Manaaki Whenua
Landcare Research

Nitrogen leaching under grazed lucerne

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Nitrogen leaching under grazed lucerne

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Summary

Project and Client

- Lake Taupō Protection Trust (LTPT), the Sustainable Farming Fund (SFF), Landcorp, Fertiliser Association of New Zealand, AGMARDT, and Waikato Regional Council have funded a field trial on nitrogen (N)-leaching under grazed lucerne on a Taupo Lake Care (TLC) member's Tihoi farm. At this site an underground facility is used to collect leachate from large diameter lysimeters. The leaching data will be made available to the Overseer® Committee to update the lucerne module within Overseer®.

Objective

- To quantify N-leaching from autumn-grazed lysimeters planted with lucerne or ryegrass/clover pasture. Grazing was simulated by the application in autumn of ewe lamb or cow urine collected from animals whose diet included lucerne.

Methods

- A lysimeter facility at Tihoi was refurbished and extended that contained large undisturbed soil barrel lysimeters (0.9 m diameter × 1.5 m high).
- The 20-barrel lysimeters contained 4 replicates each of:
    - Lucerne with one autumn cow urine application
    - Lucerne with one autumn ewe lamb urine application
    - Lucerne control (no urine application)
    - Ryegrass/clover pasture with one autumn cow urine application
    - Ryegrass/clover pasture control (no urine application).
- All leachate from each lysimeter was collected and sampled periodically for leachate volume, ammonium-N (NH4-N), nitrate-N/nitrite-N (NOx-N), total N.

Results

- Total nitrogen leached from lucerne lysimeters with one cow urine application in autumn was 56.3, 33.8, and 21.5 kg TN/ha for Years 1, 2, and 3 respectively.
- Total nitrogen leached from lucerne lysimeters with one ewe-lamb urine application in autumn was 20.4, 9.4, and 23.9 kg TN/ha for Years 1, 2, and 3 respectively.
- Total nitrogen leached from control lucerne lysimeters was 2.1, 0.6, and 0.4 kg TN/ha for Years 1, 2, and 3 respectively.
- Total nitrogen leached from pasture lysimeters with one cow urine application in autumn was 27.9, 19.2, and 47.4 kg TN/ha for Years 1, 2, and 3 respectively.
- Total nitrogen leached from control pasture lysimeters was 4.1, 1.2, and 1.0 kg TN/ha for Years 1, 2, and 3 respectively.
- Expressed on a paddock basis, leaching from lucerne with one simulated grazing by cattle in autumn was 3.9, 1.7, and 1.1 kg TN/ha for Years 1, 2, and 3 respectively.
- Expressed on a grazed paddock basis, leaching from control (ungrazed) lucerne was 2.1, 0.6, and 0.4 kg TN/ha for Years 1, 2, and 3 respectively.

- Expressed on a grazed paddock basis, leaching from pasture with one cow urine application in autumn was 4.9, 1.8, and 2.6 kg TN/ha for Years 1, 2, and 3 respectively.
- Expressed on a grazed paddock basis, leaching from control (ungrazed) pasture was 4.1, 1.2, and 1.0 kg TN/ha for Years 1, 2, and 3 respectively.
- The 3-year average total nitrogen leached, expressed on a grazed paddock basis was 2.3 kg TN/ha/yr for lucerne and 3.1 kg TN/ha/yr for pasture. These results were not significantly different, indicating there was no vegetation effect.

Conclusions

- A single autumn urine application (simulated grazing) significantly increased N leaching compared to controls, but no significant differences were found between pasture or lucerne vegetation.
- When expressed at the paddock scale, assuming urine patches cover 3% of the paddock during a single autumn grazing, the three-year average was 2–3 kg TN/ha/yr (lucerne 2.3 kg/ha/yr TN, pasture 3.1 kg/ha/yr TN)

Recommendations

- The total N leaching from one autumn grazing of lucerne by cows can be set to 2.3 kg TN/ha assuming c. 3% urine patch coverage in an established lucerne crop.
- So that Overseer® can process data for four seasons we recommend further work with urine applications each season. If using the Tihoi facility, the work should be carried out over four leaching seasons rather than five as root architecture likely differs from open paddock growth.
- To understand how much N is leached when deep-rooted lucerne is sprayed with glyphosate and converted to the next crop, existing lysimeters could be sprayed with glyphosate and leachate TN measured for both pasture and lucerne

1 Introduction

This is the final report to Taupō Lake Care Inc. (TLC) and the Ministry for Primary Industries under Grant No 13/059 in relation to nitrogen (N) leaching under grazed lucerne grown in large diameter lysimeters at Tihoi. The report covers leachate collected during the period from 2017 to 2019.

2 Background

Lake Taupō Protection Trust (LTPT), the Sustainable Farming Fund (SFF), Landcorp, Fertiliser Association of New Zealand, AGMARDT, and Waikato Regional Council funded a field trial on N-leaching under grazed lucerne on a TLC member's Tihoi farm (Fig. 1). At this site an underground facility is used to collect leachate from large diameter lysimeters. The leaching data can be used by the Overseer© Committee to update the lucerne module within Overseer®.

Figure 1. Aerial view of lysimeter facility at Tihoi. Pasture lysimeters and pasture guard crop are generally to the left of the central underground leachate collection facility, while lucerne lysimeters and guard crop are generally to the right. Immediately to the left of the shed are manuka lysimeters and guard crop not involved in the SFF study.

3 Objective

To quantify N-leaching from autumn-grazed lysimeters planted with lucerne or ryegrass/clover pasture. Grazing is simulated by the application in autumn of ewe lamb or cow urine collected from animals whose diet includes lucerne.

4 Methods

A lysimeter facility at Tihoi (Fig. 2) was refurbished and enlarged with new undisturbed soil core lysimeters (0.9 m diameter × 1.5 m high with 10 mm internal annulus) collected from a nearby recently grazed paddock and installed. The lysimeters have 50-cm-long hanging fibreglass wicks to provide 0.5 kPa suction to the base of the soil core. Without suction, the base of the soil core must become saturated before leachate can drip out to the free atmosphere of a collection vessel, and the saturation can lead to changes in the form of nitrogen and leachate volumes. Suction of 0.5 kPa was established by measuring the soil suction mid-summer at 1.5 m below the soil surface. Before establishing crops in the lysimeters, they were drip irrigated (8 L h^{-1}) from the farm stock water supply to flush any urine-N entrained within the soil column from the recent grazing (Fig. 3).

Figure 2. Lysimeter facility at Tihoi under refurbishment. Note the grey dropper pipe under the lysimeter housing the fibreglass wicks.

Figure 3. Farm stock water drip irrigation system used to flush any urine-N entrained within the soil column from grazing.

Treatments

The treatments were:

- Lucerne with 2.1 L cow urine applied once during autumn
- Lucerne with 2.1 L ewe lamb urine applied once during autumn
- Lucerne control, no urine application
- Ryegrass/clover pasture with 2.1 L cow lamb urine applied once during autumn
- Ryegrass/clover pasture control, no urine application

There were four replicates of each treatment.

As no ewe lamb urine was available for the first year, cow urine was substituted. In the first year only one 525-mL application was made centrally to the surface of the lysimeter, while in years two and three, four 525-mL applications of ewe lamb urine were made equally spaced on the lysimeter, bringing the total ewe lamb urine applied to 2.1 L.

Lucerne was hand planted (Fig. 4) at a rate of 120 seeds per square metre and 2.8 g of ryegrass/clover planted on each lysimeter.

Figure 4. Lucerne seeds being hand planted to lysimeters.

Grazing was simulated by the application of cow or ewe lamb urine (Fig. 5).

(a) **(b)**

Figure 5. Applying cow (a) and ewe lamb (b) +urine to lysimeters in April.

When the animal urine was collected, lucerne formed part of the animal's normal diet. Ewe lamb urine was collected from beneath the grating of a woolshed (Fig. 6) and cow urine collected directly into 5-L jugs while the cows were on a rotary milking platform during milking.

Figure 6. Ewe lamb urine being collected into 60-L vessels via plastic tarpaulins spread under the grating in a woolshed.

Loading rate of urine onto lysimeters

Selbie et al. (2015) define urine loading rate as:

Urine N rate (kg N/ha) = Conc (g N/L) × ((Vol (L)/Surface area (m2)) × 10.

Following Selbie et al. (2015), for a dairy cow we assume the urine patch wetted area to be 0.24 m^2. This area is similar to that assumed by Haynes and Williams (1993) of 0.2 m^2 for a dairy cow. For a sheep urine patch, Haynes and Williams (1993) reported an area of 0.03 m^2. As the wetted area of a urine patch for ewe lambs is not given, we assume that of sheep. The concentration of total N in the urine is shown in Table 2, while the loading rate of urine onto +urine lysimeters is shown in Table 3.

Before the spring growing season a 150-mm-deep soil sample was obtained from each lysimeter by tube-type soil corer and bulked by treatment. The soil samples were sent to Hills Laboratories for analysis and the results forwarded to Ballance and Ravensdown for fertiliser recommendation.

Lucerne was harvested at approximately 10% flowering (Fig. 7) or immediately before urine application. For any harvest, all lucerne lysimeters were harvested at the same time.

Pasture was harvested on a similar rotation to the grazing of the surrounding paddock, or immediately before urine application. For any harvest, all pasture lysimeters were harvested at the same time.

Phosphorus, potassium, and magnesium fertiliser was added following every second harvest, based on the amount removed by plants.

No fertiliser N was applied to any treatment.

Figure 7. Lucerne ready for harvest.

Leachate was collected into 80-L barrels (Fig. 8) and sampled periodically based on volume collected and anticipated weather conditions. Before determining collected leachate volume, a 50-mL aliquot was subsampled for analyses of ammonium-N (NH_4-N), nitrate-N and nitrite-N (NO_x-N) and total N. Analyses were conducted at the Manaaki Whenua–Landcare Research Environmental Chemistry Laboratory. Test number 310 was used and details can be found at:
http://www.landcareresearch.co.nz/resources/laboratories/environmental-chemistry-laboratory/services/water-testing/methods-water#310

Figure 8. Leachate collection barrels in the underground facility. Numbers on the wall indicate lysimeter number. Lysimeters 16, 18, 23, and 24 grow a separate crop and are not part of this study. Under some lysimeters, leachate passes via tipping bucket recording devices to monitor leachate volume.

Reported concentrations, in milligrams per litre (mg/L) of TN in the leachate, were converted to kg/ha based on the volume of leachate and the area of the lysimeter. Leachate volume was also expressed as pore volumes (PV). A PV (648 L) is the amount of air (pores) in the soil and is about 70% of the total volume of the soil core. Using PV allows comparison of data across different soils. Pore volume based on total porosity (TP) was established using undisturbed cores 75 mm high and 100 mm diameter following Carter and Ball (1993). Nitrate was the dominant form of nitrogen leached, with ammonium often below the detection limit.

Scaling to a paddock level

For scaling to the paddock level Moir et al. (2011) suggest 6,240 cow urine patches per hectare deposited annually from 11 grazings per year by dairy cattle on ryegrass/clover pasture. Thus, from a single grazing the number of urine patches is 567 per hectare. Since a lysimeter (0.61 m^2) covers approximately the effective area of a cow urine patch (Selbie et al. 2015), only c. 3% of a paddock hectare is affected by a cow urine patch and c. 97% is unaffected.

For ewe lambs, scaling to the paddock level is unreliable because published data for urination volume, number of urine patches per hectare and wetted area have high uncertainty. Indeed, Selbie et al. (2015) state that for improved data on urine patch N loading rate, experiments need to measure volume, N concentration, and surface area.

Error bars on graphs show the standard error of the mean (SEM) for each of the treatments. The SEM is a measure of the spread of the sample means around the population mean. Statistical analysis was performed on the data using Genstat (18th edition, VSN International Ltd). Statistically significant differences within years (<0.05) are identified by different letters shown above bars on Figures 9 and 10.

5 Results

This report gives the results for 2017 to 2019 leaching seasons with urine applied to +urine treatments in autumn.

Leaching years for the experiment are shown in Table 1. The start and stop dates are when leachate collections were made, not necessarily when drainage (leaching) started and stopped, given the collection barrels were generally sampled only when there was at least c. 10 L of leachate.

Table 1. Dates when leachate collection started and stopped

	Year 1	Year 2	Year 3
Start date	3 January 2017	27 March 2018	17 April 2019
Stop date	28 November 2017	24 January 2019	7 November 2019

Nitrogen leaching from the four lucerne control lysimeters (3, 7, 12, 14,) showed much variability. Lysimeters 12 and 14 had a poor crop of lucerne that became weedy. Lysimeters 12 and 14 had greater TN leaching and took up less nitrogen into herbage compared with lysimeters 3 and 7. Thus lucerne control results are presented from lysimeters 3 and 7 only.

Total N concentration of cow and ewe lamb urine in grams per litre (g/L) is given in Table 2 below. In year 3, cow urine had to be collected over 2 days because the cows were drying off and insufficient urine was able to be collected on the first day. N loading rates, calculated from the urine concentration (Table 2) and wetted area of a urine patch, are shown in Table 3.

Table 2. Total N concentration (g/L) of cow and ewe lamb urine for Years 1–3

	Total N in cow urine (g/L)	Total N in ewe lamb urine (g/L)
Year 1	5.89	5.89
Year 2	7.05	2.44
Year 3#	4.30 (*Cow urine on lucerne)* 5.73 (*Cow urine on pasture)*	5.42

#As the cows were drying off, cow urine was collected over 2 days.

Table 3. Loading rate (kg N/ha) of cow and ewe lamb urine onto +urine lysimeters for Years 1–3

	Loading rate of cow urine (kg N/ha)	Loading rate of ewe lamb urine (kg N/ha)
Year 1	515	1031
Year 2	617	427
Year 3#	376 (*Cow urine on lucerne)* 501 (*Cow urine on pasture)*	949

#As the cows were drying off, cow urine had to be collected over 2 days.

Tables A1 to A3 in Appendix 1 show data for leachate collections between 2017 and 2019. On each leachate sampling date, the tables show litres of leachate collected, the cumulative volume of leachate since the beginning of the experiment expressed in pore volumes, and concentration of TN in the leachate (mg/L).

Tables A4 to A7 in Appendix 1 show calculated data for leachate collections between 2017 and 2019. For each year, the tables show TN leached (kg/ha) from lucerne or pasture lysimeters, their average, and their standard error of mean (SEM). They also show TN leaching (kg/ha) from a grazed lucerne or pasture paddock, their average, and SEM. These data are summarised in Table 4 and Figure 9.

The average amount of TN leached from each treatment of lysimeters ranged from c. 0.4 kg/ha for the lucerne control, which received no urine, to c. 56.4 kg/ha for cow urine applied to lucerne in the first year. Leaching from control pasture and lucerne lysimeters was significantly lower than for urine treatments in all years except for year 2 for ewe lamb urine (when only 525 ml was applied in the previous autumn as opposed to 2.1 litres for the following 2 years). There were no significant differences between urine treatments within years except the lucerne with cow urine treatment in year 1, which was significantly higher than the lucerne ewe lamb treatment. There were no significant differences in leaching between pasture and Lucerne vegetation when all years were combined.

Table 4. Average amount of total nitrogen leached (kg/ha) from lysimeter treatments on a yearly basis. Standard error of the mean is shown in parentheses. These numbers do not reflect the paddock-scale effect because only a small proportion of a paddock receives urine for a single grazing event

	Total nitrogen leached from lysimeters (kg/ha)				
	Lucerne +cow urine	Lucerne +ewe-lamb urine	Lucerne control	Pasture +cow urine	Pasture control
Year 1	56.4 (5.0)	20.4 (6.0)	2.1 (0.1)	27.9 (5.4)	4.1 (0.6)
Year 2	33.8 (12.0)	9.4 (4.5)	0.6 (0.2)	19.2 (6.4)	1.2 (0.6)
Year 3	21.5 (5.8)	23.9 (8.1)	0.4 (0.0)	47.4 (23.0)	1.0 (0.3)

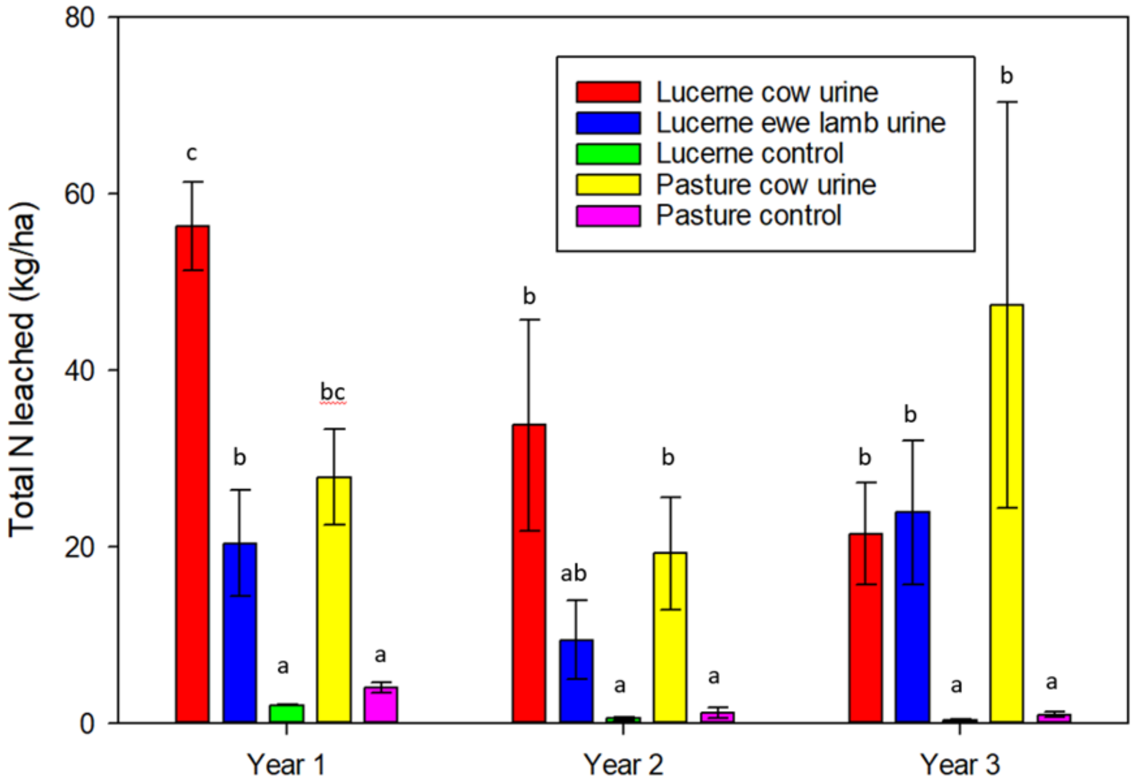

Figure 9. Average amount of total nitrogen leached (kg/ha) from lysimeter treatments on a yearly basis. Error bars show standard error of the mean. Different letters within each year denote differences (p<0.05) between treatments for that year. These numbers do not reflect the paddock-scale effect because only a small proportion of a paddock receives urine for a single grazing event.

The average annual amount of TN leached from each treatment expressed on a paddock basis assuming a single autumn grazing (with crop harvested via cutting at other times) ranged from c. 0.4 kg/ha for the lucerne control which received no urine to c. 4.9 kg/ha for cow urine applied to lucerne in the first year (Table 5 and Figure 10). In Year 1, for data expressed on a paddock scale there was no significant differences between the pasture control and the pasture and lucerne urine treatment but the non-grazed lucerne was significantly lower. In Years 2 and 3 there was no significant differences between urine treatments and controls expressed at the paddock scale, largely because the controls lysimeters accounted for 97% of the leaching when expressed at the paddock scale from a single autumn grazing

Table 5. Average amount of total nitrogen leached (kg/ha) from lysimeter treatments on a yearly paddock basis. Standard error of the mean is shown in parentheses. For one grazing urine patches are assumed to cover c. 3% of a paddock

	Lucerne +cow urine	Lucerne control	Pasture +cow urine	Pasture control
Year 1	3.9 (0.2)	2.1 (0.1)	4.9 (0.2)	4.1 (0.6)
Year 2	1.7 (0.4)	0.6 (0.2)	1.8 (0.2)	1.2 (0.6)
Year 3	1.1 (0.2)	0.4 (0.0)	2.6 (0.8)	1.0 (0.3)
Average	2.3	1.0	3.1	2.1

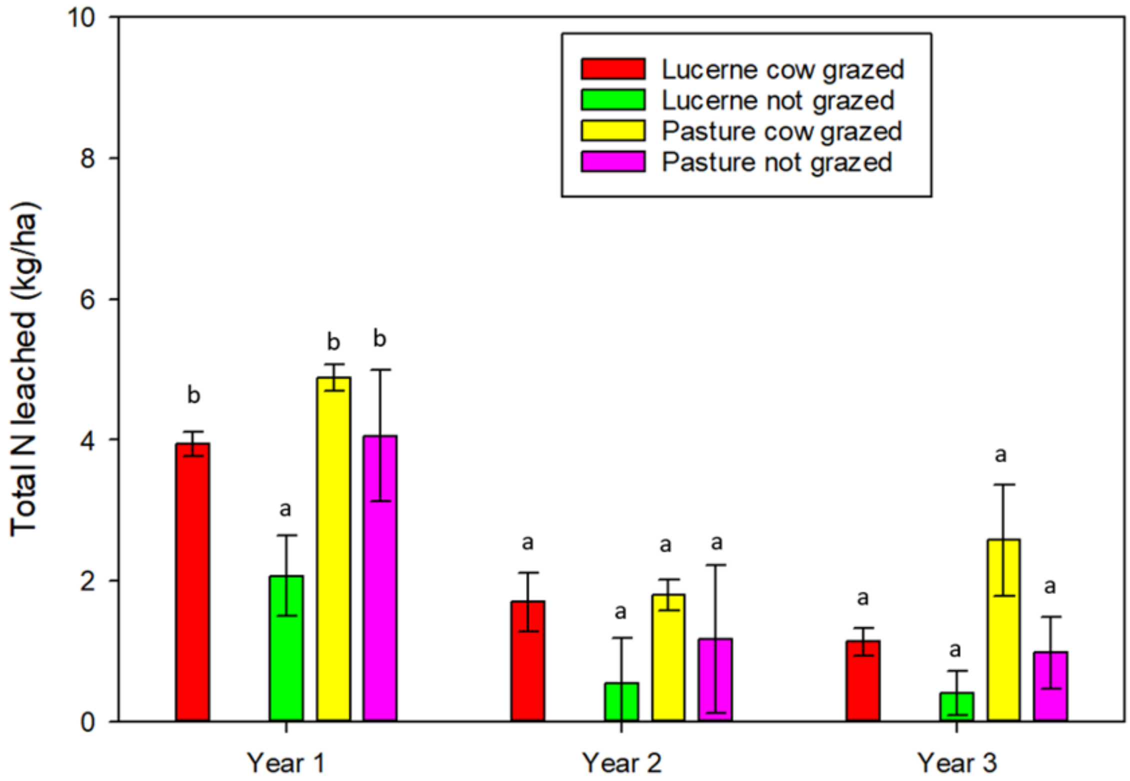

Figure 10. Total N leached (kg/ha) expressed on a grazed paddock basis. It is assumed urine patches for one grazing cover c.3% of a paddock. Error bars show standard error of the mean. Different letters within each year denote differences (p<0.05) between treatments within that year.

6 Discussion

Grazing of lucerne or pasture, simulated by the addition of urine from cows or ewe lambs to lysimeters increased the amount of TN leached from the soil compared to controls which did not receive urine. For example, for lucerne, a single autumn cow urine application to large lysimeters resulted in TN leaching of c. 56, 34, and 21 kg/ha for Years 1, 2, and 3 respectively compared to c. 2, 0.5, and 0.4 kg/ha for Years 1, 2, and 3 respectively for controls which did not receive urine. Leaching from urine treatments in this study were considerably lower than from other studies. For example, Welton et al. (2018) reported consistently large leaching losses of inorganic-N of >200 kg N/ha from a single application of cow urine in autumn from free-draining volcanic soil but using much smaller lysimeters. From a sandy loam developed in greywacke alluvium, Woods et al. (2016) also reported similarly high leaching losses. Both Welton et al. (2018) and Woods et al. (2016) acknowledge studying a deep-rooting crop of lucerne with 700-mm-deep lysimeters may have limited the ability of lucerne roots to intercept urine-N at depth > 700 mm. Our use of large lysimeters may explain the differences between this study and those of Welton et al. (2018) and Woods et al. (2016).

Quantitative measurement of leaching at paddock scale is problematic because of high spatial variation (Ledgard 1996; Lilburne et al. 2012). Although we used large barrel lysimeters in this study, scaling from the lysimeter to the paddock still requires several assumptions. Here we assume 20% annual urine patch coverage from grazing cows (Selbie et al. 2015) and 11 grazings per year (Moir et al. 2010), giving c. 3% urine patch coverage per grazing. Expressed on a grazed paddock basis, TN leached over the 3 years averaged c. 2.3, 1.0, 3.1, and 2.1 kg/ha for lucerne with cow urine, lucerne control, pasture with cow urine, and pasture control respectively. However, caution must be exercised when extrapolating leaching from an average of TN leached over the 3-year trial because more TN will be leached early in the trial as plant root systems are not fully developed and cultivation before sowing releases a pulse of nitrogen (McLeod 2015). Total nitrogen leaching declined each year for lucerne with cow urine. This likely occurred because deep lucerne roots became established and this did not happen in pasture where a dense root structure may not have established to the full depth of the lysimeter.

In Year 1, more TN was leached from lucerne with cow urine than lucerne with ewe lamb urine lysimeters (Fig. 9). This result was expected, as 2.1 L cow urine was applied compared with 0.525 L ewe lamb urine. In Year 2 the result was similar, although in this year 2.1 L ewe lamb urine was applied. Previous work (McLeod 2015) suggested it took approximately 1 year for surface events to appear in the leachate. By Year 3 the amount of TN in leachate from lucerne lysimeters treated with either cow or ewe lamb urine was similar.

Because the lysimeters were pre-leached, the soils within likely had greater water content than the surrounding soil on the farm and in part responded to rainfall with drainage rather than some initial rainfall satisfying soil water deficit. Furthermore, rainfall recorded at the Waikato Regional Council soil moisture monitoring station, about 50 m to the west, shows about 1,720 mm rainfall over the Year 1 leaching season, with 1,145 and 860 mm in Years 2 and 3 leaching seasons respectively (data not presented). We hypothesise that the cumulative load of TN leached in Year 1 was greater than if the soils had not been pre-leached and rainfall over each of the leaching seasons had been similar.

Conversion from pasture to either lucerne or pasture (both grazed simulated by the addition of urine from cows) revealed that in Year 1 more TN was leached from lucerne than pasture, though the difference was not significant ($p > 0.05$). The outcome expressed on a grazed paddock basis was similar in Year 2, although the values were lower and with no significant difference ($p > 0.05$). By Year 3, on average more TN leached from pasture lysimeters compared with lucerne lysimeters but the difference was not significant ($p > 0.05$) (Fig. 10).

Total nitrogen loading rates (Table 3) are within the ranges shown by either Selbie et al. (2015) or Haynes and Williams (1993). Differences are likely to be a function of the TN in the applied urine. Scaling up to kg/ha values on a grazed paddock basis for a ewe lamb urine patch is not attempted because of limited data on both the size (especially the effective area) of the sheep urine patch wetted area and on the number of ewe-lamb urine patches per hectare. Indeed, Selbie et al. (2015) suggest the values presented for sheep should be used with caution. Further caution should be exercised if scaling on a seasonal basis, as Pakrou and Dillion (1995) have shown lower TN in autumn cow urine compared with winter, spring and summer values.

Urine was applied to the lysimeters in autumn because autumn is thought to represent the greatest potential for leaching; plant nitrogen uptake slows and rainfall generally increases, while evapotranspiration decreases, potentially leading to increased leaching. We only applied urine to the +urine treatments yearly as more frequent application can result in "pre-priming", whereby frequent urine applications may stimulate plant uptake from the background nitrogen pool (Selbie et al. 2015).

Nitrogen in leachate from soils can be in the form of ammonium–N or nitrate–N. Animal urine generally contains large amounts of ammonium–N that this is converted by soil microbes to nitrate–N. Ammonium–N is positively charged and can be bound to soil particles, whereas nitrate–N is negatively charged, does not bind to soil particles as readily, and is leached by water moving through the soil. As we collected the leachate after it had passed through 1.5 m of soil, most of the nitrogen could be expected to be in the nitrate–N form, which was confirmed by analyses of the soil leachate. Note the analyses of the applied sheep and cow urine do contain large amounts of ammonium–N.

Remaining questions

Overseer® can accept N leaching losses on a seasonal basis. This study has revealed N leaching losses for an autumn application of urine only, but N losses from spring and summer urine applications and un-grazed winter N losses need to be investigated. Fresh lysimeters would need to be collected with four replicates for each season. Only one urine source (cows) needs to be considered, but four leaching seasons should be reported.

Finally, to complete the cycle we need to understand how much N is leached when deep rooted lucerne is sprayed with glyphosate and converted to the next crop. If the lysimeters at Tihoi were to be used for this work, they should be extracted, roots trimmed to the base of the lysimeter, and results reported for a depth of 1.5 m. This is because previous experience has shown that after 4 years lucerne roots have grown into (and potentially blocked) the collection funnel below the lysimeters.

7 Conclusions

A single autumn urine application (simulated grazing) significantly increased N leaching compared to controls, but no significant differences were found between pasture or lucerne vegetation.

When expressed at the paddock scale, assuming urine patches cover 3% of the paddock during a single autumn grazing, the three-year average was 2–3 kg TN/ha/yr (lucerne 2.3 kg/ha/yr TN, pasture 3.1 kg/ha/yr TN)

8 Recommendations

The total N leaching from one autumn grazing of lucerne by cows can be set to 2.3 kg TN/ha, assuming c. 3% urine patch coverage in an established lucerne crop.

So that Overseer® can process data for four seasons, we recommend further work with urine applications each season. If using the Tihoi facility, the work should be carried out over four not five leaching seasons. After five years, lucerne roots are likely to have grown into the leachate collection area, and thus will not mimic field-grown conditions.

To understand how much N is leached when deep rooted lucerne is sprayed with glyphosate and converted to the next crop, existing lysimeters could be sprayed with glyphosate and leachate TN measured for both pasture and lucerne.

9 Acknowledgements

Thanks to Mike and Sharon Barton for providing a continued overview of the site (and sustenance), to TLC (Inc.), LTPT, SFF and the Fertiliser Association of New Zealand for continued funding. Thanks for encouragement from Rob van Duivenboden, (Landcorp) and Prof. Derrick Moot (Lincoln University). The continued field assistance of Alexandra McGill, David Hunter, Pip Rhodes, and Jack Pronger is also appreciated, especially when collecting urine from behind cows. Bryan Stevenson undertook the statistical analysis. Jack Pronger provided much useful discussion and checking. Thanks to Colin Gates for facilitating collection of ewe lamb urine, and to Landcorp for facilitating collection of cow urine.

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Appendix 1 – Leachate data

Table A1. Lysimeter leachate volumes (L) for the 2017–2019 leaching seasons.
CL=cow urine on lucerne, EL=ewe urine on lucerne, LC=lucerne control, CP=cow urine on pasture, PC=pasture control

Date	Lysimeter number																			
	2CL	5CL	8CL	9CL	4EL	6EL	11EL	15EL	3LC	7LC	12LC	14LC	1CP	17CP	19CP	22CP	10PC	13PC	20PC	21PC
3-Jan-17	23.15	10.50	22.45	23.15	24.15	19.55	20.95	31.95	16.60	8.60	16.70	31.45	21.85	26.50	26.25	22.65	21.65	25.35	28.85	25.28
7-Feb-17	8.60	2.50	6.30	7.10	4.40	1.50	5.70	10.40	2.50	5.50	1.20	12.80	3.20	6.10	10.50	7.00	3.60	4.70	8.80	4.30
7-Mar-17	16.40	4.10	7.00	4.40	3.10	1.00	1.60	12.60	6.80	6.80	1.80	11.90	5.50	3.75	17.10	16.00	3.60	9.10	3.10	0.80
30-Mar-17	42.34	38.57	39.27	42.04	46.04	35.17	33.77	47.14	37.37	54.24	38.37	47.10	56.90	48.20	54.84	53.84	56.90	61.31	44.44	45.44
14-Apr-17	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00	80.00
3-May-17	53.54	58.24	55.04	57.84	80.00	50.64	55.34	57.94	54.84	51.09	50.84	57.04	59.84	64.51	57.84	50.74	56.91	66.61	61.11	62.31
13-May-17	37.27	29.02	43.69	38.47	22.87	40.84	43.54	21.47	42.64	38.17	38.07	41.59	40.36	21.97	34.67	30.77	43.14	41.74	21.67	37.77
26-May-17	53.74	59.34	53.84	60.71	77.01	53.44	57.14	58.14	56.84	56.64	51.34	56.14	59.54	60.81	53.64	53.64	59.64	64.11	59.34	60.04
6-Jun-17	20.77	18.80	21.87	20.87	25.17	20.47	22.97	23.17	18.30	19.00	18.70	22.97	20.97	20.77	20.17	16.90	21.10	22.17	20.47	20.57
21-Jun-17	15.20	8.70	15.90	14.00	16.70	13.80	16.40	17.80	14.40	11.30	12.60	17.40	15.70	13.90	14.50	10.90	15.10	15.60	15.50	14.80
5-Jul-17	38.97	25.37	38.97	32.77	29.37	35.17	38.27	38.57	40.34	38.47	34.27	38.77	37.17	45.74	34.57	31.67	43.74	40.84	33.77	37.27
19-Jul-17	30.37	28.67	30.57	33.27	41.04	30.67	32.27	33.07	24.37	28.27	28.67	32.87	33.67	35.07	32.97	31.67	31.67	35.97	32.87	30.17
25-Jul-17	45.74	38.67	44.84	42.14	20.47	43.34	44.64	44.94	42.54	43.04	43.04	45.64	46.04	46.24	41.34	41.04	47.34	45.64	41.14	43.84
15-Aug-17	44.14	36.37	42.34	43.71	54.14	41.74	43.04	45.44	40.34	38.97	39.27	45.94	44.94	46.04	42.94	32.77	45.14	47.84	43.94	45.44
25-Aug-17	45.24	40.74	44.74	43.44	45.54	44.44	45.64	45.94	43.04	43.74	44.04	45.84	47.94	48.24	44.34	37.97	48.44	48.64	44.04	46.24
4-Sep-17	23.57	19.40	23.77	21.27	25.57	23.07	23.97	24.87	21.77	21.07	20.87	24.67	25.37	25.17	23.17	17.30	25.27	26.27	23.57	24.77
14-Sep-17	51.94	46.04	52.94	45.74	41.24	48.94	51.24	51.34	50.44	48.84	49.24	52.94	53.04	53.54	49.94	44.24	53.74	54.64	50.44	52.04
2-Oct-17	42.84	37.67	45.94	39.57	56.34	41.54	46.04	45.54	44.44	40.34	39.37	47.04	49.54	48.44	43.84	34.87	49.34	53.24	47.04	47.54

Date	Lysimeter number																			
	2CL	5CL	8CL	9CL	4EL	6EL	11EL	15EL	3LC	7LC	12LC	14LC	1CP	17CP	19CP	22CP	10PC	13PC	20PC	21PC
30-Oct-17	43.74	30.17	44.54	35.87	43.74	35.87	41.14	46.04	36.27	33.37	35.97	47.84	47.24	42.54	39.37	28.37	44.84	47.64	42.84	42.54
28-Nov-17	8.70	0.31	4.10	0.60	3.00	2.10	3.30	9.50	0.10	0.03	0.55	10.80	7.50	4.30	4.10	0.70	6.00	8.50	9.30	7.60
27-Mar-18	8.70	6.10	0.00	4.10	12.80	9.80	0.00	36.67	0.00	0.00	2.60	31.82	16.20	7.80	0.00	18.20	22.37	29.47	19.50	12.50
18-Apr-18	5.50	8.70	0.00	12.70	10.60	16.40	5.00	15.20	4.20	0.00	3.40	14.70	12.80	7.00	2.10	5.50	17.20	0.00	10.80	8.20
21-May-18	77.91	77.91	50.54	77.91	77.91	77.91	77.91	77.91	77.91	53.34	77.91	77.91	77.91	77.91	77.91	77.91	77.91	77.91	77.91	77.91
7-Jun-18	58.84	60.24	58.74	60.34	60.51	61.91	61.21	60.04	58.34	39.37	57.34	61.91	63.41	60.91	57.54	56.84	63.21	42.04	60.51	60.51
27-Jun-18	51.34	57.44	58.54	55.54	64.91	57.74	57.84	59.64	57.94	39.07	51.74	56.94	59.54	58.44	52.54	53.64	57.74	65.90	55.74	56.74
12-Jul-18	34.27	34.57	32.77	34.97	28.77	36.17	36.87	34.97	30.87	23.17	33.07	37.77	35.57	30.67	30.37	29.87	34.17	33.67	35.47	34.37
3-Aug-18	39.17	43.24	44.84	40.74	49.54	42.74	44.24	45.44	43.94	32.57	36.87	42.84	45.24	44.14	36.57	38.67	42.34	49.04	42.34	43.04
30-Aug-18	67.01	56.04	67.71	66.91	61.41	48.24	70.91	70.51	61.41	56.54	62.61	71.51	71.51	65.41	60.84	62.21	71.81	73.31	63.11	64.91
14-Sep-18	30.87	30.47	31.47	31.37	33.27	31.57	31.57	33.37	31.47	21.57	27.67	33.17	32.07	30.47	26.87	27.87	31.17	34.47	30.67	31.87
12-Oct-18	13.30	7.00	10.50	6.30	9.20	8.00	8.20	14.40	4.40	0.35	4.10	13.70	5.20	5.70	3.40	5.10	5.30	6.40	9.70	7.80
24-Jan-19	17.60	17.20	0.00	15.30	25.87	6.90	0.00	24.87	8.80	8.30	10.10	20.17	0.00	0.00	0.00	4.50	11.40	16.50	4.70	15.90
17-Apr-19	1.80	0.50	0.00	0.00	1.70	0.90	0.30	3.10	0.00	0.00	0.00	2.20	0.00	0.30	0.00	1.30	1.20	1.40	0.80	1.40
24-Jun-19	35.17	43.94	0.55	24.67	35.54	46.34	11.00	55.74	16.90	11.20	49.74	36.17	23.47	19.60	38.67	21.07	55.24	54.54	32.47	48.84
18-Jul-19	79.16	79.16	79.16	79.16	79.16	79.16	79.16	79.16	79.16	79.16	79.16	79.16	79.16	79.16	79.16	66.86	79.16	79.16	79.16	79.16
2-Aug-19	39.37	41.34	45.24	37.27	43.74	39.27	43.64	43.44	38.47	25.07	41.04	41.84	45.04	45.14	37.27	21.17	42.74	46.44	37.17	42.74
15-Aug-19	44.54	48.14	47.64	47.84	38.67	49.74	50.34	49.84	48.64	34.37	51.74	52.04	53.94	51.44	44.44	33.47	53.54	53.54	45.94	51.94
6-Sep-19	40.27	21.17	43.84	39.17	47.04	39.97	43.64	44.44	34.57	17.20	41.64	42.74	42.74	42.14	35.67	14.20	40.69	44.74	36.87	43.54
12-Oct-19	54.34	34.60	56.50	53.70	47.90	53.90	55.90	57.80	49.34	21.17	59.84	59.34	58.64	58.64	48.90	13.00	58.64	60.51	43.60	60.80
7-Nov-19	23.17	13.20	20.67	18.30	20.17	24.87	22.97	26.87	20.77	2.60	30.17	29.77	32.27	31.07	25.37	4.00	32.97	31.67	23.97	32.87

Table A2. Lysimeter cumulative leachate volumes for the 2017–2019 leaching seasons expressed in pore volumes.
CL=cow urine on lucerne, EL=ewe urine on lucerne, LC=lucerne control, CP=cow urine on pasture, PC=pasture control. One pore volume equals 648 L

Date	Lysimeter number																			
	2CL	5CL	8CL	9CL	4EL	6EL	11EL	15EL	3LC	7LC	12LC	14LC	1CP	17CP	19CP	22CP	10PC	13PC	20PC	21PC
3-Jan-17	0.04	0.02	0.03	0.04	0.03	0.03	0.03	0.05	0.03	0.01	0.03	0.05	0.03	0.04	0.04	0.03	0.03	0.04	0.04	0.04
7-Feb-17	0.05	0.02	0.04	0.05	0.04	0.03	0.04	0.07	0.03	0.02	0.03	0.07	0.04	0.05	0.06	0.05	0.04	0.05	0.06	0.05
7-Mar-17	0.07	0.03	0.06	0.05	0.05	0.03	0.04	0.08	0.04	0.03	0.03	0.09	0.05	0.06	0.08	0.07	0.04	0.06	0.06	0.05
30-Mar-07	0.14	0.09	0.12	0.12	0.12	0.09	0.10	0.16	0.10	0.12	0.09	0.16	0.13	0.13	0.17	0.15	0.13	0.16	0.13	0.12
14-Apr-17	0.26	0.21	0.24	0.24	0.24	0.21	0.22	0.28	0.22	0.24	0.21	0.28	0.26	0.25	0.29	0.28	0.26	0.28	0.25	0.24
3-May-17	0.35	0.30	0.32	0.33	0.37	0.29	0.30	0.37	0.31	0.32	0.29	0.37	0.35	0.35	0.38	0.36	0.34	0.38	0.35	0.34
13-May-07	0.40	0.34	0.39	0.39	0.40	0.35	0.37	0.40	0.37	0.38	0.35	0.44	0.41	0.39	0.43	0.40	0.41	0.45	0.38	0.39
26-May-07	0.49	0.44	0.47	0.48	0.52	0.44	0.46	0.49	0.46	0.46	0.43	0.52	0.50	0.48	0.52	0.49	0.50	0.54	0.47	0.49
6-Jun-17	0.52	0.46	0.51	0.52	0.56	0.47	0.50	0.53	0.49	0.49	0.46	0.56	0.54	0.51	0.55	0.51	0.53	0.58	0.51	0.52
21-Jun-17	0.54	0.48	0.53	0.54	0.59	0.49	0.52	0.56	0.51	0.51	0.48	0.58	0.56	0.53	0.57	0.53	0.56	0.60	0.53	0.54
5-Jul-17	0.60	0.52	0.59	0.59	0.63	0.54	0.58	0.62	0.57	0.57	0.53	0.64	0.62	0.61	0.62	0.58	0.63	0.67	0.58	0.60
19-Jul-17	0.65	0.56	0.64	0.64	0.69	0.59	0.63	0.67	0.61	0.61	0.57	0.69	0.67	0.66	0.67	0.63	0.67	0.72	0.63	0.65
25-Jul-17	0.72	0.62	0.71	0.70	0.73	0.66	0.70	0.74	0.68	0.68	0.64	0.76	0.74	0.73	0.74	0.69	0.75	0.79	0.70	0.71
15-Aug-07	0.79	0.68	0.77	0.77	0.81	0.72	0.76	0.81	0.74	0.74	0.70	0.84	0.81	0.80	0.80	0.74	0.82	0.87	0.76	0.78
25-Aug-07	0.86	0.74	0.84	0.84	0.88	0.79	0.84	0.88	0.80	0.81	0.77	0.91	0.89	0.88	0.87	0.80	0.89	0.94	0.83	0.86
4-Sep-17	0.89	0.77	0.88	0.87	0.92	0.83	0.87	0.92	0.84	0.84	0.80	0.94	0.92	0.92	0.91	0.83	0.93	0.98	0.87	0.89
14-Sep-17	0.97	0.84	0.96	0.94	0.98	0.90	0.95	1.00	0.92	0.92	0.88	1.03	1.01	1.00	0.99	0.89	1.01	1.07	0.95	0.97
2-Oct-17	1.04	0.90	1.03	1.00	1.07	0.97	1.02	1.07	0.98	0.98	0.94	1.10	1.08	1.07	1.05	0.95	1.09	1.15	1.02	1.05
30-Oct-17	1.11	0.95	1.10	1.06	1.14	1.02	1.09	1.14	1.04	1.03	0.99	1.17	1.16	1.14	1.11	0.99	1.16	1.22	1.08	1.11
28-Nov-07	1.12	0.95	1.11	1.06	1.14	1.02	1.09	1.15	1.04	1.03	1.00	1.19	1.17	1.14	1.12	0.99	1.17	1.23	1.10	1.12

Date	Lysimeter number																			
	2CL	**5CL**	**8CL**	**9CL**	**4EL**	**6EL**	**11EL**	**15EL**	**3LC**	**7LC**	**12LC**	**14LC**	**1CP**	**17CP**	**19CP**	**22CP**	**10PC**	**13PC**	**20PC**	**21PC**
27-Mar-18	1.13	0.96	1.11	1.07	1.16	1.04	1.09	1.21	1.04	1.03	1.00	1.24	1.19	1.16	1.12	1.02	1.20	1.28	1.13	1.14
18-Apr-18	1.14	0.97	1.11	1.09	1.18	1.06	1.10	1.23	1.05	1.03	1.00	1.26	1.21	1.17	1.12	1.03	1.23	1.28	1.15	1.16
21-May-18	1.26	1.09	1.19	1.21	1.30	1.18	1.22	1.35	1.17	1.11	1.12	1.38	1.33	1.29	1.24	1.15	1.35	1.40	1.27	1.28
7-Jun-18	1.35	1.18	1.28	1.30	1.39	1.28	1.31	1.44	1.26	1.17	1.21	1.48	1.43	1.38	1.33	1.24	1.45	1.47	1.36	1.37
27-Jun-18	1.43	1.27	1.37	1.39	1.49	1.37	1.40	1.54	1.35	1.23	1.29	1.56	1.52	1.47	1.41	1.32	1.54	1.57	1.45	1.46
12-Jul-18	1.49	1.32	1.42	1.44	1.54	1.42	1.46	1.59	1.39	1.27	1.34	1.62	1.58	1.52	1.46	1.37	1.59	1.62	1.50	1.51
3-Aug-18	1.55	1.39	1.49	1.50	1.61	1.49	1.53	1.66	1.46	1.32	1.40	1.69	1.65	1.59	1.52	1.43	1.65	1.69	1.57	1.58
30-Aug-08	1.65	1.48	1.59	1.61	1.71	1.57	1.64	1.77	1.56	1.41	1.50	1.80	1.76	1.69	1.61	1.52	1.77	1.81	1.66	1.68
14-Sep-18	1.70	1.52	1.64	1.65	1.76	1.61	1.69	1.82	1.60	1.44	1.54	1.85	1.81	1.74	1.65	1.56	1.81	1.86	1.71	1.73
12-Oct-18	1.72	1.54	1.66	1.66	1.77	1.63	1.70	1.84	1.61	1.44	1.55	1.87	1.81	1.74	1.66	1.57	1.82	1.87	1.73	1.74
24-Jan-19	1.75	1.56	1.66	1.69	1.81	1.64	1.70	1.88	1.63	1.45	1.56	1.90	1.81	1.74	1.66	1.58	1.84	1.90	1.73	1.76
17-Apr-19	1.75	1.56	1.66	1.69	1.82	1.64	1.70	1.89	1.63	1.45	1.56	1.91	1.81	1.74	1.66	1.58	1.84	1.90	1.73	1.77
24-Jun-19	1.80	1.63	1.66	1.73	1.87	1.71	1.72	1.97	1.65	1.47	1.64	1.96	1.85	1.77	1.72	1.61	1.93	1.98	1.78	1.84
18-Jul-19	1.92	1.75	1.78	1.85	1.99	1.83	1.84	2.09	1.77	1.59	1.76	2.08	1.97	1.90	1.84	1.72	2.05	2.10	1.91	1.96
2-Aug-19	1.98	1.82	1.85	1.90	2.06	1.89	1.91	2.16	1.83	1.63	1.82	2.15	2.04	1.97	1.90	1.75	2.11	2.18	1.96	2.03
15-Aug-19	2.05	1.89	1.92	1.98	2.12	1.97	1.98	2.24	1.91	1.68	1.90	2.23	2.13	2.05	1.97	1.80	2.20	2.26	2.03	2.11
6-Sep-19	2.12	1.92	1.99	2.04	2.19	2.03	2.05	2.31	1.96	1.71	1.97	2.30	2.19	2.11	2.02	1.82	2.26	2.33	2.09	2.18
12-Oct-19	2.20	1.98	2.08	2.12	2.27	2.11	2.14	2.40	2.04	1.74	2.06	2.39	2.28	2.20	2.10	1.84	2.35	2.42	2.16	2.27
7-Nov-19	2.24	2.00	2.11	2.15	2.30	2.15	2.17	2.44	2.07	1.75	2.11	2.43	2.33	2.25	2.14	1.85	2.40	2.47	2.20	2.32

Table A3. Total nitrogen content of the leachate (mg/L) for the 2017–2019 leaching seasons.
CL=cow urine on lucerne, EL=ewe urine on lucerne, LC=lucerne control, CP=cow urine on pasture, PC=pasture control

Date	Lysimeter number																			
	2CL	5CL	8CL	9CL	4EL	6EL	11EL	15EL	3LC	7LC	12LC	14LC	1CP	17CP	19CP	22CP	10PC	13PC	20PC	21PC
3-Jan-17	0.34	0.12	0.19	0.22	0.20	0.18	0.14	0.27	0.10	0.33	0.85	0.19	0.77	0.67	0.82	0.13	0.22	0.25	0.23	0.10
7-Feb-17	0.41	0.12	0.20	0.19	1.45	0.71	0.31	0.40	0.17	3.84	1.12	0.27	0.53	0.37	0.95	0.15	0.29	0.41	0.30	0.17
7-Mar-17	0.28	0.13	0.30	0.11	1.80	0.39	0.78	0.56	0.81	0.81	1.57	0.28	0.53	0.53	1.11	0.13	0.56	0.55	0.41	0.25
30-Mar-17	0.27	0.13	0.21	0.11	0.89	0.35	1.65	0.58	0.23	0.55	1.12	0.24	0.40	0.40	0.92	0.16	0.32	0.57	0.27	0.20
14-Apr-17	0.60	0.35	0.38	0.99	0.98	0.93	0.69	1.06	0.27	0.55	1.46	0.52	0.63	0.72	1.19	0.25	0.33	0.50	0.45	0.49
3-May-17	1.24	0.44	0.41	0.43	1.13	0.63	0.26	1.06	0.27	0.14	1.81	0.56	0.83	0.94	1.83	0.16	0.23	0.34	0.32	0.47
13-May-17	1.23	0.61	0.79	0.65	1.16	1.14	1.04	1.39	0.23	0.19	2.05	0.86	0.75	0.89	1.56	0.22	0.25	0.24	0.38	0.68
26-May-17	1.54	0.69	0.80	0.73	1.16	0.78	0.32	1.19	0.21	0.11	2.42	0.94	0.58	0.79	1.97	0.31	0.25	0.27	0.39	0.56
6-Jun-17	2.04	0.82	0.99	0.91	1.13	0.83	0.31	1.26	0.20	0.09	2.64	1.05	0.55	0.73	2.21	0.36	0.21	0.25	0.45	0.50
21-Jun-17	2.21	0.87	1.05	1.04	1.16	0.90	0.31	1.41	0.17	0.09	2.85	1.15	0.53	0.75	2.20	0.41	0.20	0.27	0.51	0.51
5-Jul-17	2.38	0.92	1.35	1.27	1.23	1.21	0.50	1.61	0.16	0.07	2.88	1.25	0.52	0.77	2.00	0.47	0.15	0.24	0.57	0.53
19-Jul-17	2.99	0.98	1.40	1.43	1.31	1.21	0.25	1.59	0.13	0.08	2.84	1.30	0.55	1.13	2.21	0.51	0.11	0.24	0.52	0.46
25-Jul-17	3.36	1.57	1.93	2.08	2.20	1.54	0.35	1.66	0.13	0.06	2.79	1.47	0.83	1.95	2.05	0.68	0.42	0.24	0.50	0.46
15-Aug-17	4.53	3.44	2.50	2.26	2.06	1.61	0.25	1.75	0.14	0.10	2.63	1.61	1.52	3.49	2.46	0.93	0.09	0.24	0.46	0.44
25-Aug-17	5.77	8.70	3.89	4.20	3.15	2.12	0.26	2.31	0.11	0.08	2.51	1.56	2.88	4.95	2.85	1.21	0.08	0.23	0.39	0.38
4-Sep-17	7.43	15.90	5.76	5.87	3.38	2.41	0.26	3.34	0.08	0.05	2.38	1.47	4.85	6.05	3.21	1.52	0.06	0.23	0.35	0.36
14-Sep-17	10.25	24.29	11.56	11.24	3.68	3.58	0.56	6.70	0.08	0.03	2.31	1.57	8.20	7.50	3.84	2.64	0.04	0.20	0.33	0.33
2-Oct-17	16.16	29.12	18.09	15.54	3.31	3.86	0.98	9.17	0.13	0.04	2.19	1.50	9.32	8.96	5.22	4.92	0.04	0.18	0.29	0.30
30-Oct-17	20.94	27.30	21.48	19.94	3.00	3.50	1.04	10.61	0.11	0.10	2.08	1.74	6.14	10.71	8.35	8.14	0.19	0.26	0.45	0.41
28-Nov-17	25.56	27.50	22.64	26.24	2.06	0.27	0.27	11.10	0.26	1.01	2.37	1.60	0.73	14.09	13.45	9.20	0.18	0.37	0.36	0.45

Date	Lysimeter number																			
	2CL	5CL	8CL	9CL	4EL	6EL	11EL	15EL	3LC	7LC	12LC	14LC	1CP	17CP	19CP	22CP	10PC	13PC	20PC	21PC
27-Mar-18	24.58	21.58	0.00	17.59	0.15	0.20	0.00	5.43	0.00	0.00	0.24	0.29	0.33	8.76	0.00	9.88	0.20	0.50	0.10	0.23
18-Apr-18	21.39	16.26	0.00	9.53	0.89	0.30	0.44	1.78	0.23	0.00	0.21	0.46	0.28	2.21	16.46	8.86	0.14	0.49	0.10	0.16
21-May-18	15.12	9.03	0.17	6.24	0.16	0.16	0.14	1.94	0.19	0.15	0.19	0.22	0.17	0.47	9.69	6.74	0.15	0.27	0.13	0.18
7-Jun-18	12.60	3.86	0.12	3.60	0.35	0.12	0.06	1.52	0.12	0.11	0.07	0.10	0.14	0.11	8.80	3.68	0.11	0.20	0.03	0.06
27-Jun-18	9.71	1.87	0.10	2.08	0.57	0.22	0.06	1.18	0.05	0.08	0.07	0.14	0.15	0.10	6.05	1.80	0.04	0.52	0.03	0.04
12-Jul-18	7.00	1.34	0.13	1.09	0.83	0.46	0.08	1.23	0.07	0.06	0.10	0.24	0.16	0.15	4.50	0.78	0.05	0.80	0.04	0.05
3-Aug-18	6.23	1.30	0.14	0.85	1.23	1.09	0.07	1.50	0.10	0.07	0.14	0.44	0.28	0.19	3.12	0.45	0.06	0.76	0.15	0.05
30-Aug-18	5.09	2.00	1.45	1.28	1.89	3.34	0.09	2.94	0.13	0.05	0.22	1.09	5.60	0.28	2.21	0.15	0.03	0.45	0.03	0.03
14-Sep-18	5.76	7.18	8.44	3.92	1.93	5.80	0.35	6.47	0.10	0.03	0.26	1.75	21.53	0.61	2.27	0.20	0.02	0.20	0.03	0.02
12-Oct-18	7.84	15.80	16.12	5.82	1.96	6.74	0.80	10.39	0.06	0.15	0.29	1.20	26.72	1.28	3.49	0.60	0.06	0.16	0.05	0.05
24-Jan-19	7.14	23.35	0.00	4.94	1.75	0.60	0.00	4.38	0.07	0.10	0.07	0.11	0.00	0.00	0.00	2.76	0.18	0.23	0.10	0.09
17-Apr-19	5.90	29.58	0.00	0.00	1.22	0.33	12.94	0.23	0.00	0.00	0.00	0.13	0.00	13.05	2.63	0.00	1.70	0.53	1.68	3.69
24-Jun-19	0.38	6.52	7.96	0.07	0.08	0.08	1.17	0.06	0.04	0.10	0.03	0.07	8.30	0.34	12.12	4.90	0.06	0.13	0.07	0.06
18-Jul-19	2.20	5.74	0.20	0.19	0.24	1.78	0.41	0.27	0.15	0.26	0.15	0.18	6.86	0.18	19.85	10.96	0.16	0.22	0.15	0.17
2-Aug-19	4.21	4.64	0.10	0.27	1.33	3.57	0.13	0.43	0.07	0.07	0.12	0.10	1.78	0.28	27.14	11.57	2.01	0.14	0.14	0.15
15-Aug-19	5.53	3.58	0.30	0.43	6.21	5.95	0.39	3.52	0.04	0.04	0.05	0.05	0.97	0.53	27.15	8.51	0.04	0.07	0.05	0.04
6-Sep-19	7.98	3.84	4.46	0.71	6.21	8.91	0.08	9.19	0.05	0.06	0.06	0.08	4.68	1.44	25.60	6.83	0.05	0.09	0.05	0.05
12-Oct-19	11.01	8.59	14.29	2.32	7.44	13.57	0.89	18.13	0.05	0.05	0.06	0.08	14.03	4.24	23.72	6.43	0.07	0.11	0.05	0.08
7-Nov-19	13.20	13.70	18.70	4.60	9.44	14.30	2.99	28.00	0.06	0.12	0.09	0.10	15.80	7.65	23.70	8.58	0.09	0.11	0.12	0.18

Table A4. Total nitrogen in leachate from lucerne lysimeters (kg/ha), average and standard error of mean (SEM) for the 2017–2019 leaching seasons. CL=cow urine on lucerne, EL=ewe urine on lucerne, LC=lucerne control

Year	Lysimeter number															
	3LC	7LC	Average	SEM	4EL	6EL	11EL	15EL	Average	SEM	2CL	5CL	8CL	9CL	Average	SEM
Year 1	1.99	2.14	2.07	0.08	22.06	17.54	6.52	35.52	20.41	6.00	60.56	67.25	53.86	43.76	56.36	5.01
Year 2	0.71	0.38	0.55	0.16	6.74	8.31	0.82	21.89	9.44	4.45	65.47	37.19	9.28	23.10	33.76	12.01
Year 3	0.37	0.44	0.40	0.04	19.09	33.31	3.23	39.91	23.89	8.14	30.17	27.60	23.47	4.66	21.48	5.77

Table A5. Total nitrogen in leachate from pasture lysimeters (kg/ha), average and standard error of mean (SEM) for the 2017–2019 leaching seasons. CP=cow urine on pasture, PC=pasture control

Year	Lysimeter number											
	1CP	17CP	19CP	22CP	Average	SEM	10PC	13PC	20PC	21PC	Average	SEM
Year 1	30.04	38.17	30.83	12.55	27.90	5.43	2.50	3.99	4.63	5.10	4.06	0.57
Year 2	21.19	3.12	34.06	18.58	19.24	6.35	0.60	3.07	0.46	0.53	1.16	0.64
Year 3	39.53	10.06	113.99	25.99	47.39	23.00	1.89	0.82	0.48	0.70	0.97	0.31

Table A6. Total nitrogen leaching (kg/ha), from a grazed lucerne paddock average and standard error of mean (SEM) with one autumn urine application (we assume c. 3% urine patch coverage) for the 2017–2019 leaching seasons.
CL=cow urine on lucerne, LC=lucerne control

Year	Lysimeter number									
	3LC	7LC	Average	SEM	2CL	5CL	8CL	9CL	Average	SEM
Year 1	1.99	2.14	2.07	0.08	4.08	4.31	3.85	3.50	3.94	0.17
Year 2	0.71	0.38	0.55	0.16	2.79	1.81	0.85	1.33	1.69	0.41
Year 3	0.37	0.44	0.40	0.04	1.43	1.34	1.2	0.55	1.13	0.20

Table A7. Total nitrogen leaching (kg/ha), from a grazed pasture paddock, average and standard error of mean (SEM) with one autumn urine application (we assume c. 3% urine patch coverage) for the 2017–2019 leaching seasons.
CP=cow urine on pasture, PC=pasture control

Year	Lysimeter number											
	1CP	17CP	19CP	22CP	Average	SEM	10PC	13PC	20PC	21PC	Average	SEM
Year 1	4.95	5.23	4.98	4.35	4.88	0.19	2.50	3.99	4.63	5.10	4.06	0.57
Year 2	1.86	1.23	2.30	1.76	1.79	0.22	0.60	3.07	0.46	0.53	1.16	0.64
Year 3	2.30	1.29	4.87	1.84	2.57	0.79	1.89	0.82	0.48	0.70	0.97	0.31