COMPARISON OF SOIL N-DYNAMICS ACROSS DIFFERENT MODELS

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Abstract
Soil nitrogen (N) is essential for plant growth, but in excess it can lead to environmental pollution via leaching and greenhouse gas emissions. A good understanding of soil N dynamics is therefore crucial for improving farm management. Field studies typically measure only some parts of the N cycle as temporal snapshots. Large uncertainties are involved when these observations are scaled up to farm system, regional or national scale and/or extrapolated to produce long-term estimates. Process-based models have the potential to simulate the entire N-cycle, thus enabling the integration of knowledge and improved estimates. However, such models contain a large number of processes that need to be parameterised and validated.

Many models have been developed to simulate different aspects of the soil-N cycle. These models include different assumptions and simplifications, depending on the original purpose of the model. Comparing the behaviour of different models for the same dataset can be a useful way of determining which processes lead to significant differences in model output, and therefore where greater understanding of the underlying processes may lead to model improvement.

Here we report on existing and planned comparisons between the NZ-DNDC, CenW, APSIM, and OVERSEER models.

Introduction

Soil N is essential for plant growth. However, in excess it can lead to environmental pollution via leaching, ammonia (NH_3) volatilisation, and greenhouse gas emissions (particularly nitrous oxide, N_2O). Nitrogen can occur in many chemical forms and there are a large number of interacting processes involved in its cycling through the environment. Figure 1 illustrates the major processes involving N in grazed pasture systems:

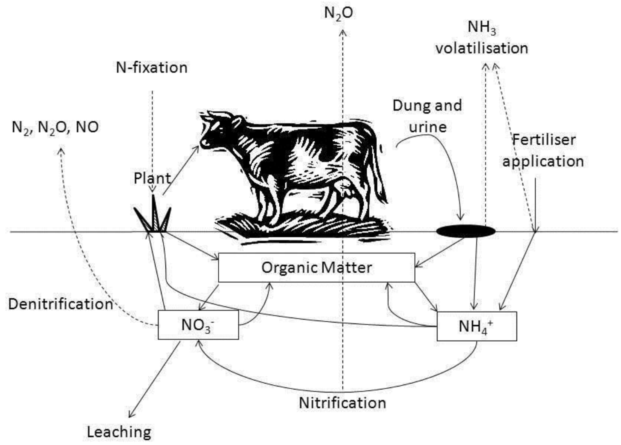


Figure 1: N-cycling in grazed pasture system (dashed lines represent gaseous fluxes)

Due to the large number of processes and different chemical forms of N, there are very few studies where all processes are measured simultaneously, especially under actual farming conditions. Process-based models that describe the many processes involved in N-cycling can be useful for determining the impacts of changes in farm management on various parts of the N-cycle. However, such models require a large number of parameters and need to be validated and parameterised over a range of processes in order to have confidence in their results.

In this paper we describe three process-based models (APSIM, CenW, and NZ-DNDC) and the widely used nutrient balance model OVERSEER®, and the initial research into comparing the behaviour of these models with respect to the description of the N dynamics in New Zealand pasture soil.

Model descriptions

APSIM

APSIM (Agricultural Production systems SIMulator) is a framework of biophysical modules that simulate physical, chemical, and biological processes in agricultural systems (Keating et al. 2003). The model simulates the water balance, the soil N and C cycling, including leaching and soil greenhouse gas fluxes, as well as plant growth. For the simulations of New Zealand pasture systems the SoilN and SurfaceOM modules (Probert et al. 1998) were used to describe the C-N cycle, SWIM2 (Verburg et al. 1996) for water and solutes transport, and the AgPasture module (Li et al. 2011) to simulate pasture development. The SOILWAT module of Probert et al. (1998) is sometimes used as an alternative soil and water transport model.

CenW

CenW is a process-based model (Kirschbaum 1999) that has been applied to forest (Kirschbaum & Watt, 2011) and pasture systems (M.U.F. Kirschbaum, unpublished) in New Zealand. It simulates plant growth and soil carbon and N dynamics, but the N cycling does not distinguish between different N compounds.

NZ-DNDC

The DNDC (DeNitrification DeComposition) model (Li et al. 1992) is a process-based model that simulates C and N biogeochemical cycles in agricultural systems. The model consists of

5 interacting sub-models simulating thermal-hydraulic processes, aerobic decomposition, nitrification/denitrification, fermentation and plant growth. It has been widely used internationally to simulate a range of different farm systems (Giltrap et al. 2010a). NZ-DNDC is the New Zealand specific version of the DNDC model that has been modified for New Zealand's grazed pasture systems (Saggar et al. 2007a).

OVERSEER®

OVERSEER® is a farm nutrient budgeting model that is widely used in New Zealand (Wheeler et al. 2006; www.overseer.org.nz). While not process-based, *OVERSEER®* has been calibrated for New Zealand's farming systems and uses inputs that are easily accessible by farmers. The model considers the nutrient inputs (feed brought into the farm, fertiliser applications, and biological N fixation) and animal production (milk, meat, wool) to calculate the nutrient outputs (animal products, run-off, leaching, and greenhouse gas emissions). The nutrient budget calculated represents long-term average annual values, rather than year-to-year variation. Version 6 of *OVERSEER®* uses a relationship derived from APSIM simulations to determine the amount of nitrate leaching.

Model validations

Table 1 lists publications where models have been validated against field data for New Zealand pasture systems.

Table 1: Model comparisons with measurements from New Zealand pastures

Model	**Reference**	**Outputs compared to field data**	**Number of sites compared**
APSIM	Li et al. (2011)	Net herbage accumulation	27
	Snow et al. (2007)	Soil water deficit, soil water content, drainage and run-off	1
	Cichota et al. (2010a)	Drainage, NH_4^+ and NO_3^- leaching	1
	Cichota et al. (2010b)	NH_4^+ and NO_3^- leaching	1
CenW	M.U.F. Kirschbaum (unpublished)		
NZ-DNDC	Giltrap et al. (2011)	N_2O, WFPS	1
	Giltrap et al. (2010b)	N_2O, soil NH_4^+, NO_3^-, WFPS	1
	Saggar et al. (2010)	N_2O	1
	Saggar et al. (2007b)	N_2O, soil CH_4, WFPS	1
	Saggar et al. (2004)	N_2O, WFPS	2
OVERSEER®	Parfitt et al. (2009)	N and P leaching	2
	Ledgard et al. (2006)	N leaching	4

Model Comparisons

Validation with experimental data is an important part of the model development process. Models can also be compared with each other, although care needs to be taken to use equivalent input data. Comparing model simulations can be useful for understanding the relative importance of different processes in each model and how these differences interact.

In this paper we present the results of two model comparisons. In the first comparison, the APSIM and NZ-DNDC models were compared with field measurements of soil NO_3^- and NH_4^+ for the top soil layer (0–75 mm), and N_2O emissions from a urine patch applied to Horotiu soil in May. In the second comparison, SOC and SON dynamics were compared using CenW and NZ-DNDC for a hypothetical dairy-grazed farm in the Manawatu.

APSIM and NZ-DNDC

Data for soil NO_3^- and NH_4^+ (averaged over the top 75 mm) and for N_2O emissions were measured following animal urine application to Horotiu silt loam soil (Typic Orthic Allophanic Soil) located in the Waikato Region. This dairy farm had a stocking rate of about 22 stock units ha^{-1} (about 3.15 cows ha^{-1}) and was managed under a typical rotational grazing regime. Fresh animal urine was applied to the soil in May 2000 at a rate of 592 kg N/ha. The methodology and results are reported in more detail in de Klein et al. (2003).

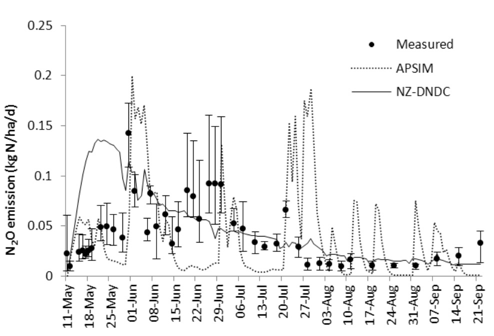
Soil parameters for each model were established based on site measurements. For NZ-DNDC, the initial soil NO_3^- and NH_4^+ at the surface were based on the control values for the first day of the trial, and initial soil moistures were also based on initial values at the start of each trial; APSIM simulations were pre-run for 6 months before the experimental start to obtain appropriate initial conditions. For both models the urine patch was simulated as an application of urea with the addition of 10mm water.

NZ-DNDC and APSIM both use exponential functions to determine the soil properties at lower layers based on the surface properties. Detailed description of the setup in APSIM is given in Cichota et al. (2012). For these simulations, the APSIM model simulated the soil processes to a depth of 1000 mm. However, as NZ-DNDC simulates down to 500 mm, only the top 500 mm were considered when comparing the APSIM and NZ-DNDC model outputs.

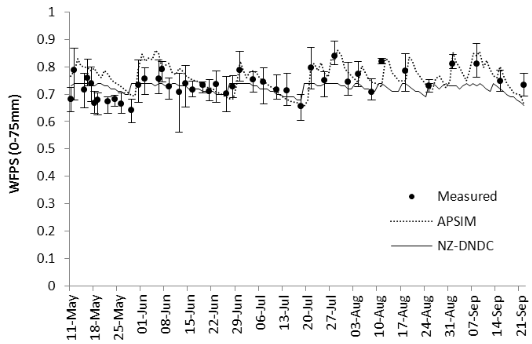
Giltrap et al. (2010b) found that when simulating emissions from urine patches, it was necessary to increase the ammonia volatilisation rate to simulate the soil NH_4^+ dynamics accurately. The enhanced rate of NH_3 volatilisation was used for this simulation.

Daily climate data for the simulations were downloaded from climate stations near the study sites.

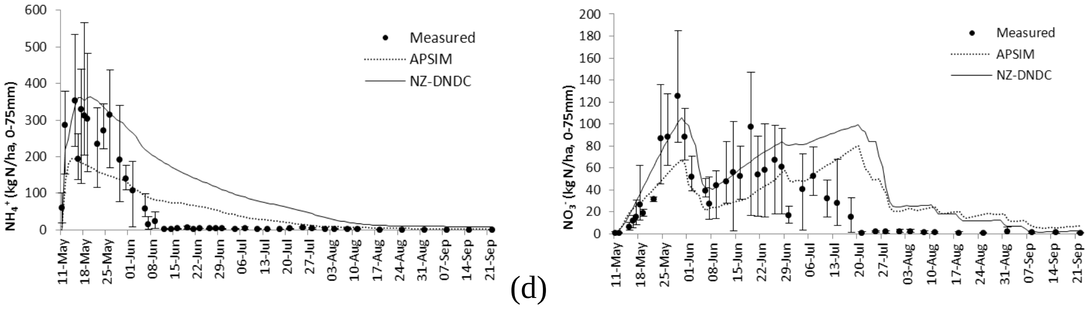
Figures 2(a)–(d) show the measured and modelled N_2O emissions, water-filled pore space (WFPS), soil NH_4^+, and soil NO_3^- respectively.



(a)



(b)



(c) (d)

Figure 2: APSIM and NZ-DNDC model results compared with measured values following dairy urine application of 592 kg N/ha in May 2000 on Horotiu soil for (a) N_2O emissions, (b) WFPS, (c) NH_4^+ , and (d) NO_3^-. Soil WFPS, NH_4^+ and NO_3^- values are for the top 75 mm. Error bars show the maximum and minimum values of 4 replicates.

Both models produced plausible estimates of the 0–75 mm WFPS, soil NH_4^+ and NO_3^-. The pattern of N_2O emissions simulated by the two models differed both from each other and the measured pattern. However, the total N_2O emissions over the period simulated by APSIM (5.31 kg N/ha) and NZ-DNDC (6.17 kg N/ha) were similar to the measured value (mean 4.93 kg N/ha, range 3.90–6.38 kg N/ha).

As APSIM and NZ-DNDC are both process-based models we can also compare the simulations of other N-transformation processes that were not directly measured (Figure 3).

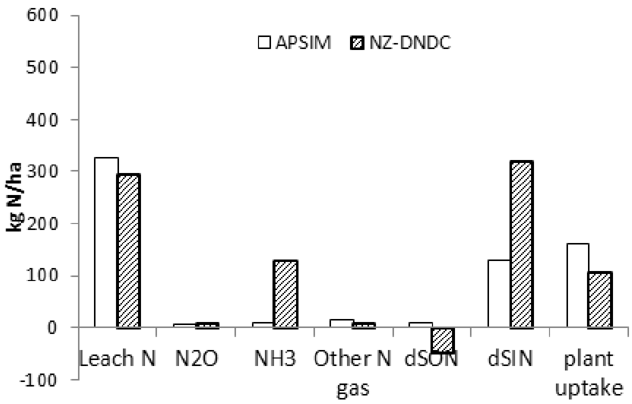


Figure 3: Allocation of N between various pools for the APSIM and DNDC models. Note: dSON is the change in the soil organic N and dSIN is the change in the soil inorganic N pool over the measurement period.

Figure 3 shows some significant differences between the models' simulations of the various N transformation processes. In particular, NZ-DNDC estimated a much higher rate of NH_3 volatilisation while APSIM showed slightly higher rates of leaching and plant uptake. While APSIM has previously been validated for plant growth and NO_3^- leaching, neither APSIM nor NZ-DNDC has been validated against NH_3 emission measurements. Although in this particular example the difference between the two models' estimates of NH_3 emissions did not result in a large difference in N_2O emissions, this will not always be the case. This example also demonstrates that simply because the estimated N_2O emissions are close to the measured values does not mean that all processes are being correctly simulated.

Similar experiments and comparisons have been performed for other soils and seasons. There were cases when both models either succeeded or failed to estimate N_2O emissions within the range of the field measurements, and cases when one model performed well and the other poorly. These results will be published in a future paper.

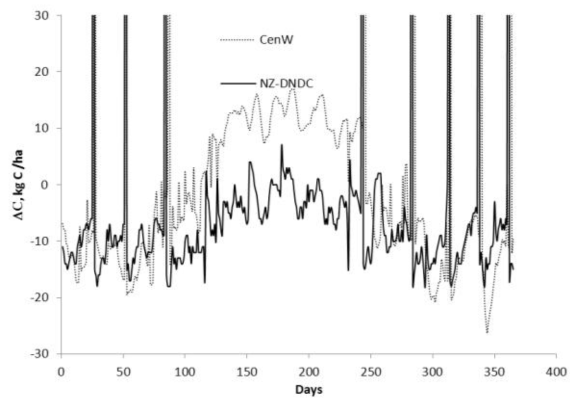
CenW and NZ-DNDC

CenW and NZ-DNDC were compared by simulating a hypothetical New Zealand dairy farm over a 5-year period. The soil was assumed to be a Tokomaru silt loam and 5 years (1980–1985) of climate data from the Manawatu were used.

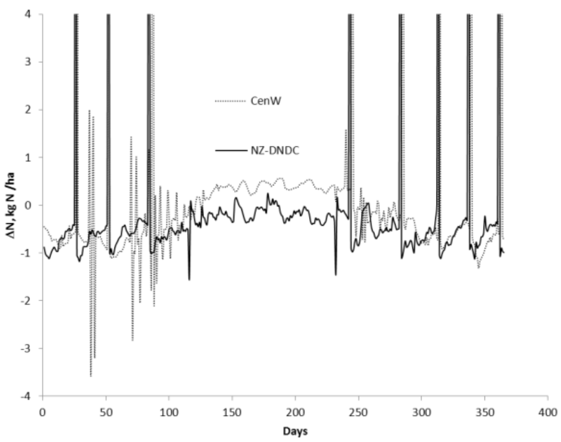
The management practices simulated were fertiliser applications and grazing events. In each model, fixed amounts of urea were applied on 5th Feb (32 kg N/ha) and 27th August (14 kg N/ha) each year.

In NZ-DNDC, grazing events are pre-defined by a date, number of animals per hectare and the duration of the grazing event. CenW has a similar option, but it can also simulate grazing by having a grazing event triggered when pasture dry weight exceeds a predefined value (set to 2 t DW/ha = 1 t C/ha), and grazing continues until a lower limit of the pasture dry weight is reached (set to 1 t DW/ha = 0.5 t C/ha). This has the advantage that grazing frequency changes automatically with seasonal dry matter production rates and reflect inter-annual variations in feed production. To allow proper comparison between the models, we generated a set of grazing events over our 5-year simulation interval using CenW and then used these to set up grazing events in NZ-DNDC.

CenW has an equilibrium-generating routine that enabled the generation of equilibrium conditions for all plant and soil pools under the given climate and management regime. Once these equilibrium conditions had been generated, CenW was run for a further 5 year-period to generate a sequence of grazing events. As there was no equivalent routine in NZ-DNDC the initial conditions were not in equilibrium. The first year of the simulation was therefore not considered in this analysis as the system was still changing significantly towards equilibrium conditions.



(a)



(b)

Figure 4: Comparison of daily change in (a) d SOC and (b) SON simulated by NZ-DNDC and CenW. Data are shown for 3rd year of the 5-year simulation.

Figure 4 shows the daily changes in (a) SOC and (b) SON for the 3rd year of the 5-year simulation using CenW and NZ-DNDC. The large spikes correspond to manure deposits on grazing days. In both plots, it can be seen that CenW has a stronger seasonal variation in the daily change in SOC and SON than NZ-DNDC. This is due to the different temperature sensitivity of decomposition in the two models. CenW uses a temperature dependence based on Kirschbaum (2000), while NZ-DNDC uses a temperature dependence based on the work of Nyhan (1976). Figure 5 shows the change in the relative temperature sensitivity of decomposition of the two models. At soil temperatures above 5°C, decomposition is less sensitive to changes in temperature in NZ-DNDC than in CenW.

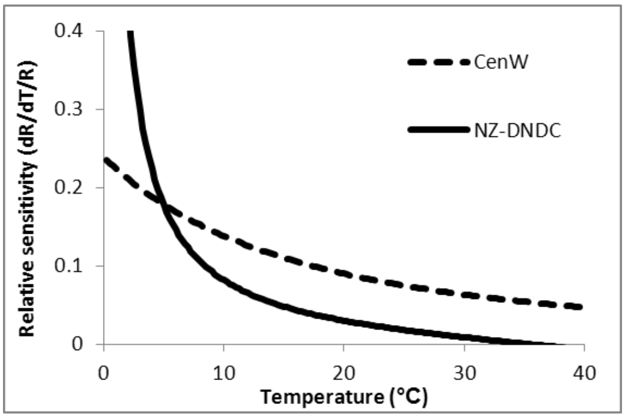


Figure 5: Change in relative sensitivity of decomposition with temperature for CenW and NZ-DNDC models.

Discussion and Conclusion

Process-based models are a useful and necessary tool for upscaling from field measurements to regional and national scales. They are also useful for scenario analyses to assess the potential impacts of, for example, mitigation strategies, climate change, or land-use change. Process-based models may also be used to generate simplified models that still reflect the important trends but require less input data and/or processing time. For example, thousands of APSIM simulations across different combinations of New Zealand soils and climates were used to generate a relationship between the proportion of N leached and the cumulative water drained (in terms of soil pore volume) that is used in OVERSEER® version 6 (Wheeler et al. 2011). However, such applications require that the models be well validated.

The N-cycle contains many interacting processes. Most process-based models have been validated for some aspects of the N-cycle (e.g. NO_3^- leaching, N_2O emissions). However, no model has been validated for all processes in New Zealand grazed pasture systems. Similarly, there is a lack of comprehensive field data where all the forms of N have been measured or where all the various N loss pathways have been monitored. This is especially relevant for describing N_2O losses because it represents a fairly small fraction of the total N cycle. To reduce the uncertainties of greenhouse gas estimates it is important to ensure that the main parts of the system are accurately described.

Comparison of different process-based models on the same dataset can be useful for determining under which circumstances each model performs best. Even when experimental data are not available, model comparisons can indicate which processes behave similarly between models, and which are different. Such information can highlight critical knowledge gaps. In addition, sensitivity analyses can be used to find parameters and processes to which the model output is particularly sensitive and where improvements will have the biggest impacts on model performance.

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