URINE TIMING: ARE THE 2009 WAIKATO RESULTS RELEVANT TO OTHER YEARS, SOILS AND REGIONS?

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Abstract

To be effective, mitigation of N leaching must target the critical times of year that produce the greatest risk of leaching. Historically, much research has concentrated on winter as that critical time. More recently, modelling results have suggested that the greatest leaching risk in New Zealand might be from urine patches deposited in late summer rather than winter. An experiment conducted on the Horotiu silt loam in the Waikato in 2009 generally confirmed earlier exploratory modelling and also provided a validation dataset to test the modelling. This paper compares modelling results, using APSIM, to the experimental data, examines whether the 2009 Waikato results were likely to be representative of other years in the Waikato and then examines if the trial results are likely to be representative of other regions and soil types.

The comparison between the experimental and modelled results showed good general agreement. The model reflected well the measured trend of N leaching with time of deposition. The deviation between modelled and measured leaching ranged between -13% and +4% of the applied N. There was no relationship between the deviation and deposition date. A sensitivity analysis showed that, whilst some parameters (particularly those associated with nitrification rate, urine deposition depth and rooting depth) had a strong effect on the amount leached, none of them changed the pattern of leaching with time of urine deposition.

To explore the possible effects of soil and region, simulations replicating the 2009 Waikato experiment were performed across 36 years of climate data for the Waikato (Horotiu and Oropi soils) and Canterbury (Templeton and Lismore soils, both irrigated). In all cases the leaching risk peaked in summer and declined through winter to spring, confirming the general relevance of the results from the Waikato experiment for other soils and climates. However, the trend between timing of urine deposition and N leached was considerably muted in Canterbury and showed wider year-to-year variability. Some of this variability might be attributed to irrigation effects. More work is required to fully understand implications for regional differences between N leaching risk and time of urine deposition.

Introduction

Mitigation actions for reducing N leaching are more effective when targeting the critical times of year that produce the greatest risk of leaching. Historically, much research in New Zealand (e.g. Cameron *et al.*, 2007; Monaghan *et al.*, 2009), and overseas (e.g. Cuttle and Bourne, 1993; McGechan and Topp, 2004), has concentrated on late autumn and winter as that critical time. To some extent, the focus on winter as the critical leaching time makes sense. At that time of year drainage rates are increasing and pasture growth is decreasing and this combination could be regarded as likely to lead to a high leaching risk. However in winter soil temperatures are low, which reduces nitrification rates and thereby assists with retention of N in the pasture root zone. The retained N is then more likely to be taken up by pasture when growth rates increase in spring. Conversely in summer, nitrification rates are likely to be high. Summer drought can reduce pasture growth and N uptake, and episodic summer rains have the potential to push mineral N lower in the root zone and all of these can increase leaching risk.

More recently exploratory modelling results (Bryant and Snow, 2009; Vogeler *et al.*, 2010a) have suggested that in New Zealand the greatest leaching risk might be from urine patches deposited in late summer and autumn rather than in winter. Following these modelling results, in 2009 Shepherd *et al.* (2010) conducted a field trial examining the effect of urine deposition timing on ultimate leaching amount. This experimental work generally confirmed the modelling predictions. Here we use APSIM, a process-based simulation model, to explore if the results of Shepherd *et al.* (2010) can be generally applied to other years, soils, and climates or if they resulted from a particular and unusual combination of weather conditions during the experiment. This paper validates the model against the experimental data and then examines whether the trial results are likely to be representative of other locations.

Materials and Methods

The approach employed consisted of initially using the data from the 2009 urine timing experimental data (Shepherd *et al.*, 2010) to validate the simulation model. That validation, while mostly using measured inputs and default parameters, showed some uncertainty in a few parameter values. Thus the validation was followed with a sensitivity analysis to examine the impact of some key assumptions and parameters on the conclusions about the pattern of leaching with urine deposition date. The final step was to apply the model to combinations of soils and climates to examine if the conclusions made from the experimentation would be likely to hold under other conditions.

Model description

The APSIM simulation model (Keating *et al.*, 2003) was used for all simulations. Critical modules for the simulations reported here included: SWIM2 (Verburg *et al.*, 1996) for soil water and solute movement, AgPasture (Li and Snow, 2010; www.apsim.info/Wiki/AgPasture.ashx) for pasture growth and N uptake, and SoilN2 (Probert *et al.*, 1998) for soil C and N transformations. Daily weather data was obtained from the NIWA Virtual Climate Station dataset (VCS, Tait and Turner, 2005; Cichota *et al.*, 2008). For the simulations of the 2009 Waikato experiment the VCS rainfall was replaced with values measured on-site. Soil properties were adapted from published sources including (Singleton, 1991; Webb *et al.*, 2000; Close *et al.*, 2003; Webb, 2003; Wilde, 2003; Vogeler *et al.*, 2011). APSIM has been extensively validated in many environments and systems, and in New Zealand it has been validated against a limited range of drainage (Snow *et al.*, 2007) and leaching under urine-patch conditions (Cichota *et al.*, 2010; Vogeler *et al.*, 2010a).

Model validation

In summary, the field experiment used for model validation applied 800 kg N/ha urine patches approximately monthly from March to August 2009. The trial was on the Horotiu silt loam (Typic Orthic Allophanic, Hewitt, 1998) in Hamilton at DairyNZ's Scott Farm. VCS weather data was used with the exception that the rainfall was substituted with that measured at the site during the trial. The simulations were initiated in August 2008 assuming that the soil was at field capacity. For these simulations urea-N, at 15 kg N/ha, was applied at monthly intervals between August and December 2008. From August 2008 to the trial start, March 2009, the pasture was cut at 21-day intervals to a residual dry matter of 1700 kg DM /ha. During the trial period the cutting dates and residuals were set as recorded in the field diary. Cutting intervals ranged from 20 to 33 days depending on growth rates. The residual pasture height was constantly 75 mm but the residual dry matter ranged between 1550 to 2375 kg DM /ha (P. Phillips, AgResearch, personal communication, 2010).

The primary sources for the soil properties were (Close *et al.*, 2003) and (Wilde, 2003) with the ammonium adsorption estimated following the pedotransfer functions described in Vogeler *et al.* (2011). The allophane content in the soil resulted in an anion adsorption, as noted for bromide by Close *et al.* (2003). Nitrate adsorption parameters were not available for the soil and while the general principles of anion retention are known, retention characteristics have also been shown to be quite spatially variable (e.g. Ryan *et al.*, 2001). For this study the nitrate adsorption was assumed to be linear. The distribution coefficient was estimated as a linear correlation to the initial slope of the Freundlich ammonium adsorption isotherm as given in Vogeler *et al.* (2011). Given the parameters in the pedotransfer function this made the distribution coefficient highly dependent on the clay and organic matter contents of the soil layers. Previous work (Asseng *et al.*, 1998; Meier *et al.*, 2006) has presented evidence suggesting that properties affecting the nitrification rate in APSIM's SOILN2 module requires some site-specific settings or perhaps that the process description is insufficiently complex. In SOILN2 the potential nitrification rate is independent of the soil microbial biomass (Vogeler *et al.*, 2010b). It might be that in soils with little ammonium and low organic matter contents, such as in the tropical cropping soils for which most of the APSIM testing has taken place, the nitrification rates are relatively insensitive to these effects. However in temperate pastoral soils under urine-patch conditions this assumption is not reasonable. To overcome this it was assumed that the potential nitrification rate would scale with the soil organic matter content with the default parameter value, 40 µg N/mg soil /day, applied to soils with 2% organic carbon.

Model sensitivity

Because there was some uncertainty associated with some of the model parameters, a sensitivity analysis was undertaken. The purpose was not to find parameters that produced a better fit to the data but rather to understand if there were any parameters that if assigned with a different value would change the conclusions about the pattern of likely leaching losses with time of deposition. The parameters tested were:

- the amount of active organic N in the soil (similar to development status),
- ammonium adsorption,
- nitrate adsorption,
- depth in the soil to which ammonium N is subject to volatilisation,
- the buffering in the soil that determined the return to pre-deposition pH,
- the minimum air temperature that would result in a cessation of pasture growth,
- rooting depth,
- propensity to fix N under high soil mineral N conditions,
- depth of urine deposition,

- denitrification rate parameter,
- denitrification water factor,
- potential nitrification rate parameter,
- nitrification half saturation coefficient, and
- the temperature optimum for nitrification.

The variables were varied one by one and used to simulate the leaching losses with each deposition date. The simulation end date was extended to the winter 2010 drainage season in order to include the fate of the mineral-N remaining in the soil in November 2009.

Generalisation to other years, soils and regions
In order to explore if the 2009 Waikato results would apply to other years, soils and climates the model was set up for four combinations of climate and soil type. In the Hamilton climate the soils were the Horotiu silt loam and the Oropi sand (Buried Allophanic Orthic Pumice, Hewitt, 1998). These soils were not irrigated. The second climate was Lincoln and the soils were the Lismore stony silt loam (Pallic Orthic Brown, Hewitt, 1998) and Templeton silt loam (Typic Immature Pallic, Hewitt, 1998). These soils were assumed to be irrigated with settings typical of a centre pivot irrigator. Weather data for 1972 to 2009 was obtained from the NIWA VCS dataset. Generally following the experimental design of the Waikato experiment, urine patches of 800 kg N /ha were applied in separate simulations on the first day of the month from February to August for each year from 1973 to 2006.

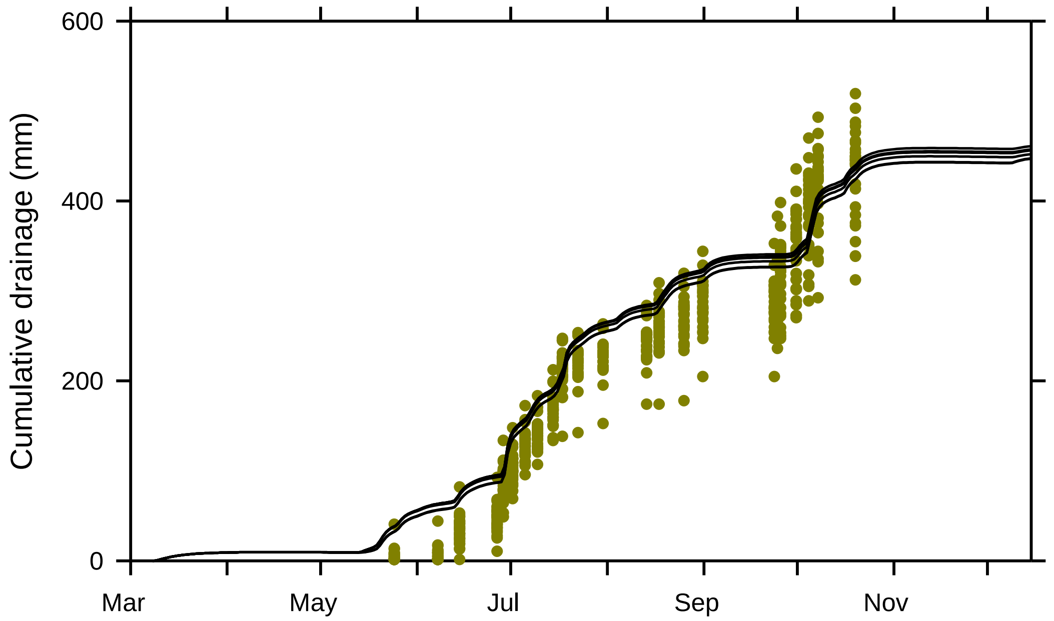

Figure 1. Drainage, cumulative from 9 March 2009, measured in nearby lysimeters (points) and simulated with APSIM (lines – the treatments are not differentiated).

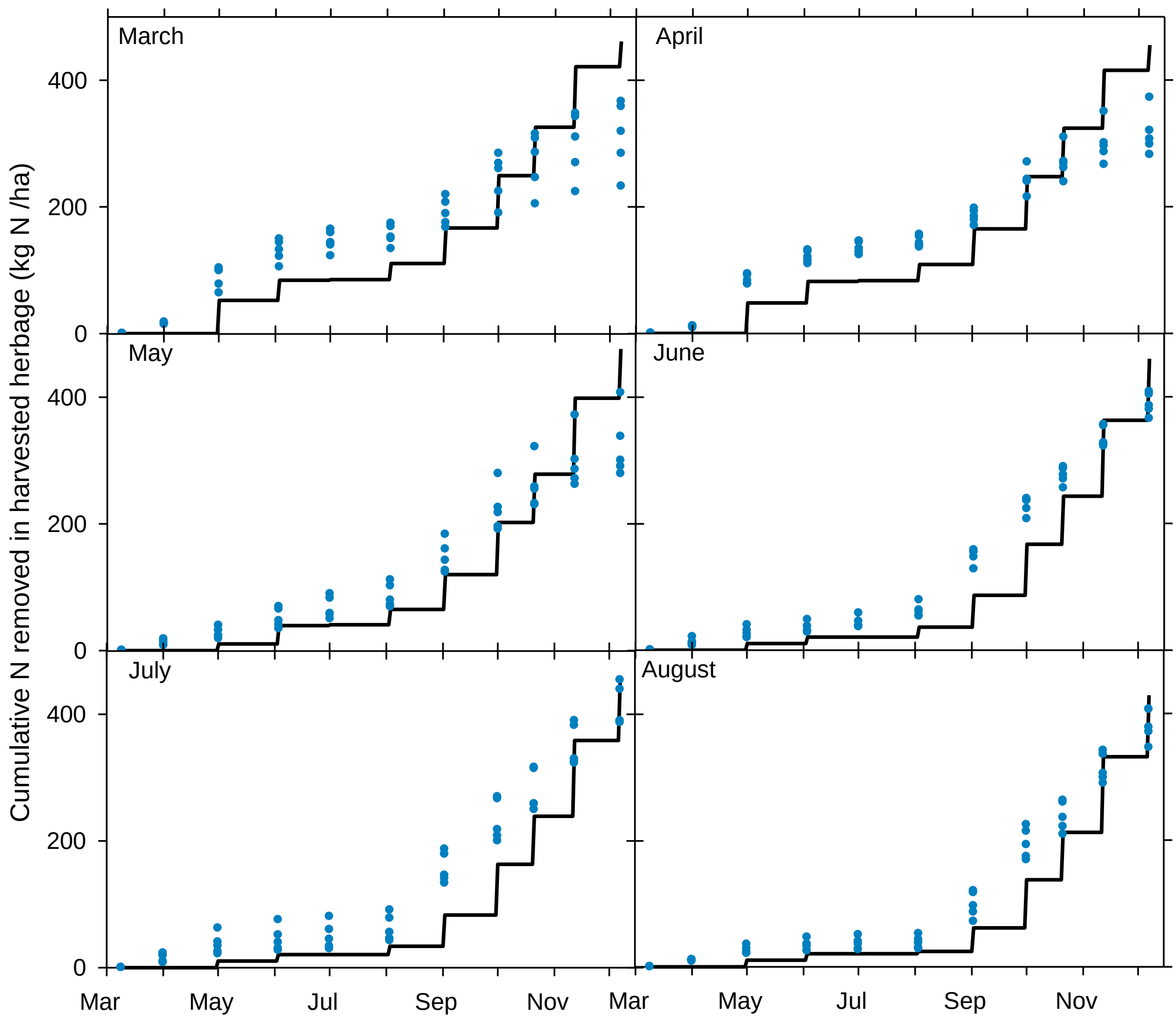

Figure 2. N removed in harvested herbage, cumulative from 9 March 2009, measured (points) and simulated (lines).

Results and Discussion

Waikato 2009 experiment

Figure 1 shows the drainage measured from the nearby lysimeters and that simulated by APSIM. Generally the comparison is good with some suggestion of a slightly earlier drainage season from the model compared with that measured by the zero-tension lysimeters. The differences between the measurements and model are unlikely to be sufficient to materially affect calculated leaching. Cumulative removal of N in the harvested pasture is shown in Figure 2 and summarised in Table 1 for each of the treatments. While overall off-take is overestimated (Table 1), there is a general trend to underestimate the off-takes in winter with a compensating overestimate in spring. From a mass-balance perspective when intending to estimate leaching, it might be argued that the final values are more important than the pattern in time. There is a greater tendency for total off-take to be overestimated for March to June depositions and, if not compensated for by increased N fixation, this might lead to an underestimation of leaching.

Soil cores were taken twice during the experiment. Figure 3 shows the total ammonium-N and mineral-N to 0.6 m deep as measured and simulated. In general the comparison is good. With the exception of the June application the error between the mean measured and simulated mineral-N at the end of the experiment was within 6% of the applied urine-N (Table 1). Figure 3 shows that, for the June deposition, the model simulated more ammonium-N in the soil at the first soil sampling than measured. The comparison of data and model suggests that the difference has arisen from the nitrification rate rather than as a result of transport processes. The overestimation of the ammonium-N at the first sampling seems to have resulted in an overestimation of the mineral-N remaining in the soil at the end of the experiment. If not compensated for by other factors, the overestimation in stored mineral-N would be expected to lead to an underestimation in leaching.

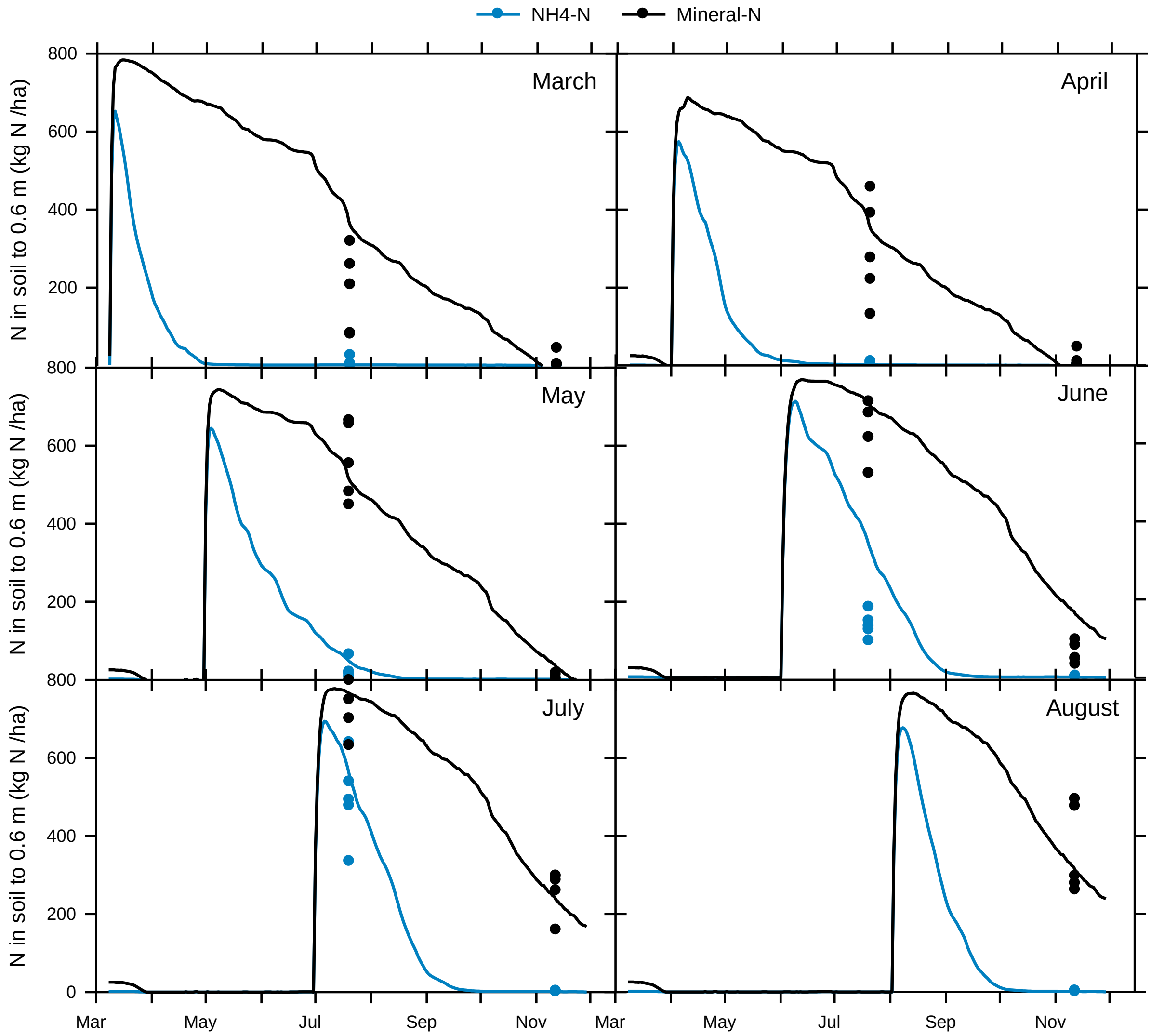

Figure 3. Ammonium-N (blue) and Ammonium + Nitrate-N (black) in the soil to 0.6 m deep, measured (points) and simulated with APSIM (lines).

Figure 4 shows the cumulative leaching from individual soil solution samplers and the simulated leaching. The simulated leaching is well within the spread of the data and, with the exception of the June deposition, is within 5% of the measured mean leaching (Table 1). As suggested above, the overestimation in mineral-N stored in the soil has lead to an underestimation in leaching for the June deposition. As with the experimental work, the modelling clearly shows that N leaching decreased with the winter and spring depositions compared to summer and autumn, urine depositions. Extension of the simulation time to the end of winter 2010 did not result in substantially more leaching from the August deposition (data not shown) because APSIM simulated that the mineral-N left in the soil at the end of the experiment was taken up by the pasture.

Additional simulation results, for N transformations or losses not measured, are given in Table 1 for information.

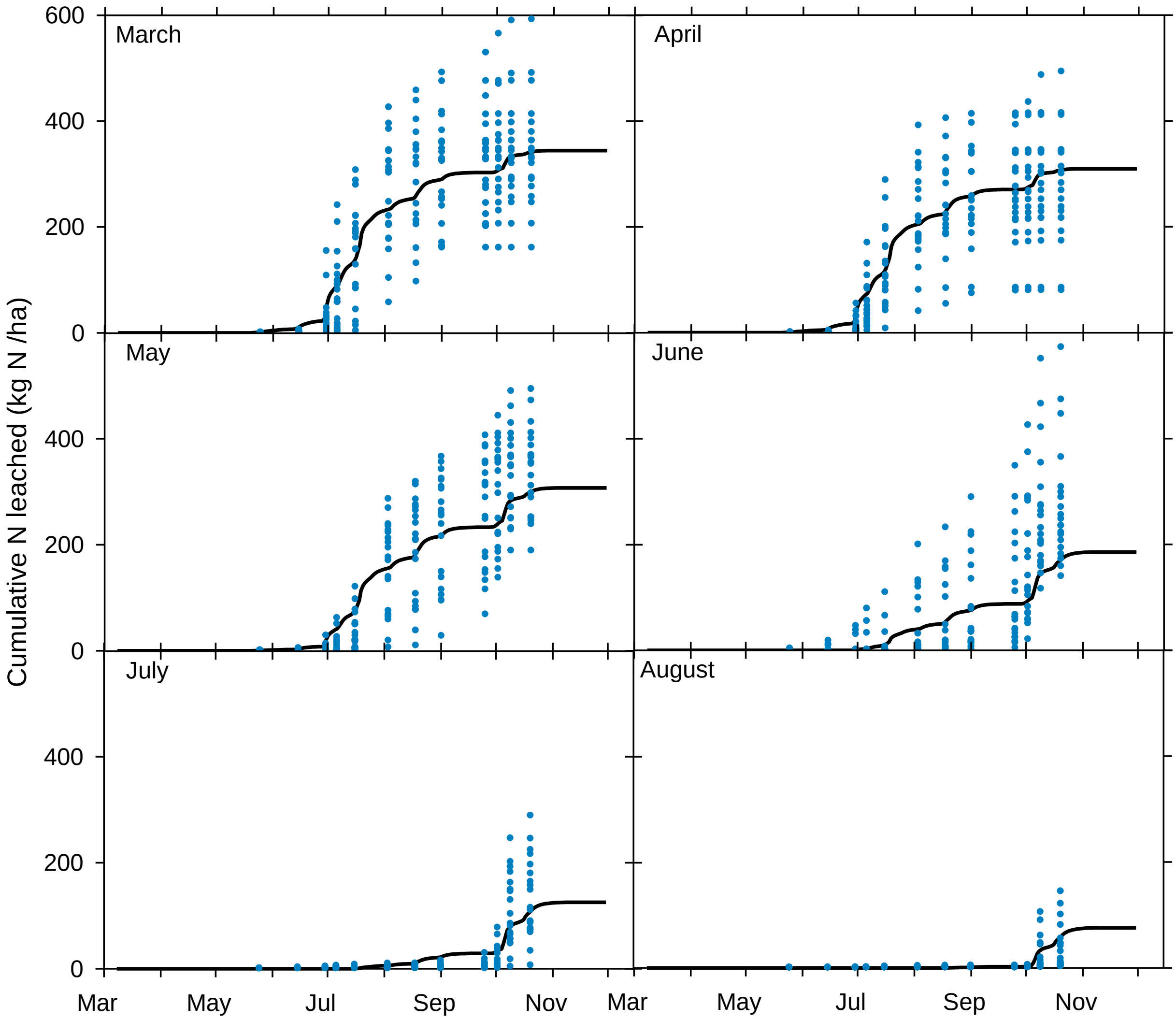

Figure 4. Leaching, cumulative from 9 March 2009, calculated from measured soil solution nitrate-N concentration and measured drainage (points) and simulated with APSIM (lines).

Table 1. Measured and simulated drainage, N removed in herbage, mineral N in the soil to 0.6 m deep, N leached and simulated denitrification, volatilisation and net mineralisation to various dates as given in the table. Measured values are given as means with standard deviations in parentheses. The differences between measured and simulated values are expressed as (Measured – Simulated) / Urine N applied / 100.0

	Month of Application					
	Mar	**Apr**	**May**	**Jun**	**Jul**	**Aug**
	Drainage to 20 Oct 2009 (mm)					
Measured	423 (52)					
Simulated	433					
	Removed in herbage to 7 Dec 2009 (kg N /ha)					
Measured	312 (55)	316 (34)	323 (52)	389 (17)	411 (33)	382 (26)
Simulated	461	455	476	460	456	429
Difference	19%	17%	19%	9%	6%	6%
	Mineral N in soil on 12 Nov 2009 (kg N /ha to 0.6 m deep)					
Measured	11 (19)	14 (19)	6 (7)	62 (27)	260 (58)	361 (114)
Simulated	0	0	33	162	236	311
Difference	-1%	-2%	3%	13%	-3%	-6%
	Leached to 20 Oct 2009 (kg N /ha to 0.6 m deep)					
Measured	344 (100)	274 (104)	340 (82)	274 (112)	132 (75)	37 (43)
Simulated	342	307	300	171	108	59
Difference	0%	4%	-5%	-13%	-3%	3%
	Denitrified to 20 Oct 2009 (kg N /ha)					
Simulated	139	130	135	117	104	85
	Volatilised to 20 Oct 2009 (kg N /ha)					
Simulated	40	83	40	31	11	15
	Net mineralisation to 20 Oct 2009 (kg N /ha to 0.6 m deep)					
Simulated	23	23	24	26	23	24

Sensitivity Analysis

Several parameters were tested with a range of values to examine if changes in parameter values would change conclusions about the pattern of leaching with time of deposition. Although all changes of parameter values resulted in changes to the amount of leaching or the shape of the breakthrough curve, of those parameters tested only four had a significant effect on the pattern of leaching with deposition time. These were: the initial urine deposition depth, the pasture rooting depth, the optimum temperature for nitrification and the potential nitrification rate. The effect of the parameter values on the pattern of leaching is given in Figure 5. While all these parameters changed the pattern of leaching, none of them would change the general conclusion that, for the Horotiu soil in 2009, there was more leaching from urine patches deposited in late-summer and early-autumn than later in the year. The simulation end date was extended to the winter 2010 drainage season in order to include the fate of the mineral-N remaining in the soil in November 2009.

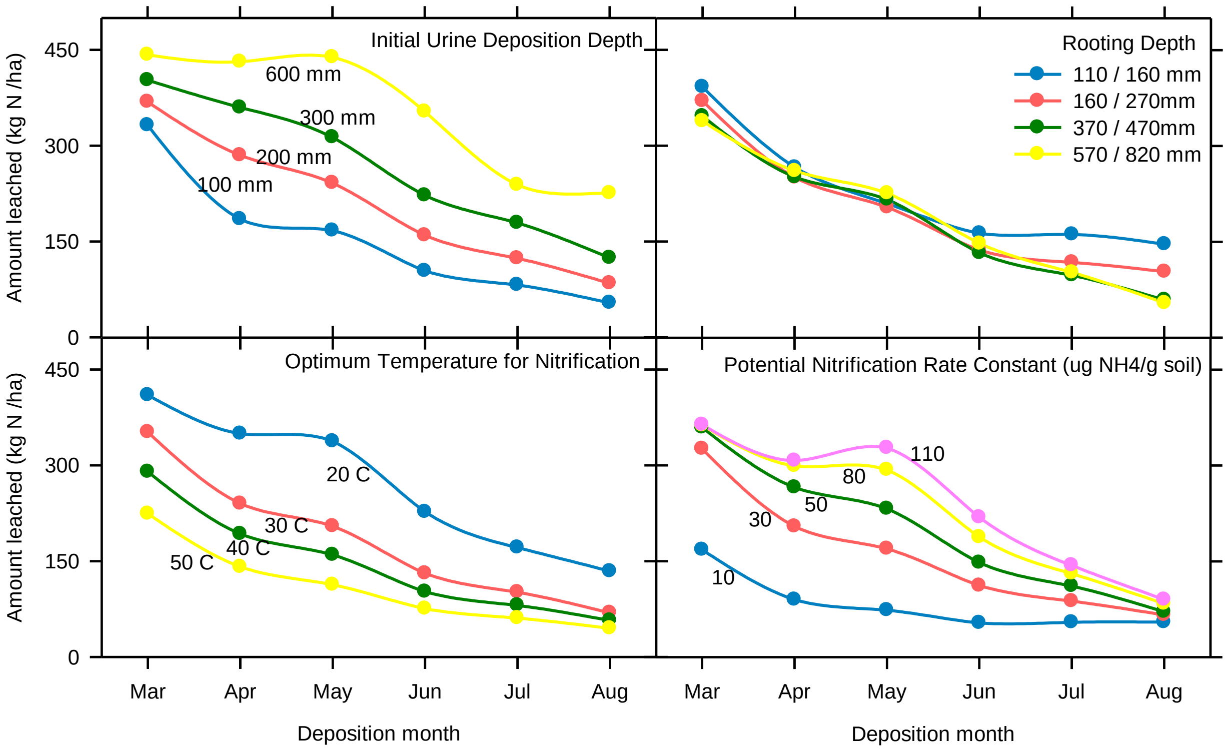

Figure 5. Sensitivity of the amount of N leached to different values of four key parameters in APSIM. The pairs of rooting depth parameter values refer to the depth above which 90% and 100% of the roots are contained.

Other Years, Soils, and Climates

The simulation experiment was repeated for deposition years of 1973 to 2006 for four combinations of soil and climate. The results for the two soils in the Waikato climate are shown in Figure 6. In all years the average of the leaching from the February and March urine patches exceeded the average of the July and August patches. This suggests that the 2009 Waikato experiment can generally be applied to other soils in the region and that the observed pattern of leaching in 2009 experiments were not the result of unusual weather.

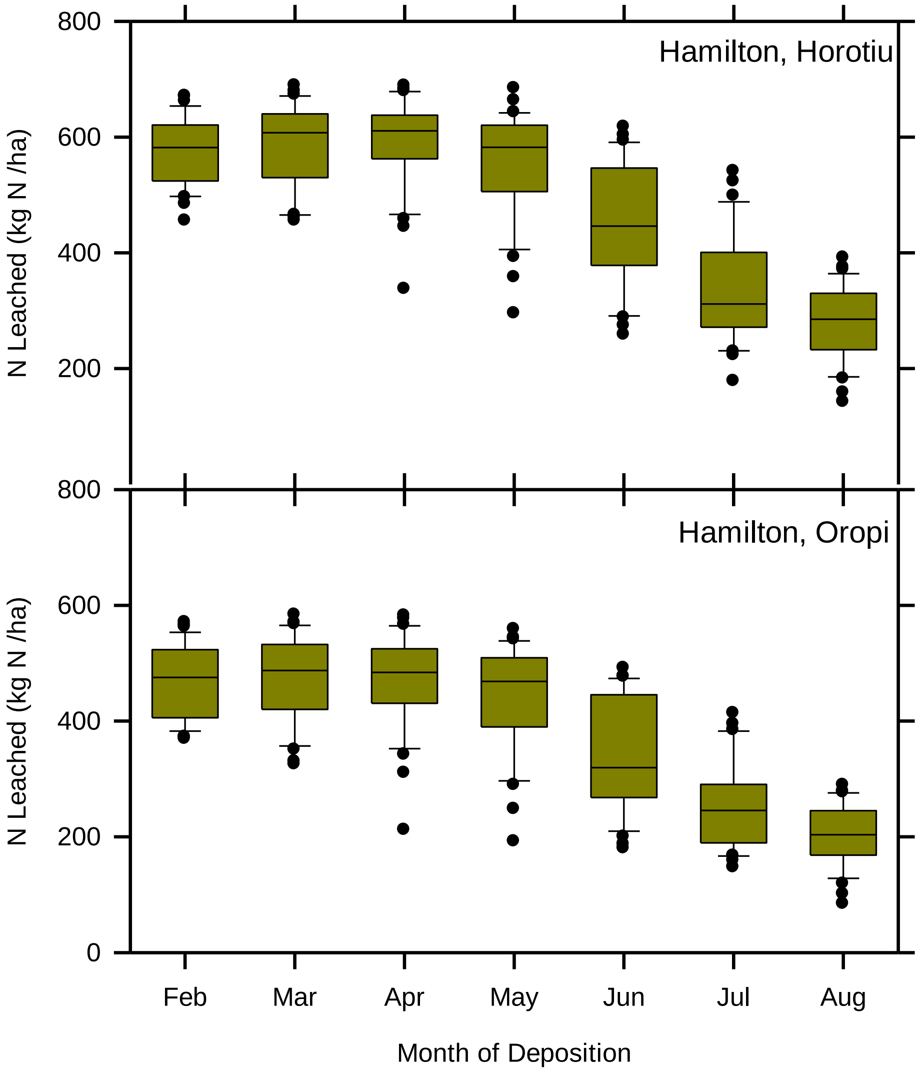

Figure 6. Leaching simulated from an 800 kg N /ha urine patch deposited on the first of the month for two Waikato soils using weather for Hamilton from the NIWA Virtual Climate Station network. The plot shows the variation in leaching resulting from deposition year ranging from 1973 to 2006 with the boxes indicating the 25th, 50th, and 75th percentiles, the whiskers showing the 5th and 95th percentiles and the points showing the outliers.

For the Lincoln climate, as is usual for the more intensive pasture production, the soils were irrigated to mimic a centre pivot irrigator. The general patterns observed for the Hamilton climate were repeated in the Lincoln climate (Figure 7) but some differences are evident. The pattern of leaching with deposition time is more variable from year to year in the Lincoln than in the Hamilton climate. The pattern at Lincoln is also more muted showing lower average leaching in summer and higher average leaching in winter than in the Hamilton climate. The higher year to year variability at Lincoln is likely to be the result of the combination of irrigation and rainfall events coinciding with urine depositions. The muted pattern of average leaching with deposition time seems to be a result of increased pasture growth in summer with the irrigated conditions but reduced pasture growth in winter because of lower temperatures at Lincoln compared to Ruakura. In contrast to Hamilton, the pattern of leaching with deposition time in Lincoln in some years did not follow the general trend.

Of the 34 years simulated, in 4 years for the Lismore soil and 5 years for the Templeton soil the pattern of leaching was flat with time rather than decreasing with time. Those years were 1982, 1985, 1988 and 2005 in both soils and additionally 1980 in the Templeton soil. For those years (Figure 7) the pattern was not one of increasing leaching with deposition time but rather unusually low leaching in summer followed by unusually high leaching in winter. Nevertheless, the general pattern observed in the Hamilton climate, one of higher leaching from the summer- and autumn-deposited urine patches than winter- and spring-deposited patches remains.

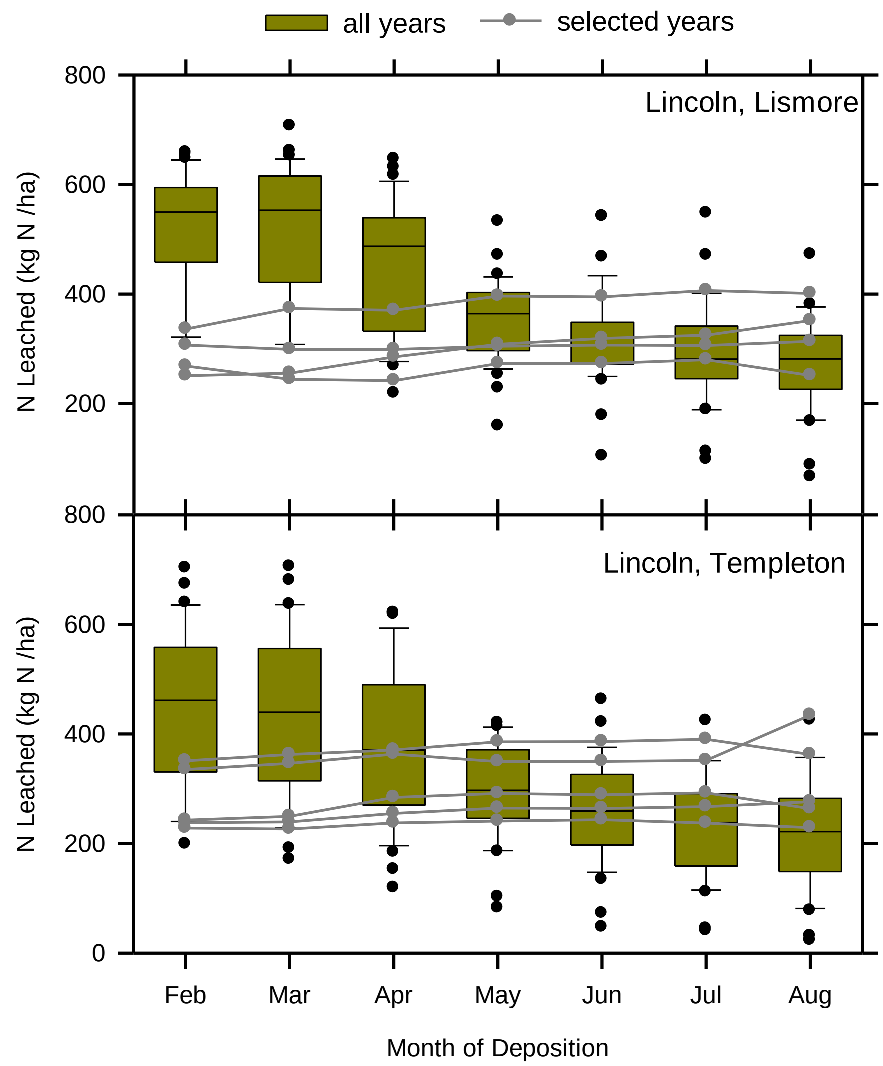

Figure 7. Leaching simulated from an 800 kg N /ha urine patch deposited on the first of the month for two Canterbury soils using weather for Lincoln from the NIWA Virtual Climate Station network. The plot shows the variation in leaching resulting from deposition year ranging from 1973 to 2006 with the boxes indicating the 25th, 50th, and 75th percentiles, the whiskers showing the 5th and 95th percentiles and the points showing the outliers. The lines show leaching from selected years that do not display the general trend.

This work focuses on the fate of urine from a single urine patch of a particular N concentration. Leaching outcomes at paddock and farm level will depend on the aggregation of many urine patches. It has been shown that there is considerable variation in urine-N concentration between animals fed the same diet (Betteridge *et al.*, 2010; Hoogendoorn *et al.*, 2010) and it is likely that there will also be seasonal changes in mean urine-N concentration as pasture conditions, management and physiological state change (Tas, 2006). These effects should be considered in concert with the leaching risk from individual patches when targeting mitigation practices.

Conclusions

APSIM was validated against data from an experiment examining the pattern of pasture growth, soil N and N leaching in 2009 on the Horotiu silt loam in Hamilton. While there were some areas of differences between the data and model, in general a very good validation was obtained. The model agreed with the experimental data that there was a greater risk of leaching from late-summer/early-autumn deposited urine patches than those deposited later in the year. A sensitivity analysis explored if there were changes in any key parameters that might change this conclusion and showed that, although several parameters affected the pattern of leaching, none had sufficient effect to change the general trend. The modelling analysis was extended to four combinations of soils and climate for deposition years between 1973 and 2006. The trend for reduced leaching risk with deposition time going into winter was observed every year for soils in the Hamilton climate. The trend was more muted and more variable in the Lincoln environment, but was still confirmed for averages. In the latter case, depending on the soil, 4 or 5 of the 34 years tested did not have lower leaching as the deposition time advanced into winter. In these cases the pattern was caused by unusually low leaching from summer depositions followed by unusually high leaching from winter depositions.

Ideally the leaching patterns with deposition time should be explored for more combinations of soil and climate, and also for different urine N amounts. Nonetheless, the combination of the experimental data and modelling results do concur, suggesting that the greatest risk of leaching from high N urine patches is in late summer and early autumn. In turn, this suggests that management and mitigation practices to reduce leaching should target the urine depositions of late summer and autumn.

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