NITROGEN FERTILISER AND URINE PATCH INTERACTION – USE OF APSIM TO AID EXPERIMENTAL DESIGN

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Abstract

Previous studies have shown that leaching losses from pasture-based systems occurs predominantly from urine deposited by grazing animals, but also following fertiliser application. However, there is limited understanding of the interaction and fate of urinary N and fertiliser N.

The objective of this study was to use APSIM modelling software to generate pre-experimental data to aid with the design of a lysimeter experiment that will endeavour to study the interactions of fertiliser urinary N on N leaching and N_2O emissions.

APSIM simulations were run to explore the likely fate of several combinations of urine and fertiliser N under experimental conditions normally imposed on lysimeters, using the weather records for Hamilton from 1972 to 2009. The soil type used was a Horotiu silt loam with a urine-N rate of 800 kg/ha and fertiliser rates of 0 to 500 kg N/ha per year.

The modelled data suggested two hypotheses, including that:

- NO_3-N leaching from autumn-deposited urine will be greater than from spring-deposited urine at the same urinary fertiliser N application rates.
- There will be a greater N fertiliser effect on NO_3-N leaching from under spring-deposited urine than under autumn-deposited urine.

Based upon prior knowledge and examination of data from the pre-experimental modelling, we were able to determine that the most appropriate fertiliser rates for the lysimeter experiment should include a control rate of 0 kg N/ha per year; a middle rate of 200 kg N/ha per year and an upper rate of 400 kg N/ha per year. Due to the cost and time limitations of a lysimeter experiment, a one year investigative period has been proposed. Analysis of the modelled data using climate inputs for each year from 1972 to 2009, concluded that the likelihood of this single year design producing anomalous results is low. The modelled data also indicated that leaching from the lysimeters should continue to be monitored for 18 to 20 months in order to capture leachate associated with both the autumn and spring-applied urine. The information from the modelled data has been used in the final design of the experiment. The lysimeter experiment was commenced in February 2011, and will test the above-mentioned hypotheses.

Introduction

In New Zealand, the demand and use of N fertiliser has increased considerably in the last 30 years, from less than 25,000 tonnes nationally in 1980, to around 350,000 tonnes in 2005 (Austin *et al*., 2006). Previous studies have clearly demonstrated that both leaching and gaseous N losses occur predominantly from urine depositions, but also following N fertiliser application (Silva *et al*., 1999; Di *et al*., 2002; Monaghan *et al*., 2005; Di *et al*., 2007). However, there is a limited understanding surrounding the interaction of urinary N and fertiliser N and its fate.

Therefore a lysimeter experiment has been proposed to quantify the effects of urine N deposition, in combination with recently applied N fertiliser, on leaching, gaseous losses, plant uptake and the soil N pool, as affected by the season in which urine deposition occurred.

In this study, APSIM, a process-based simulation model, was used to generate pre-experimental data based on the proposed lysimeter experiment. The objective was to use this pre-experimental data to help answer some key questions related to the experimental design. These questions include: what fertiliser rates should be used, how likely is it that the single-year design will produce anomalous results because of atypical weather patterns, and how long should the leaching be monitored before the experiment is terminated?

Materials and Methods

Model description and simulation set up

The APSIM (Agricultural Production Systems sIMulator) model (Keating *et al.*, 2003) was used for all simulations in this study. The critical modules for these simulations included; SWIM (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 SoilN (Probert *et al.*, 1998) for soil C and N transformations. APSIM has been used and validated in many environments and systems, and has recently been validated against a range of drainage and leaching data from New Zealand, particularly under urine-patch conditions (Cichota *et al.*, 2010; Vogeler *et al.*, 2010), for example Snow *et al.* (2011) presents a validation of the model for leaching from urine patches in the Horotiu silt loam.

In this study, soil properties for a Horotiu silt loam (Typic Orthic Allophanic soil), (Hewitt, 1998) were adapted from published sources (including Singleton, 1991; Webb *et al.*, 2000; Close *et al.*, 2003; Webb, 2003; Wilde, 2003; Vogeler *et al.*, 2011) and used in the simulations. The daily weather data for the simulations was obtained from the NIWA Virtual Climate Station dataset (VCS, Tait and Turner, 2005; Cichota *et al.*, 2008) for Hamilton (latitude -37.775, longitude 175.325) from 1972 to 2009.

The proposed treatment design includes nine treatments. The proposed treatments include three rates of N urea fertiliser to be spread in eight applications over the year. Superimposed on the fertiliser rates will be urine applied in spring or autumn at 800 kg N/ha or no urine.

APSIM was setup to mimic the proposed lysimeter experiment using the soil and weather properties as described above. To minimise rainfall-induced variability from this single-year experiment, APSIM was set up to apply irrigation (if required) on a weekly basis to all treatments, to “top up” the cumulative annual rainfall to meet the 30-year long-term average rainfall for Hamilton. The annual accumulations were calculated from 16th February each year.

Simulations were run for each of the proposed no urine, spring urine and autumn urine applications with fertiliser rates varying from 0 to 500 kg N/ha/yr. Each simulation was initiated on 1st January of the year with a'pre-treatment' conditioning comprising 150-mm irrigations on the 1st and 10th of January and February. The experimental period was considered to start on the 16th of February. If needed, according to the simulated treatment, urea fertiliser was added into the top 20 mm of soil on the 20th of every month except January, March, June and July. If required according to the simulated treatment, 800 kg N/ha of urine-N was deposited into the top 150 mm of soil with 10 mm of water on the 20th of April or August. Throughout the simulation, the pasture was cut every 21 days to a residual value of 1500 kg DM/ha. All clippings were removed. Separate simulations were run for each treatment in each year from 1972 to 2008.

Results and Discussion

What fertiliser rates should be used?

The N fertiliser rates should ideally be within the upper and lower limits of what farmers in the Waikato region would apply, however, for the experiment to be successful, the data obtained from the different fertiliser rates needs to differ enough to show any fertiliser effect on the leaching, should this effect exist. The pre-experimental modelling simulated applications of fertiliser N from 0 to 500 kg N/ha per year in conjunction with no urine, and urinary N applications of 800 kg N/ha in either spring or autumn. The modelled data showed that, in the no urine treatment, N leaching was minimal until the fertiliser application rate reached approximately 300 kg N/ha, and at the maximum fertiliser rate of 500 kg N/ha, leached N equated to only 26.3 kg/ha. This fits well with the expectation that pasture under a 'cut and carry' regime can remove large amounts of fertiliser N, with increases in N leaching not occurring until 300-400 kg N/ha has been applied (Scholefield *et al*., 1991).

Under the autumn-applied urine treatments, although the overall N leached was greater than under both the spring-applied and no urine treatments (190 to 249 kg N/ha), the additional effect on leaching due to fertiliser was minimal. Under an autumn-applied urine patch with no fertiliser, the average amount of N leached was 191 kg N/ha, however with the maximum fertiliser rate of 500 kg N/ha, the mass of N leached was 249 kg N/ha (range = 58 kg N/ha; Figure 1).

The additional fertiliser effect on spring-applied urine was much greater. Losses of N under the spring-applied urine treatment were, overall, less than under autumn-applied urine (14.7 to 172 kg N/ha), however, under a spring-applied urine patch with no fertiliser, leaching losses were 15 kg N/ha and with a fertiliser rate of 500 kg N/ha, the leaching losses were 173 kg N/ha (range = 158 kg N/ha). In other words, the range in N leaching between the lowest (0) and highest (500 kg N/ha) fertiliser rates was far greater under spring-applied urine, than under autumn-applied urine (Figure 1).

These modelling results strongly suggest that urine is the primary contributor to N leaching. The results also show that under a urine patch where fertiliser is applied, the fertiliser rate plays a significant role in N leaching, particularly with spring-applied urine. Based on these modelled data, it would be appropriate to have an upper application rate of 400 kg N/ha because, under no urine, N leaching as a result of fertiliser application was minimal up to a rate of 300 kg N/ha; it would be appropriate to use a fertiliser application rate above this baseline for experimental purposes, therefore. A maximum rate of 400 kg N/ha is most appropriate because it is unlikely that any farmers in the Waikato region would apply fertiliser at a rate greater than this. A control fertiliser rate of 0 kg N/ha is necessary, as is a fertiliser rate of 200 kg Nha, because (a) it is halfway between 0 and 400 kg N/ha and (b) this represents the current 'best practise' fertiliser application rates in the Waikato region (NZFRMA, 2007).

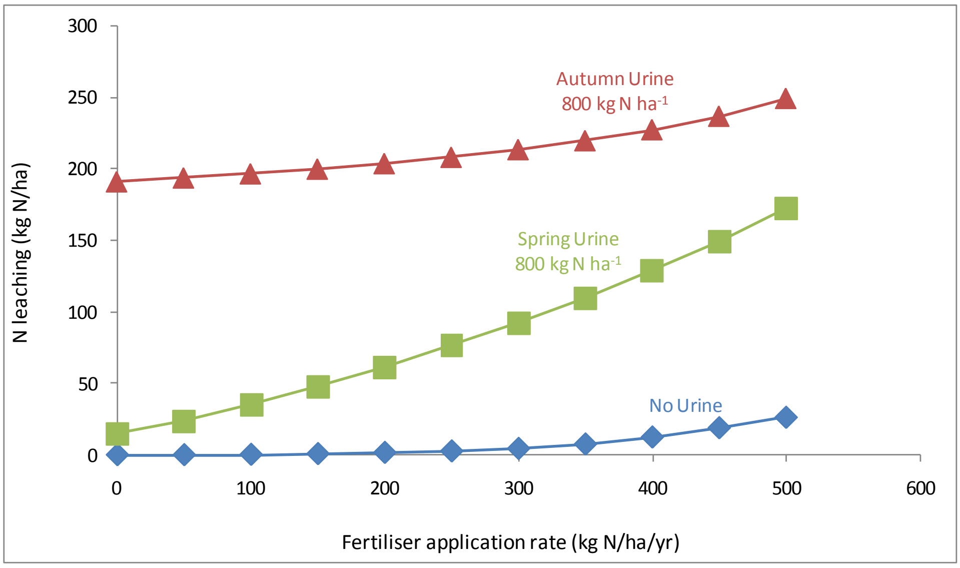

Figure 1: Modelled estimate of N leaching under fertiliser rates ranging from 0 to 500 kg N/ha per year

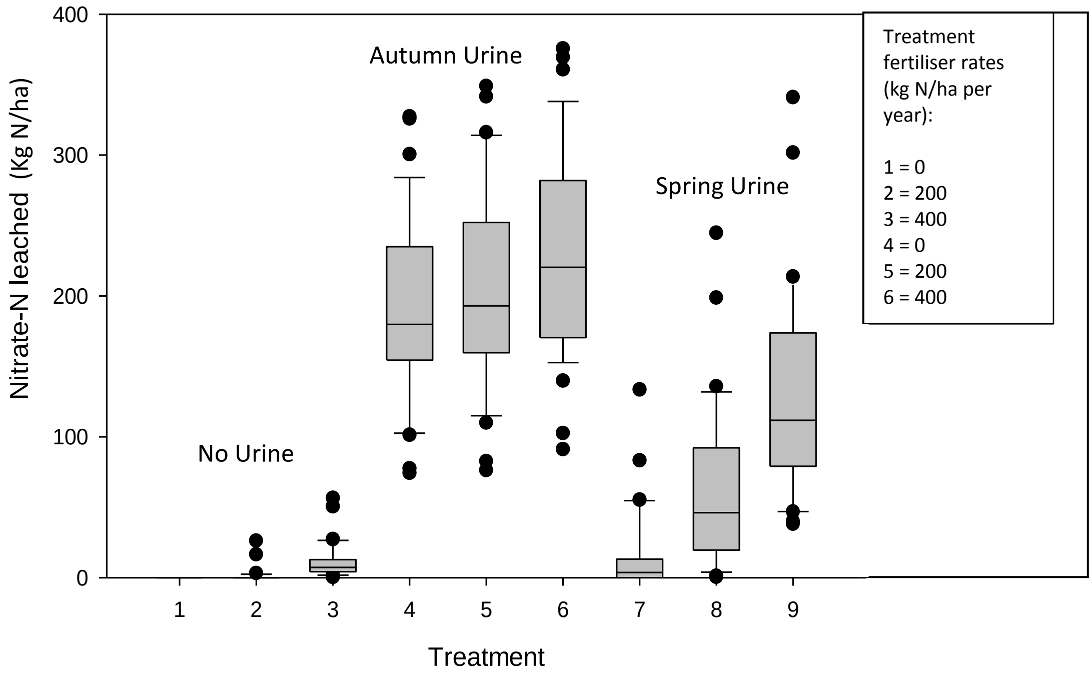

Figure 2: Box plot showing average NO_3-N leaching over 37 years (1972-2009) for three different fertiliser rates applied with three different urine applications (nine treatments in total).

Having selected fertiliser rates of 0, 200 and 400 kg N/ha per year, this raised the question of how variable the data would be from year to year when these treatment rates are applied. Figure 2 depicts the average NO_3-N leached over 37 years of weather data (1972-2009) under the three selected fertiliser rates in conjunction with no urine, autumn-applied urine, and spring-applied urine. This figure indicates two clear hypotheses:

- NO_3-N leaching from autumn-deposited urine will be greater than from spring-deposited urine at the same urinary fertiliser N application rates.
- There will be a greater N fertiliser effect on NO_3-N leaching from under spring-deposited urine than under autumn-deposited urine.

As would be expected, modelled leaching of NO_3-N from the treatments under no urine application remained significantly less than losses under their autumn/spring- applied urine counterparts.

How likely is it that the single-year design will produce anomalous results?
The pre-experimental modelling suggested that there is likely to be substantial year-to-year variability in leaching losses. The average yearly cumulative N leaching from urine patches with nil fertiliser ranged from 75-328 kg/ha and, with a fertiliser rate of 500 kg N/ha, cumulative losses were 110-435 kg N/ha over the 37 year period. This variation is most likely to result from weather variations over this time, particularly rainfall, which influences drainage volumes and the propensity for NO_3-N leaching.

Ideally a field trial and the monitoring associated with it would be carried out for several years, and as such, unusual or extreme weather events in any one year would not be expected to compromise the validity of the experiment. In reality, such long-term field trials are often not feasible. In the case of a lysimeter experiment such as the one proposed, cost and time limitations indicate that the trial can run for only 12 to 18 months. This increases the risk of anomalous results arising from unusual or extreme weather events that may not be characteristic of the “usual” scenario for that region.

Analysis was carried out on the simulation data from 1972 to 2009 to determine the likelihood that the two hypotheses described above would either be accepted or rejected.

For the first hypothesis, that NO_3-N leaching from under autumn-applied urine will be greater than under spring-applied urine under the same fertiliser application rate, the average NO_3-N leaching was calculated from the Y intercept of the regression of simulated leaching on fertiliser rate. The calculated NO_3-N leaching was firstly averaged for each consecutive three year period, and as Figure 3 shows, leaching from under autumn-applied urine, in each three year period was significantly greater than that from under spring-applied urine. This indicates that if the trial was carried out over three years, then there would be a high probability of the hypothesis bring proven correct.

The same analysis was carried out for each individual year from 1972 to 2009. In every year from 1972 to 2009, the modelled NO_3-N leaching from under autumn-applied urine was greater than that from under spring-applied urine (Figure 4). This suggests that, even in years where climate and weather are atypical of the Waikato region, there is a strong probability that the abovementioned hypothesis will be proven.

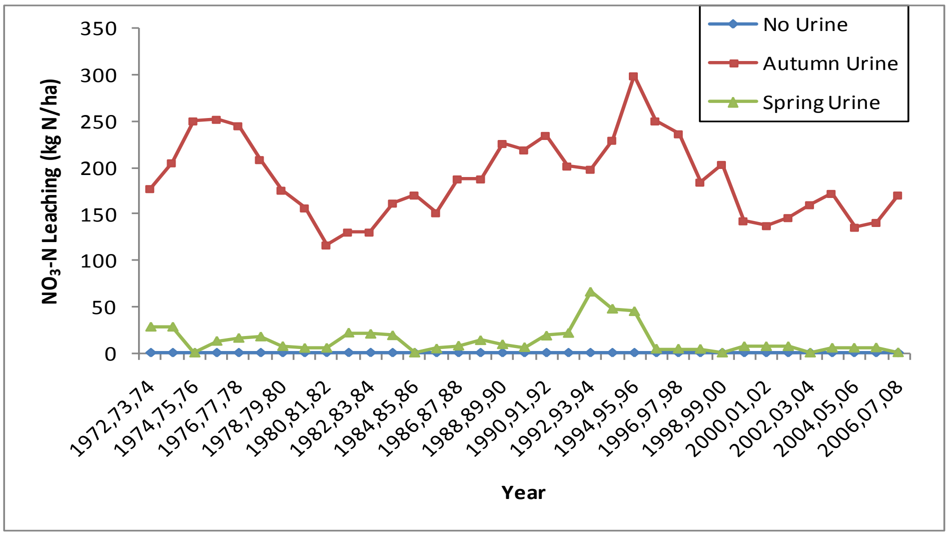

Figure 3: Average three yearly NO_3-N leaching under autumn-applied, spring-applied, and nil urine.

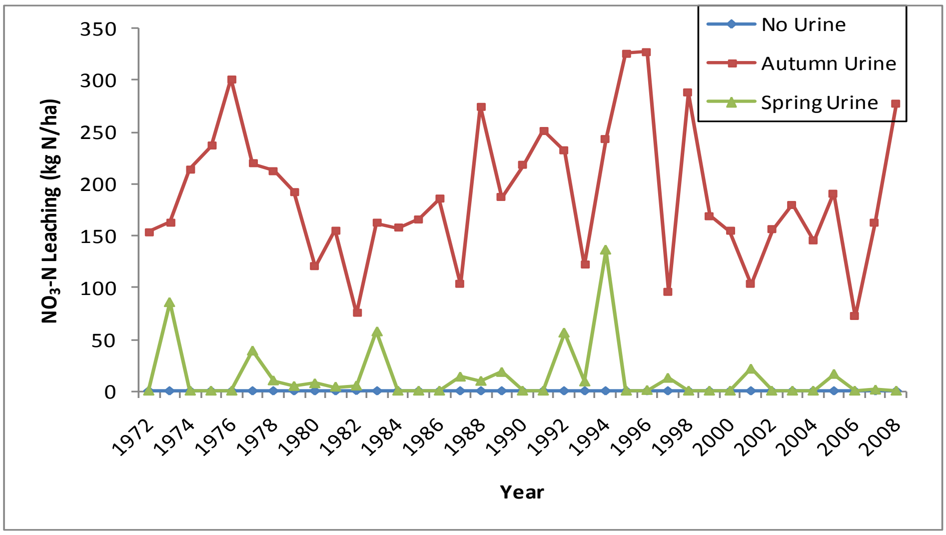

Figure 4: Average NO_3-N leaching under autumn-applied, spring-applied, and nil urine for each year from 1972 to 2009.

The analysis above was carried out by taking the average leaching from the three fertiliser rates (0, 200 and 400 kg N/ha). To determine whether taking this average provided robust results, the same analysis was carried out on each individual fertiliser rate. Under no fertiliser, leaching from under the autumn-applied urine was greater than under spring-applied urine in every year, and under 200 kg N/ha fertiliser, there was a single year (1997) where N leaching from spring-applied urine was slightly higher (119 kg N/ha) than under autumn-applied urine (110 kg N/ha). Under a rate of 400 kg N/ha there were six years (1973, 1982, 1987, 1993, 1997, and 2006) where N leaching from spring-applied urine was slightly higher than under autumn-applied urine (Figure 5). This therefore suggests the probability that the hypothesis will be proven at a fertiliser rate of 400 kg N/ha is considerably less than at the 0 and 200 kg N/ha rates.

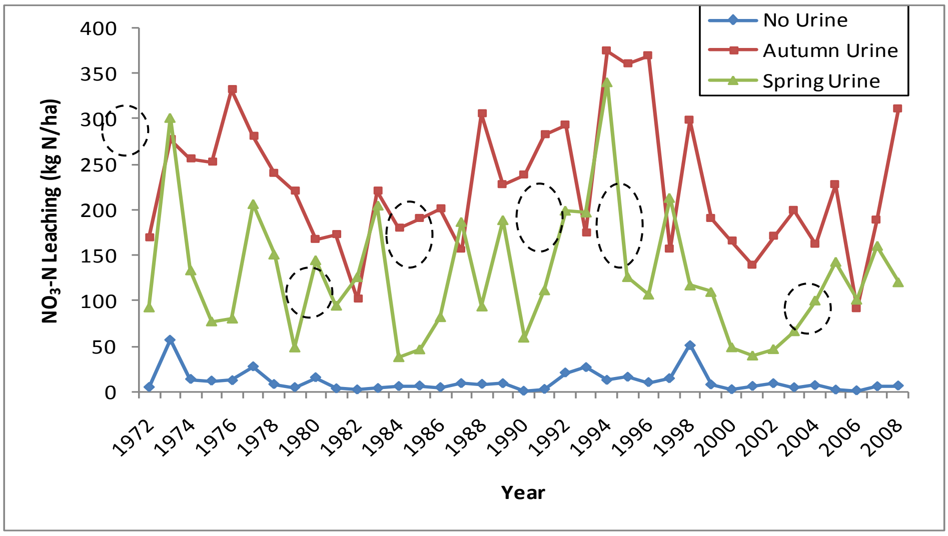

Figure 5: NO_3-N leaching under fertiliser rate of 400 kg N/ha plus autumn-applied, spring-applied or nil urine. The circled points denote the years where modelled leaching under spring-applied urine was greater than under autumn-applied urine.

For the second hypothesis, that there will be a greater fertiliser effect on NO_3-N leaching from under spring-applied urine compared to under autumn-applied urine, the slope of the relationship between each of the three fertiliser rates was analysed to determine if, the slope of leaching under spring-applied urine (at 0, 200 and 400 kg N/ha per year) was greater (or "steeper") than the slope of leaching under autumn-applied urine. The slope was averaged over each consecutive three year period (Figure 6), and also calculated for each individual year (Figure 7) from 1972 to 2009.

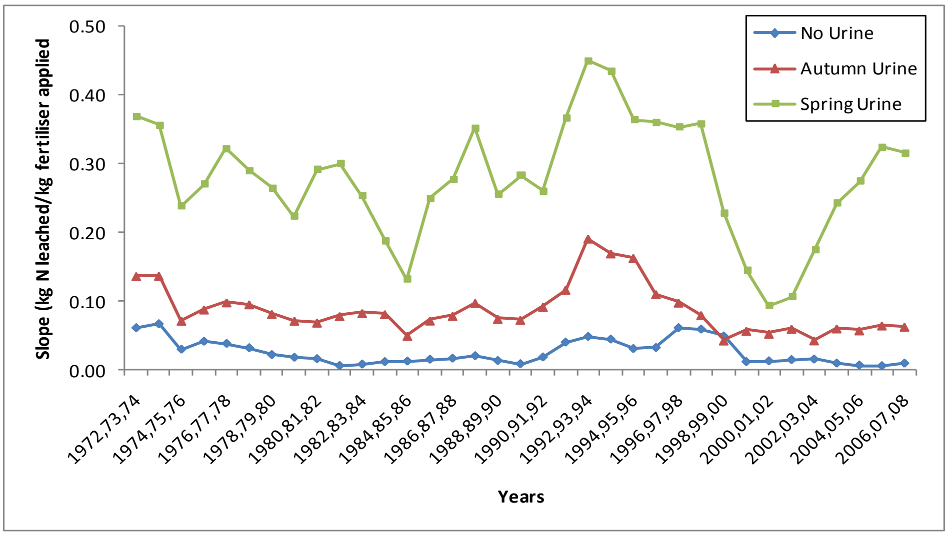

Figure 6: Average three yearly slope (1972-2009) between fertiliser rates of 0, 200 and 400 kg N/ha and simulated leaching.

Figure 6 shows that the three-yearly slope of NO_3-N leaching in response to the amount of fertiliser applied under spring-applied urine is consistently higher than under autumn-applied urine. This suggests that if this trial was carried out over a three year period, then the hypothesis would be proven correct. Although there is a lot of variability in Figure 7, this shows that the slope of the regression of N leached on fertiliser applied NO_3-N leaching from under spring-applied urine is greater than that of autumn-applied urine in every year except 2001. In other words, the modelled fertiliser effect on NO_3-N leaching was greater under spring-applied urine than under autumn-applied urine, as hypothesised, for 36 out of the 37 years, thus indicating a high probability that the hypothesis would be accepted.

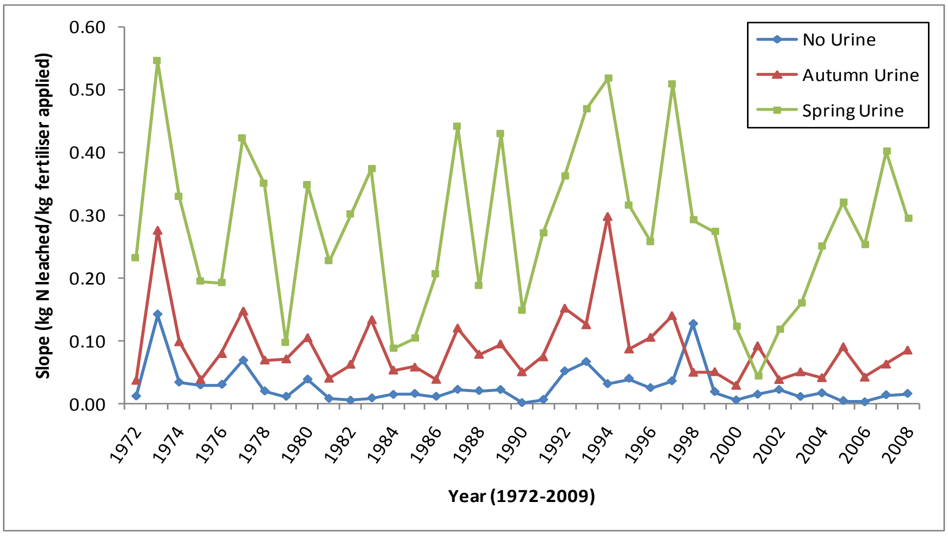

Figure 7: Slope between fertiliser rates of 0, 200 and 400 kg N/ha for each year from 1972 to 2009.

The slope of NO_3-N leaching from under spring-applied urine was, for the most part, at least 30% greater that than from under autumn-applied urine. There were also 10 out of the 37 years where the slope under spring-applied urine was at least 80% greater than under autumn-applied urine (Table 1).

Table 1: Frequency (number of years out of 37) and the degree by which the slope of NO_3-N leaching from under spring-applied urine was greater than under autumn-applied urine.

	80% greater	**70% greater**	**60% greater**	**50% greater**	**40% greater**	**30% greater**	**20% greater**
Frequency	10	20	27	31	33	34	35

Based on the above analyses of modelled data, the probabilities of the two hypotheses being proven in any individual year (based on 37 years of data – 1972 to 2009) were high therefore the risk of the proposed single year design experiment producing anomalous data is considered to be low.

How long should leaching be monitored before the experiment is terminated?
Ideally, the leaching from the lysimeter experiment should be monitored until there is no longer any applied fertiliser or urine associated NO_3-N in the drainage. However, for experimental design purposes, estimating when this will occur can prove challenging.

The modelled data was analysed and used as a decision making tool to help determine how long monitoring of NO_3-N leaching should continue before the experiment is terminated. The analysis looked at modelled soil NO_3-N data and leached NO_3-N data under no urine, autumn-applied urine and spring-applied urine (averaged over the 37 years) continuously for approximately 20 months. After preliminary analysis of the data it was evident that soil NO_3-N and leached NO_3-N were greatest, and took the longest time to return to pre-treatment conditions under the spring applied urine with the 400 kg N/ha fertiliser rate. The data from the 400 kg N/ha fertiliser application rate provided a 'worst case scenario' and was therefore used for this analysis.

Figure 8and Figure 9 show that 12 months is sufficient time for capturing the changes in soil NO_3-N as a result of urine application, however, the leaching effects of the spring urine application are not seen within this 12 month period (Figure 9). The reason for this is most likely because the experiment is proposed to start in February (summer), therefore after 12 months, the NO_3-N associated with the spring urine application will have accumulated in the soil, but will not be prone to leaching due to dry summer soil conditions.

After 20 months, the autumn and spring urine associated NO_3-N in the soil has reduced to a level similar to that at which the experiment started. If leachate monitoring from the lysimeters is carried out for 20 months, the leached NO_3-N associated with both the autumn *and* spring-applied urine will be captured, as shown by Figure 9. This means that monitoring of leachate will continue past the 12 month mark, through to the end of the following drainage season. The 20 month monitoring regime will therefore provide a more complete and robust data set, and as such, is clearly the best option for the proposed lysimeter experiment.

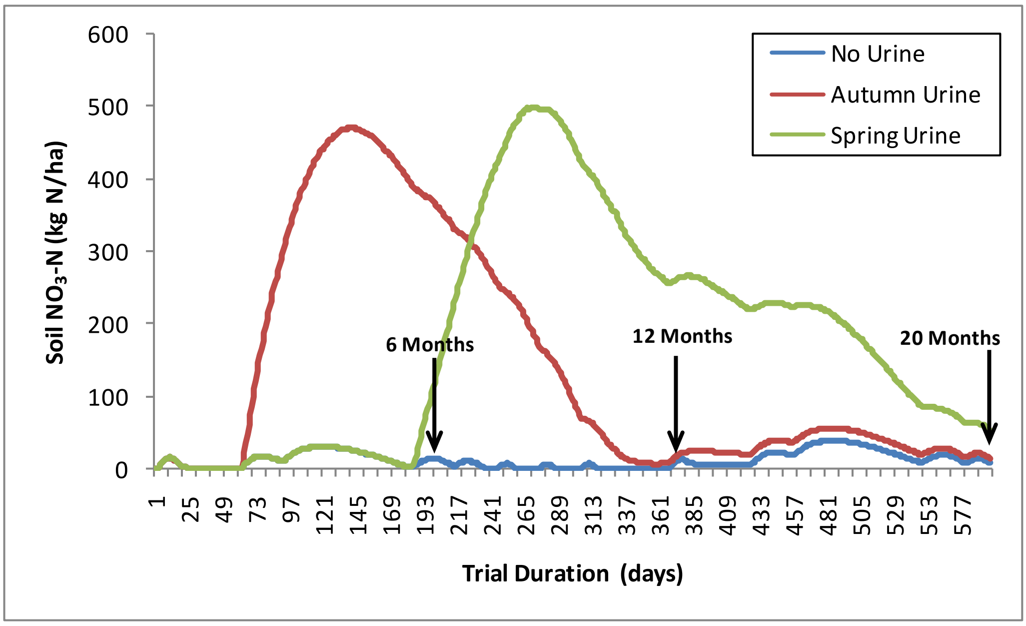

Figure 8: Average (37 year) modelled soil NO_3-N over the possible experiment duration.

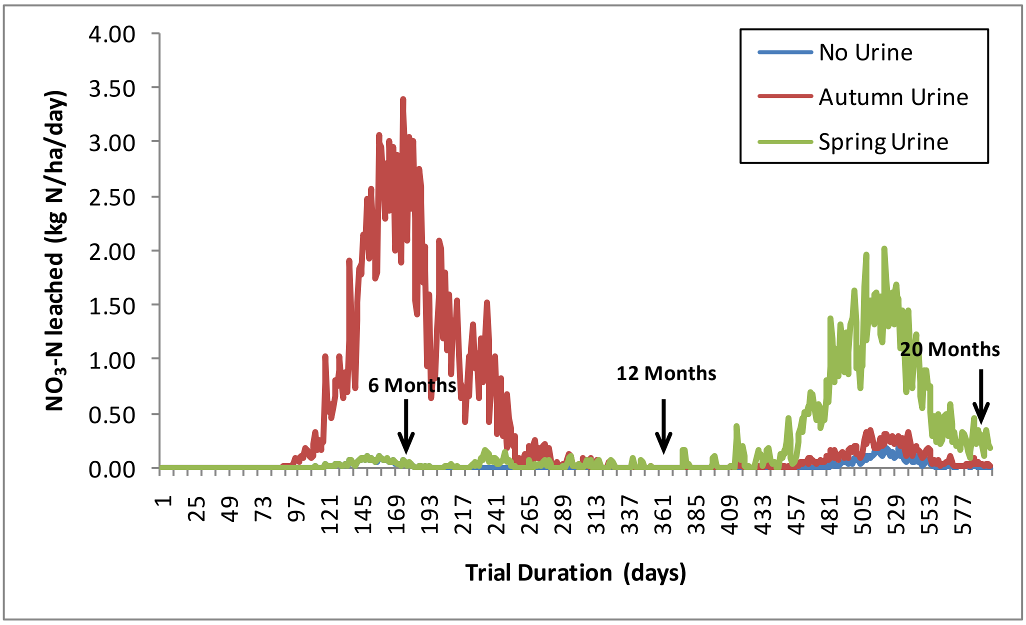

Figure 9: Average (37 year) modelled NO_3-N concentration in drainage over experiment duration.

The above results are the average of the modelled 37 years (1972 to 2009). Figure 10 shows the year to year variation of soil NO_3-N over an experiment duration of 20 months.. The greatest variation in soil NO_3-N between experimental years occurs from approximately 330 days (~ 11 months) to 550 days (~ 18 months), so it will be important to monitor NO_3-N leached in drainage during this time. From 550 to 600 days duration, soil NO_3-N is consistently trending downwards and/or reaching a plateau, further suggesting that 18 to 20 months of monitoring should be carried out before the experiment is terminated.

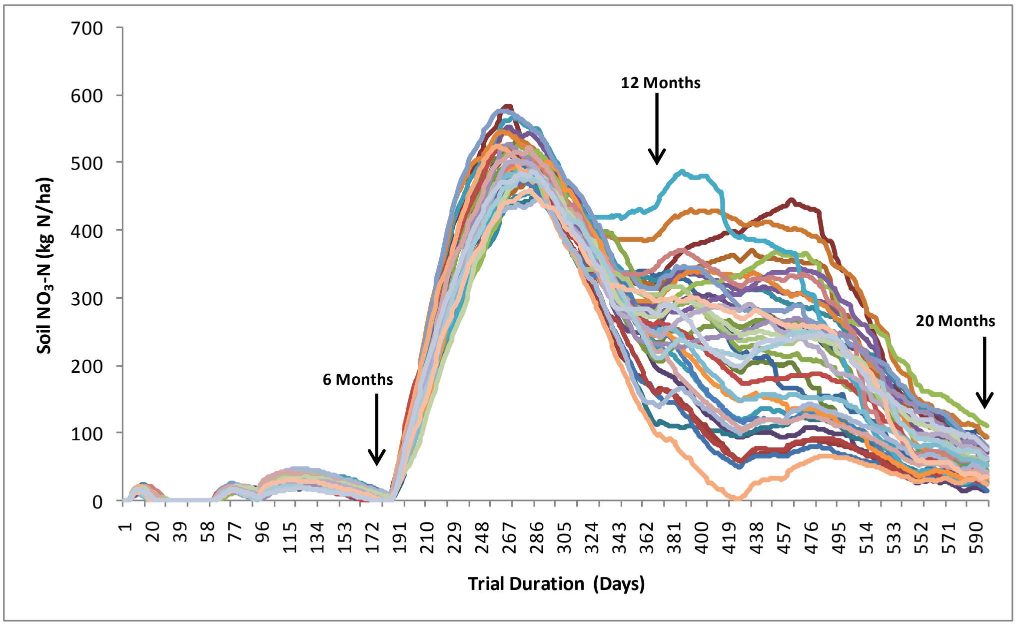

Figure 10: Modelled soil NO_3-N over experiment duration showing year to year variation.

Conclusions

Based on prior knowledge and the data from the pre-experimental modelling, two clear hypotheses were formed for the proposed lysimeter experiment, which will be tested when the experiment commences in February 2011. These include that:

- Overall, N leaching losses will be greater under autumn-applied urine than spring-applied urine;
- There will be an additional effect on N leaching from fertiliser applied over the urine patch, and that this effect will be more pronounced under spring-applied urine than under autumn-applied urine.

The pre-experimental modelling data also helped to answer three key questions related to the design of the lysimeter experiment. These included what fertiliser rates should be used, how likely is it that the single-year design will produce anomalous results, and how long should the leaching be monitored before the experiment is terminated?

In summary, the most appropriate fertiliser rates include a control rate of 0 kg N/ha per year; a middle rate of 200 kg N/ha per year and an upper rate of 400 kg N/ha per year. Due to the cost and time limitations of a lysimeter experiment, a single year deposition design is preferred. According to the modelled data from 1972 to 2009, and with the urine and fertiliser treatments discussed, the results suggested that the likelihood of single year design producing anomalous results is low. The modelled data also indicated that leaching from the lysimeters should continue to be monitored for a duration of 18 to 20 months from the commencement of the lysimeter experiment. This is because the spring-urine associated leaching losses will not be observed until the drainage season following its application, so monitoring should be undertaken to capture all these leaching losses.

An additional point to note is that the modelled data cannot decipher between the partitioning and relative contribution of N leaching sources (fertiliser and urine), and as a result, ^{15}N labelled fertiliser will be used in the lysimeter experiment. This will enable the measurement of fertiliser associated losses. At the end of the experiment, the lysimeters will also be destructively sampled, and soil and microbial N analysed to further determine the partitioning of fertiliser N over time.

Acknowledgement

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