The review of the available science and development of the modelling approach was funded by MAF’s Sustainable Farming Fund (SFF).

This DCD model within *Overseer* (v 5.4) works at the whole-farm scale (not at individual block levels) and is applicable only to grazed pasture systems. It estimates effects on NO_3 leaching and N_2O emissions from animal urine and N fertiliser (and assumes DCD to be ineffective on dung-N and on N in farm dairy effluent). The availability of experimental data to develop the model meant that various constraints were placed on its operational boundaries. *Overseer* only estimated effects for standard application times for DCD. It was assumed there were no residual effects from one application to another within a year. It was assumed that DCD was applied according to manufacturer’s recommendations around timings and rates.

The main driving factors for the DCD model were the site factors of winter temperature regime and amount of soil drainage. Thus, the DCD model provided an estimate of the effect of DCD use on N leaching and N_2O emissions, and accounted for: site characteristics (temperature, drainage); effect of periods when DCD is not applied or is ineffective; effect of variation in animal intake throughout the year (e.g. lower intake in winter compared to other times); and effect of animals grazing off over winter or on wintering pads.

The aims of this project were to re-assess the literature on DCD effectiveness on NO_3 leaching, N_2O emissions and pasture growth response to take account of science developments since the original DCD model was developed for *Overseer*; and to determine if the model could/should be re-developed.

Approach

The approach followed these steps:

- An assessment of the state of process modelling of DCD effects - and potential for adaptation for use in *Overseer*.
- Collation of the science literature on DCD effects – extensive literature searches were undertaken to collect all published material on DCD effectiveness relevant to NZ conditions. All papers were collated and key details of each experiment summarised in an Excel spreadsheet, which then allowed more formal data analysis.
- Data exploration and analysis.

Data acquisition

There have been a large number of published reports on aspects of DCD in recent years. We assembled 81 published reports, produced by 75 different author groups. The subject of the papers could be categorised as review papers (20), or papers reporting field (43), laboratory (11), and modelling-based experiments (7). Of this initial dataset, the field experiment reports were reviewed and a number were rejected from inclusion for further analysis because DCD application rates were outside normal practice, DCD was mixed with effluent or slurry, or was applied to winter brassicas. The emphasis of the analysis was effects on urine on pasture.

This left 32 field experiment datasets with a breakdown according to experimental scale of two thirds ‘urine patch’ (lysimeters or small plots with porous cups) and one third ‘paddock’. These papers formed the basis of our data analysis. About two thirds of treatments received one DCD application, one third received two applications. Time of applications was generally in the late autumn – early spring period, with the large majority applied in May and/or August.

Results and discussion

Assessment of other modelling approaches

Overseer by necessity developed an empirical approach to estimate DCD effectiveness, based on the type of experimental data available. The question was whether there was scope to take lessons from process-based models to modify the *Overseer* approach.

There is evidence that modellers are starting to model DCD at a more process-based level of detail. For example, Vogeler et al. (2007) developed a model of DCD activity based on calibrations from laboratory tests. Cichota et al. (2010) used APSIM to start to model DCD effects and they were able to draw out some ‘rules of thumb’ around drainage and effect of time between application and urine deposition on effectiveness. Giltrap et al. (2010) used the DCDN model to make a preliminary assessment of DCD on N_2O emissions.

Despite this, our assessment was that considerable work is required to understand the effects of DCD at the biological level (e.g. effects on nitrification rate and factors driving this) until anything is available to contribute to *Overseer*. We would also argue that the modellers are constrained by lack of experimental data at the required level of detail to advance their understanding sufficiently to model the processes.

Available data

Whilst extremely useful, the datasets that were collated have two limitations. Firstly, there is not a wide geographical distribution. The experiment sites were based mainly around Lincoln (generally cold and relatively dry winters) and Hamilton (mild, wetter winters), with some data also from Southland.

Secondly, the data provide little information on processes and rates. The experiments generally report what was applied at the surface of the soil and report the amounts of NO_3 that leach below 50-120 cm using lysimeters or porous ceramic cups (or N_2O emissions from the surface). Whilst this is useful and important, there are few data in this dataset that give any information on process rates and transformations. The value of these data when assembled into a body of work is: to be able to identify the main drivers of effectiveness (for further investigation); to construct empirical models based on the data; and to use for validation of, for example, independently derived, process-based models.

Data analysis – N_2O

There were 44 measurements of DCD effectiveness on N_2O losses from urine patches (equivalent N rates of 300-1000 kg N/ha). Most of the urine treatments additionally received fertiliser N (25-300 kg N/ha per year). The range of N_2O emissions in the absence of DCD was 0.4-39.8 kg N/ha. Effectiveness of the DCD, expressed as a % reduction of the untreated control, ranged from 28% to 83% (Figure 1). The mean effectiveness was 59% with a standard error of 2.2%.

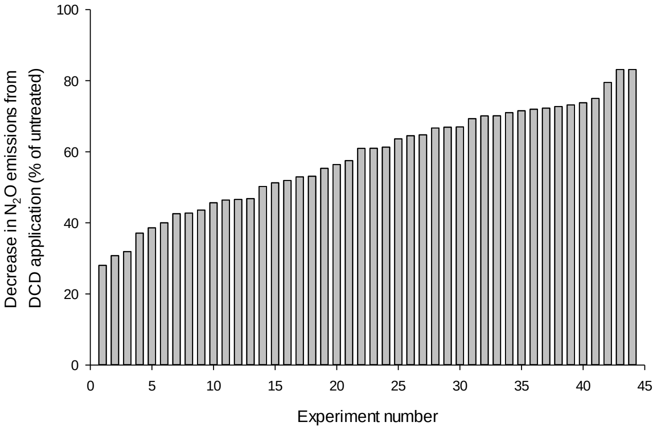

Figure 1. Range of measured effectiveness of DCD in decreasing N_2O *emissions from urine applications.*

For treatments that received urine but no fertiliser N (n=18), the average effectiveness of the DCD was 52% with a range of 31-79% and a standard error of the mean of 3.4%. This agrees reasonably well with the analysis reported by De Klein et al. (2010), who also suggested that there was some evidence of regional or soil type variability in effectiveness with the Waikato region yielding an average reduction of 33% (SE 9%; n=8), while Canterbury averaged 61% (SE 3%; n=31).

The effectiveness of the DCD on the urine patch (expressed as % of N_2O-N saved) showed a significant negative ($P<0.01$), albeit weak ($r^2=17\%$), relationship with soil temperature at the time of DCD application. The data were re-expressed as actual savings in N_2O-N, rather than % effectiveness. This was calculated as the NO_2-N saved from loss divided by the N added to the soil as urine plus fertiliser. When this was expressed as a proportion of the applied N, either as urine-N or urine+fertiliser-N, there was a wide scatter when all data were included (Figure 2a), but there was a significant negative relationship ($P<0.001$, $r^2=31\%$). The same analysis undertaken on a dataset that excluded data where N_2O losses were less than 5 kg N/ha suggested a stronger relationship (($P<0.001$, $r^2=71\%$: Figure 2b). Thus, there was an indication that DCD effectiveness is at least driven by soil temperature, as reported by Kelliher et al. (2008); this has already been captured in the existing DCD model within *Overseer*.

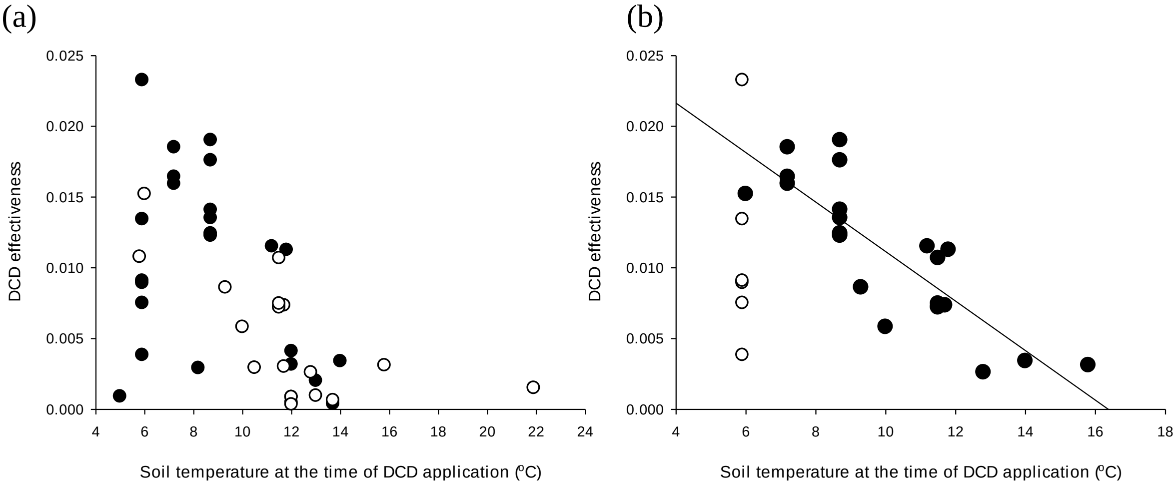

Figure 2. Relationships between soil temperature at the time of DCD application and (a) effectiveness in decreasing N_2O emissions from urine (open circles) and urine plus N fertiliser (closed circles), and (b) effectiveness in decreasing N_2O emissions from urine plus fertiliser N, excluding losses >5 kg N_2O-N/ha. The open circles are a single experiment that doesn't appear to fit the general negative trend. Effectiveness is expressed as kg N_2O-N saved per kg urine+fertiliser N applied.

Data analysis - nitrogen leaching

The experiments within the dataset were mostly of the same type: apply urine ± DCD and determine the effectiveness in terms of N saved from leaching. Most of the experiments focus on the urine patch, i.e. using lysimeters receiving urine or using whole plots covered with urine and instrumented with porous ceramic cups. These all investigate single urine applications. There were only a small number of grazing trials within the dataset. The lysimeter/porous cup trials were a mix of urinary N rates, timings of urine application, rates of DCD, timings and frequency of DCD applications, and duration of experiments. The dataset was reviewed to obtain a set of data that was reasonably consistent in approach i.e. one or two DCD applications at close to recommended application rates. This left us with c. 30 data points. The datasets fell mainly into two clusters – work in the South Island (mainly Canterbury and Southland) and work in the Central North Island (from Ruakura, Rotorua and Taupo). The average reduction in N leached was 48%, with a range of 20-83% and a SE of 3.1% (n=33), but with an indication of differences between N and S Islands (Figure 3).

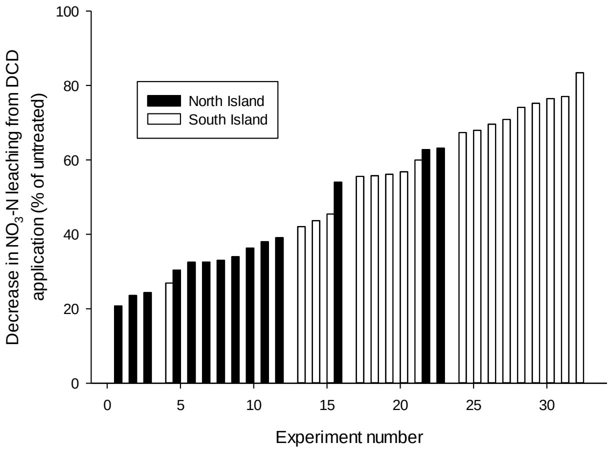

Figure 3. Range of reported DCD effectiveness on N leaching from a urine patch, categorised by location. Open bars = S. Island; closed bars = N. Island.

Investigation of the data with regression or multivariate analysis did not yield anything further than had previously been identified when the original model was developed (Ledgard et al., 2008). This is perhaps not surprising given that the data are generally more of the same. The *Overseer* DCD model assumes a negative relationship between decrease in N leaching and the amount of drainage or the soil temperature. The collated experimental data confirm this (Figure 4).

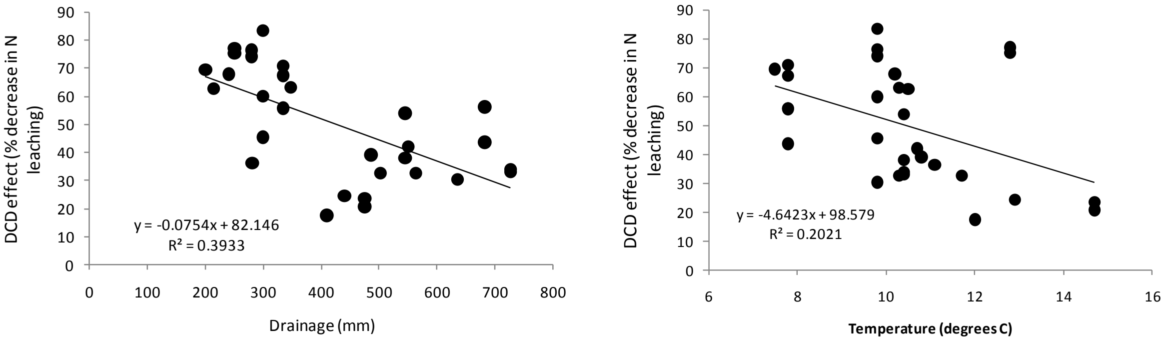

Figure 4. General relationships between N leaching reduction from a urine patch and drainage (left) or temperature (right).

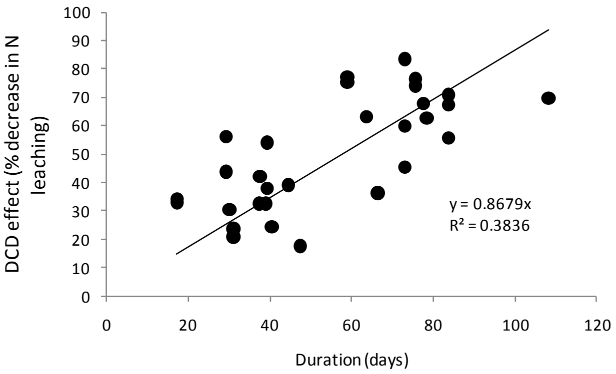

Figure 5. Relationship between DCD 'duration', as calculated using the method within Overseer, and the measured decrease in N leaching from a urine patch. The regression line was forced through zero.

The current DCD model within *Overseer* recognises the importance of these two factors by combining them into a 'duration' term based on drainage amount and half-life (a temperature driven calculation: Kelliher et al., 2008). We calculated this term and compared it with the experimental dataset that had been assembled. The results showed a reasonable correlation between this term and the measured values (Figure 5), indicating the validity of the approach within *Overseer*.

Proposed duration term for DCD effectiveness

The hypothesis was that DCD effectiveness is strongly affected by rainfall/drainage and especially rainfall in the first month after application. One possible mechanism for this is that the rainfall affects separation of DCD from the urinary NH_4-N source (Abdel-Sabour et al., 1990). It was also hypothesised that temperature plays a part (affecting rate of decay), but drainage (downward movement of DCD) is the key driver of effectiveness of DCD.

Figure 5 confirms this hypothesis (the duration term in the current model) but the aim was to develop an alternative approach to test if more of the variation in the experimental dataset could be explained. Therefore, an alternative empirical model was developed from first principles. The assumptions were:

- DCD effectiveness depends on longevity in 'topsoil' as affected by:
    - Temperature driven decay
    - Leaching below a nominal depth
- The main driver of effectiveness is the first application of DCD and how this behaves in the first month. This was on the basis that if the first application isn't effective in holding N as ammonium, then subsequent applications will also be ineffective.
- Leaching of DCD below 30 cm is the nominal depth – this assumes that most of the ammonium N from a urine patch will be in the top 30 cm after urination; DCD will lose its effectiveness when it becomes separated from the ammonium.

The Burns model (Magesan et al., 1999) was used as a simple solute leaching model to estimate the movement of DCD below 30 cm in the first month after application. The approach uses two inputs to drive it; drainage volume and volumetric water content of the soil at field capacity (both easily obtainable):

$$X = \exp(-z\Theta/I)$$

Where X is the proportion of solute remaining in the soil to depth z, theta is the volumetric soil moisture content at field capacity and I the drainage volume.

The DCD breakdown was based on Kelliher's exponential decay function (Kelliher et al., 2008), using mean temperature in the month after application. Effectiveness then becomes:

Effectiveness = (Proportion of DCD retained within depth cm in the first month) x (DCD half-life)

There was a good correlation between the calculated efficiency factor and the measured effectiveness from the experimental dataset (Figure 6). Two experiments were excluded from the comparison. Menneer et al. (2008) mixed the urine and DCD before application; this gave a higher efficiency than would be predicted from the method. We argue that this might be expected (better contact between urine and DCD) and does not fall within the boundaries of the rest of the experimental dataset. We also excluded two points that were N application rates of 300 kg N/ha; all other experimental rates were 600-1000 kg N/ha. These two points also showed a much greater efficiency than calculated and we postulate that this is related to the lower N application rate.

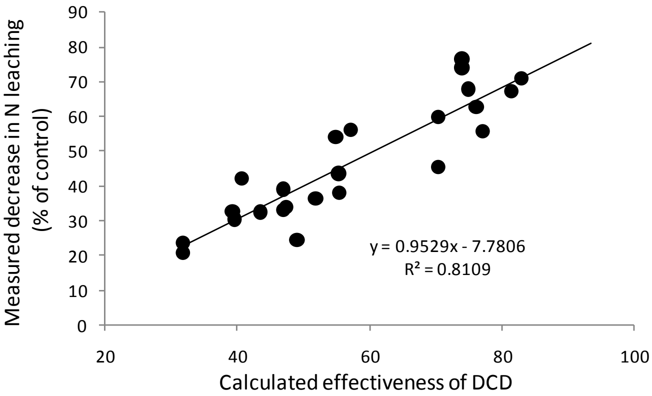

Figure 6. Comparison of calculated effectiveness of DCD on N leaching and measured effectiveness as reported in the experiment dataset.

The depth below which DCD becomes ineffective was assumed to be 30 cm for the calculation. This was a best estimate based on judgement. We ran the calculation with depths of 5, 10, 20, 30, 40 and 50 cm. Figure 7 shows that the depth had a small effect on the fit, when expressed as % variation explained, with the best fit obtained at 30 cm.

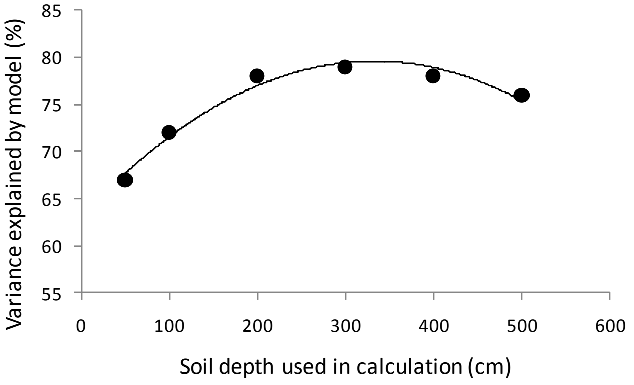

Figure 7. Effect of soil depth used in the effectiveness calculation and the variance explained by the simplified model for N leaching.

This simple approach, based on first principles, appears to show some promise as a predictor of N leaching following DCD application. It appears to explain more of the experimental variation than the previous ‘duration’ term that was used in the *Overseer* DCD model. It does, however, have the same restrictions in that it is based on the DCD being applied at recommended rates and according to recommended practice; it does not allow us to extend the model too far beyond these limits. Furthermore, it only provides the ‘building block’ for the N leaching model; the relationship still needs to be built in to a farm-scale model.

Implications for Overseer
The advantage of this approach is that input data are already in line with *Overseer* inputs. Soil-type description provides volumetric water content data and the water balance model provides an estimate of drainage depth. Climate databases provide rainfall (to drive drainage) and temperature for the decay function.

The challenge for modelling DCD effects is being able to scale up effects from the urine patch to the paddock, block and farm scale. *Overseer* scales up by calculating loads of urinary N excreted onto the management blocks on a monthly basis (e.g. Figure 8), which then forms the basis of N loss models for N_2O and NO_3.

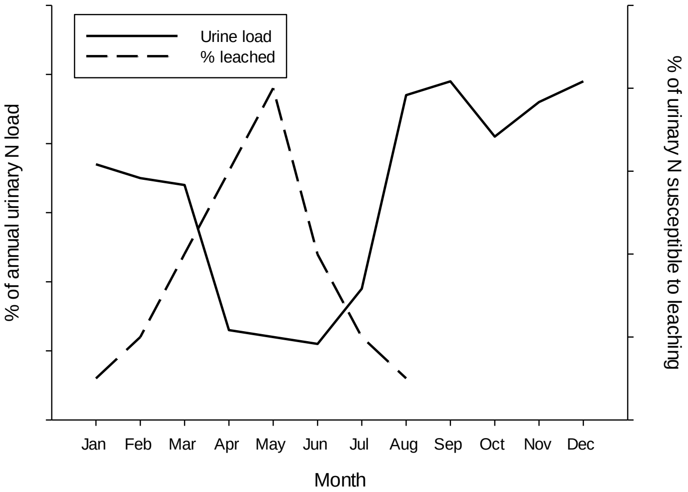

Figure 8. The principles behind Overseer's urinary N leaching calculation, based on % of the total urinary N load deposited each month and the leaching risk associated with each month's deposition.

The DCD model works by modifying the calculated losses according to the principles established above. For N_2O, this is based on modifying losses according to temperature at the time of DCD application. Similarly for NO_3, DCD modifies losses based on drainage and temperature. Figure 8 shows that most urinary N is deposited in the spring and summer months, yet DCD tends to be targeted to autumn/winter months to control N leaching. There is an argument for applying DCD earlier in the autumn or late/summer for potentially greater effect, especially if reductions in N_2O emissions are sought.

The level of pasture response to DCD is variable (e.g. Gillingham et al., 2012; Carey et al., 2012). *Overseer* does not estimate pasture response in the model described above because feed intake is based on a back calculation from animal productivity data. Therefore, any yield benefit from DCD should reflect in productivity.

Conclusions

Analysis of the published literature has drawn out trends in the data to develop 'rules of thumb' and simplified algorithms for determining the effectiveness of DCD for reducing N losses to air and water. The analysis generally supports the approach taken in the first iteration of the DCD model within *Overseer* v 5.4. This is mainly because the new data are 'more of the same', measuring the effects of DCD under different conditions. Although this accumulation of data is invaluable in understanding the size of effect of DCD and the factors affecting it (and its value would be increased by repeating the experiments under a wider range of soils and climates), further advances in process understanding and modelling are required to support further advancement in *Overseer*. Our assessment is that there was insufficient new data for *Overseer* to move away from its empirical modelling approach developed for the first version.

The main environmental drivers of effectiveness are temperature and rainfall (drainage); both are captured within *Overseer*. At the systems level (as opposed to the individual urine patch), overall effectiveness is further modified by the amount of N deposited in the winter months (when DCD is applied) and the overall contribution of this N to annual losses.

Whilst some of the effects on N leaching look large at the urine patch scale, the challenge for *Overseer* is to scale up to the paddock and farm scale. This requires up-scaling of the urine patch principles to a complex system with multiple grazings through the whole year; the DCD effect will be variable on these urine deposits. Apart from a few trials at the paddock scale to validate the whole-farm model, there are few data to validate the model across a wide range of scenarios. Much has to be placed, therefore, on expert judgement in terms of assessing the performance of the model.

Our conclusions, therefore, are:

- The empirical approach to modelling DCD effects is still appropriate and should form the refinement to the DCD model within v6.
- The main change to the DCD model within v6 relates to *Overseer* now using monthly urine (and fertiliser) inputs to estimate N leaching. The DCD model therefore has to calculate effects on monthly N depositions during the winter.
- This doesn't allow us to move beyond the current status of applications in winter.
- To make further progress, more understanding around the DCD mode of action and the ability to model the process-based effects is required, e.g. by using APSIM. This might, however, be a long-term project.

Acknowledgements

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