# Novel methods for estimating urinary N production from two contrasting dairy systems

Mark Shepherd[1], Diana Selbie[1], Gina Lucci[1], Paul Shorten[1], Maryann Pirie[1], Brendon Welten[1], Kevin Macdonald[2], Chris Roach[2] & Chris Glassey[2]

[1] AgResearch Ltd., Ruakura Research Centre, Private Bag 3123, Hamilton 3240, New Zealand, mark.shepherd@agresearch.co.nz
[2] DairyNZ Ltd., Private Bag 3221, Hamilton 3240, New Zealand

**Abstract**
Two demonstration farmlets representing the grazed pasture component of contrasting dairy systems were established in 2011 in the Waikato region of New Zealand to compare production, profitability and mineral nitrogen (N) leaching risk. The farmlets ran for four seasons and differed in: annual N fertiliser input (c. 150 vs. c. 50 kg N/ha), with stocking rate adjusted to available feed (3.2 vs. 2.6 cow/ha); and also in hours grazed during autumn and winter. We report on three methods for estimating urinary N production from the systems, which is the primary source of N leaching from grazed paddocks. We compared a herd N balance calculation and two novel methods: direct measurement of the urine patch N immediately after voiding onto the soil and urine sensors which, when attached to the cow, provide real-time measurements of urine production over a 24 hour period. The three methods differed in temporal and spatial scale of measurement but produced consistent conclusions. The low N system generated 19% less urine per ha as a mean of the three measurement methods but the same amount of urine N per cow. When cows in the low N system were removed onto a 'stand-off' pad for 6 hours per day, the urine sensors estimated a further 23% decrease in daily urine deposition directly on paddock. Using a combination of methods provides insight into N flows through complex farm systems.

**Key Words**
Nitrate leaching, dairy, nitrogen balance, urine sensors

**Introduction**
Nitrogen (N) leaching increases from pastoral production systems as N inputs increase (e.g. Ledgard et al., 2009). With concern over the implications of dairy farming on water quality in some New Zealand catchments, a joint government-industry funded Research and Development programme ('Pastoral 21') was established to provide farmers with options and production systems that aim to maintain profitability and decrease nutrient losses to water (Chapman et al., 2012). As a part of that programme, two small scale systems (farmlets) were established in the Waikato region in 2011 and have been monitored over four lactation seasons. The systems were designed using farm systems models (Burggraaf et al., 2011) and represented the Waikato region's typical system ('Current') with a system designed to decrease mineral N leaching by 30-40% while maintaining the same level of profitability ('Future'). Production and economic data have been collected and direct measurements of N leaching have been made and are currently being evaluated and reported. However, paddock measurements of N leaching only test the aggregated effect of the combined management interventions. Urinary N is the main driver of N leaching in grazed pasture (Oenema et al., 2005). Therefore, we also estimated urine N production to test hypotheses established by modelling during the farm system design. Namely, that: c. 20% less urine would be produced in the low input system due to less feed grown and eaten; and that standing cows off would further decrease urine voided directly on pasture. Furthermore, we wanted to test if there were differences between the two herds in terms of urine N production characteristics such as N per urination event. Two novel methods (urine patch soil sampling and urine sensors fitted to cows) were compared with estimates of a monthly 'herd N balance', used as a surrogate for N excretion.

**Methods**
The farmlets were based at DairyNZ's Scott Farm in Hamilton, New Zealand, with an average annual rainfall of 1250 mm. The management details of the two systems are summarised in Table 1. More detail is provided by Chapman et al. (2012). The main interventions to meet N leaching and profit goals in the Future system were: decreased fertiliser N input; lower stocking rate to meet the reduced feed supply but increased milk production per cow; and cows removed from pasture for 6-16 hours per day during March-July. The farmlets represented the 'dairy platform' (i.e. only the pasture area used for grazing lactating cows). Twenty six 0.5 ha paddocks were allocated to each system. Pastures on each farmlet were mainly AR37 perennial

ryegrass/white clover base with some Advance MaxP (tall fescue) paddocks used. Soil-types were a mix of alluvial silt loams, peaty silt loams and humic silt loams and the farmlets were matched for soil-type by splitting in paddocks in half to generate paired replicates.

**Table 1. Treatment details for Current and Future farmlets.**

| Treatment/Management options | Current | Future |
|---|---|---|
| Stocking rate (cows/ha) | 3.2 | 2.6 |
| N fertiliser (kg N/ha/year) | Up to 150 | Up to 50 |
| Dairy effluent (% of farm/ kg N/ha/year) | 23/9 | 50/19 |
| Cow BW/PW* | 90/75 | 170/240 |
| Cow liveweight (kg) | 500 | 480 |
| Standoff/restrict grazing | None | Mar-Jul |
| Grain purchased (kg DM/cow) | 0 | Up to 400 |
| Area (ha)/Cows | 13/42 | 13/34 |

* as selected on 18 May 2011; BW=breeding worth, PW=production worth

*Nitrogen balance*

A monthly herd N surplus (assumed to be equivalent to the excretal load, expressed as kg N/cow or kg N/ha) was calculated according to equation 1. The proportion of this excretal load that would be urine was estimated from the equation of Ledgard et al. (2003) (equation 2):

$$\text{N surplus} = \text{N intake in pasture} + \text{supplements} - \text{N output in milk} \qquad [1]$$

$$\text{Proportion of N load deposited as urine (\%)} = 29.9 + (11.9 \times \text{N concentration of diet (\%N)}) \qquad [2]$$

Pasture DM intake estimation was based on visual estimation of pre- and post-grazing pasture cover, and calibrated against a set of dry matter yield measurements from quadrat cuts. Nitrogen intake was calculated from DM intake and measured crude protein content of pasture samples. Records were kept of supplements fed and feed samples were also analysed for crude protein content to allow calculation of N intake. Milk yield and composition data were collected, including crude protein, allowing calculation of N removed in milk.

*Measurement of urine patch N load*

Urine patches were soil sampled immediately after voiding (June and November 2014, April and July 2015) in the 5-6 hour period between morning and afternoon milking, using the method described by Welten et al. (2013). Both herds were monitored at the same time. Briefly, after each urination event, the wetted area was identified and a chain placed around its perimeter. A wire grid comprising of 10 cm x 10 cm cells was placed over the patch and the area estimated by counting grid squares. Soil in each grid square was sampled to 7.5 cm to provide a composite soil sample from the patch. Samples were incubated overnight at 20 $^{o}$C in a closed bag to allow conversion of urea to mineral N and then extracted to measure this mineral N. Estimation of N per urination (g N) was calculated from area and mineral N content. Values were corrected for missed N below 7.5 cm by applying a recovery factor based on sampling areas where a known amount of urine N had been applied. Because we were observing urination events, this also provided data on urination frequency for each herd during the 6 hours. Total urinary N production during the 6 hr. period was calculated as:

$$\text{Urine N (g/cow)} = \text{estimated N content of urine patch x no. of urinations} \qquad [3]$$

*Measurement of 24-hour urine production*

Urine sensors (Betteridge et al., 2013) were attached to cows to collect information from each urination event, allowing real-time estimation of urine volume (by pressure sensor) and urine N concentration (by refractometer calibrated against urine samples of known N concentration). Measurements of urination events were made for three continuous days in December 2014 and April 2015. Both herds were monitored at the same time. In December, the two treatment herds were on pasture for the entire 24 h period, apart from morning and afternoon milking. In April, the cows from the Future herd were kept on a stand-off pad between morning and afternoon milking. Data from the sensors were downloaded to a portable laptop computer daily and all valid data were collated into an Excel spreadsheet recording time of event, duration, estimated volume, estimated N concentration and calculated N load per urination for statistical analysis of the data.

## Results

*Herd N balance*

Estimated annual feed N intake (540 kg vs. 462 kg N/ha/year) and annual urine N output (317 vs. 257 kg N/ha/year) were both greater for the Current herd, with a 19% reduction in urine-N per ha from the Future herd management compared with the Current system (Table 2). Although the calculated annual N intake per cow was 5% less by the Current herd (176 vs. 167 kg N/cow/year for Future and Current, respectively), the estimated urine N production per cow was the same for both herds (98 kg urine N/cow).

**Table 2. Comparing three methods for estimating urine N production per cow and per ha, comparing the two farm systems. 'Difference' is the estimated reduction in urine production per ha, relative to the Current system.**

| Method: | N balance | | Urine patch | | Urine sensors | |
|---|---|---|---|---|---|---|
| Timescale: | Annual | | 6 hours | | 24 hours | |
| Metric | Current | Future | Current | Future | Current | Future |
| | kg N/cow | | g N/cow | | g N/cow | |
| Urine N per cow | 98 | 98 | 24 | 23 | 184 | 195 |
| | kg N/ha | | g N/ha | | g N/ha | |
| Urine N per ha | 317 | 257 | 78 | 60 | 585 | 504 |
| *Difference* | | *19%* | | *23%* | | *14%* |

*Urine patch N load*

In total, c. 600 urine patches were measured over the four sampling campaigns. Averaged across all seasons, there was no difference between herds in the number of urinations per ha (7/ha for the 6 hour observation period). There was 23% less urinary N deposited by the Future herd per ha, as an average of all sampling periods (Table 2). On a per cow basis, there were 17% more urinations by the Future herd: 2.2 vs. 2.6/cow per 6 h observation. The N content per patch was highly variable, ranging from 5 to 40 g N/patch but, on average, there was less N per patch from the Future herd: 11 g N/patch from the Current herd and 9 g N/patch from the Future herd. However, when multiplied by the urination frequency, there was no difference between the two herds in the urinary N deposition per cow (24 g N/cow/6 h) (Table 2).

*24-hour urine production*

1368 urination events were recorded by the sensors. There was 14% less urinary N per ha produced by the Future herd as an average of the two measurement campaigns: 504 vs. 585 g N/ha/day. Per hectare, there were more urinations in the Current system (43 vs. 39 urinations/ha/day). Urine volume, N concentration and N load were all highly variable. There was no effect of system on the average N load per urination event, 13 g/urination, i.e. potentially 13 g per urine patch. When scaled up to a daily basis, there was no effect of system on the estimated average urinary N load per cow (184 vs. 195 g N/cow/day for Current and Future herds, respectively: Table 2). The above measurements say nothing about where the urine was deposited. Future cows were typically on the stand-off pad from 9:00 am – 3:00 pm in April. On average, 43 g N was deposited per cow per day on the pad, which was 23% of the daily N production; this only occurred for the Future farmlet herd because the Current herd remained in the paddock. However, both herds continued to be milked twice daily and 13% of daily urine N production occurred during this time.

*Comparing methods*

To compare methods, we expressed results as urine N production/ha/day, averaged over the year and both herds, although this estimate has to be treated with caution given the differences in actual timescales for each method. The sensor estimate (545 g/day) was c. 70% of the balance method (786 g/day). Soil sampling of urine patches gave the lowest estimate (281 g N/day).

## Discussion

The three methods consistently demonstrate that large reductions in urine deposition directly to the paddock are attributable to the effect of lower N inputs (less N eaten per ha) and the standoff pad; this is likely to decrease N leaching given that urine N is the primary source (Ledgard et al., 2009). The three methods of estimating urine production operate at different temporal scales but all produced a consistent conclusion when expressed as percentage differences. There were generally small differences in urine production per cow but when stocking rate was factored in, the Future system generated 19% less urine per ha, as an average of the three methods. This is in agreement with the proposed hypothesis of a 20% reduction and is not surprising, given that urinary N is driven primarily by N intake (Castillo et al., 2000). The four-year herd N balance indicated a 16% reduction in N intake per ha by the Future herd. Additionally, removing cows off-paddock to capture and recycle excreta as effluent further reduces the quantity of urine voided directly onto pasture. The urine sensor provided direct measurement of the added effect of standing cows off pasture, and indicated removing cows for 25% of the time in April reduced daily urine N return to pasture by 23%. Given that the stand-off period was extended to 16 hours per day later in the autumn/winter, we would expect proportionally more urine capture during what is a high leaching risk period. Our estimates of urine capture by stand-off are in line with the 30% reduction in leaching reported by de Klein et al. (2010). Burggraaf et al. (2011) modelled farm systems similar to the Current and Future and estimated decreased N leaching losses of 30-50% in the Future system, across a number of years. This is in line with our estimates of the reduction in urine directly voided onto the paddocks, and provides confidence in our model descriptions of the systems.

Although methods compared well in terms of relativity between systems, absolute amounts differed. However, we were comparing very different methods over different timescales and season. The lower daily urinary N estimate by soil sampling was due to fewer urinations per day and a lower N content per patch compared with urine sensors. Both of these could be due to differences in sampling period (6 vs. 24 hours), especially given a diurnal variation in urine characteristics (Betteridge et al., 2013), as well as differences in time of year. Another reason could be that the sensor is measuring urine straight from the cow whereas the urine spotting is measuring N after it has hit the soil, which may have undergone some loss processes, particularly ammonia volatilisation (Selbie et al., 2015). Further work is required to develop and test these novel methods, but based on this assessment they appear valuable tools for helping to understand the complexities of N flows in dairy production systems.

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