A model to assess the impact of potential genetic selection of dairy cows for volume per urination and total urine volume per day on nitrogen leaching

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Abstract

The purpose of this paper is to assess the impacts of changes in herd average urine genetic traits on nitrogen (N) leaching per hectare per year. Two potential urine traits being considered for genetic selection are total volume of urine per cow per day (at constant urinary N output), and average volume per urination (at a constant daily urinary volume and N output). To understand the potential reduction in N leaching that would arise if these traits could be changed using genetic selection, a model of urine patches was developed to derive the necessary relationships between urine genetic traits, patch characteristics, and N leaching. To simulate the effect on N leaching of genetic selection the mean for each urine trait was then changed from base model values by ±10%. Increasing total urine volume per cow per day by 10% was more effective (4.5% less N leaching) than decreasing volume per urination by 10% (2.9% less N leaching). Also, selection for urine traits at higher stocking rates (four cows/ha) and higher N intake (650 g/N/day) had a lower impact on N leaching compared with lower stocking rates (two cows/ha) and lower N intakes (450 g N/day). This study showed that genetic selection for urine traits could have a positive, but limited, impact on N leaching and would be a useful tool for New Zealand dairy farmers.

Keywords: Urine traits; urine patches; nitrate leaching

Introduction

A key driver of water-quality degradation caused by dairy farming in New Zealand is the loss of excess nitrogen (N) into water ways. A review by Selbie et al. (2015) reported N-loading rates within urine patches of 200 to 2000 kg N/ha, with a mean of 613 kg N/ha. Those authors concluded that of the total N deposited in urine: 41% is taken up in pasture, 20% is leached, 26% is immobilised, 12% is lost as ammonia through volatilisation, and 2% as nitrous oxide. This N loading is a function of the volume of urine per urination and urinary N concentration. Previous work has looked at the current genetic gain as a result of the national selection index (Breeding Worth, BW) and its impact on N leaching.

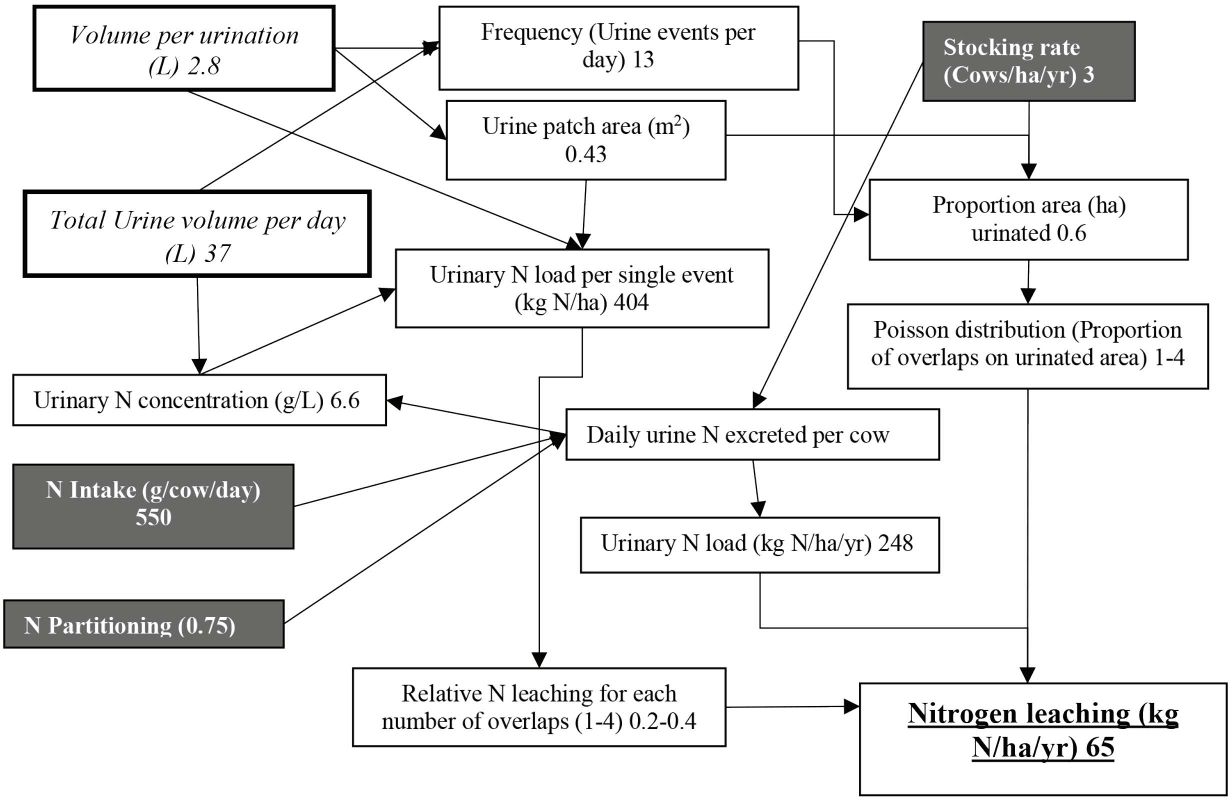
A study by Woodward et al. (2011) investigated the impact of selection breeding for a nationally used index called Breeding Worth (BW) on feed conversion efficiency (FCE) and nitrogen use efficiency (NUE) in late lactation. It was reported that high-index cows partitioned 3.5% more feed intake into milk and 6.5% less feed N intake into urine compared to low BW and PW cows. However, such benefits rely on high selection emphasis for productive traits within the BW index. Improving efficiency by encouraging higher per-cow milk production through genetic improvement combined with more-intensive farming approaches is unlikely to lead to improved environmental outcomes at a national level, if the level of total intake remains the same (Zhang et al. 2019).

Therefore, if genetic change in the New Zealand dairy herd is to make a positive contribution to water quality through reduction in N leaching, then new selection criteria and approaches to genetic improvement will be required. Previous attempts to use selection to address N leaching have focused selection of cows for reduced milk urea nitrogen due to its positive correlation with urinary nitrogen (Ciszuk et al. 1994; Jonker et al. 1998; Kauffman et al. 2001; Luo et al. 2010). Here we focus on the potential value that genetic variation in urine attributes might have as an approach to reduce N leaching. Li et al. (2012) reported that N leaching from urine deposition is very sensitive to volume per individual urination event and urinary N concentration. Therefore, by altering urine patch characteristics in particular directions, nitrogen leaching might be reduced. The hypothesis for this study was that selection among cows for greater total urine volume per day and smaller volume per urination could potentially have a meaningful impact on N leaching. A model designed to estimate the effect of urine characteristics on N leaching was used to show the degree to which genetic change in these traits could impact on N leaching. The effect of a change in total urine volume and volume per urination on N leaching from this study can then be used for future development of economic values of urine traits. They can then be weighted in selection indexes which will help determine the optimal balance of selection emphasis across competing traits.

Material and methods

A model was used to estimate annual N leaching per hectare for a farm based on urine characteristics. This method was chosen as no data on the effect of genetic selection for urine traits were available, therefore the impacts must be predicted using causal relationships between urine and N leaching that are already understood. Figure 1 provides an overview of how the model predicts nitrogen leaching per hectare. The dark boxes represent

Figure 1 Summary of the urine patch model which calculates the effect of change in total urine volume and volume per cow urination on N leaching per hectare per year.



input variables that drive the model, the boxes in italics are the two goal traits and the white boxes are calculated variables that are dependent on the input variables. Each box contains the units and the mean for each variable. The means used for total daily urine volume and volume per urination were derived from research trials in which urine sensors were attached to 300 dairy cows.

The following equations provide a detailed description of how the variables in Figure 1 are calculated. The equations are described from the output (N leaching) back to the inputs. With the equation for N leaching per hectare per year as follows.

$$NLHA = UNload(PoissonDist\ total\ urine\ area \times RelNLOverlaps),$$

where UNload is the total N load per hectare, PoissonDist total urine area is the proportion of the total urinated area with one, two, three and four urine-patch overlaps calculated using a Poisson distribution and relative N leaching (RelNLOverlaps) is the N that is lost from the soil profile as a proportion of the urinary-N load deposited in urine patches accounting for one to four urine-patch overlaps.

$$Total\ urine\ area = SR \times Urine\ Area \times Frequency \times \frac{365}{10000}$$

where *SR* is stocking rate, *Urine Area* is the area covered by a single urination event, *Frequency* is the number of urination events per day, 365 is the number of days in a year and 10,000 is the m^2 in a hectare.

Relative N leaching (RelNL) was computed as a function of urinary-N load (UNLoadSingle) in a single urine patch;

$$RelNL = 0.4811e^{(-295.6963/UNLoadSingle \times overlaps)}$$

where 0.4811 and 295.6963 are empirical constants calculated by simulating urine patches using the APSIM model, run over 10 climatic years and two dates of deposition per month, and a range on UN loads (0 to 1000 kg/ha) (Keating et al. 2003; Romera et al. 2017).

Urine-N load expressed per hectare (*UNload*) is derived from grams of urine N excreted per cow per day (*UNex*) by multiplying by stocking rate (*SR*) and days in the year as follows;

$$UNload = UNex/1000 \times SR \times 365.$$

Urine-nitrogen load per urination is computed using urine-nitrogen concentration, volume per urination and area per urination as shown in the following equation.

$$UNLoadSingle = \frac{UNconc \times VolperUr}{AUr}/1000 \times 10000,$$

where *UNconc* is the Urinary-N concentration, *VolperUr* is the volume per urination and *AUr* is the urine-patch area.

The number of urinations per cow per day *(Frequency)* is calculated by dividing total urine volume (*UrVol*) by volume per urination event (*VolperUr*).

Note: *UrVol* and *VolperUr* are the two genetic driving variables for which we wish to understand what might change with genetic selection of urination traits.

Area per urination (AUr) is calculated using a quadratic approximation (Li et al. 2012);

$$AUr = -0.0064 \times VolPerUr^2 + 0.0998 \times VolPerUr + 0.1948.$$

Urine-nitrogen concentration is calculated by dividing nitrogen excreted per cow (UNex) by total urine volume per cow, as in the following equation,

$$UNconc = \frac{UNex}{UrVol}$$

where, UrVol is the total urine volume per cow per day. Urinary Nitrogen excreted per cow (UNex) is the weight (g) of nitrogen that is excreted in urine per cow per day as shown in the following equation,

$$UNex = Nin \times 0.75 \times UNpart,$$

where, Nin is the weight (g) of nitrogen consumed in feed per cow per day, 0.75 is the proportion of feed nitrogen that is excreted by the cow and UNpart is the proportion of nitrogen excreted that is partitioned to urine, and was set at 0.55 (Selbie et al. 2015). Nitrogen intake was set at 550 grams per day (Selbie et al. 2015).

This leaves the key variables that simulate genetic change and predict N leaching per hectare to be volume per urination (L) and urination volume per cow (L/d). Nitrogen intake (Nin, g/d) and urine partitioning (UNpart, %N excreted in urine) also have a large influence on the prediction of N leaching, however these are not variables that are changing as a result of genetic selection.

To simulate the effect of genetic selection of urine traits on nitrogen leaching, the mean of each trait was changed by ±10%. At this stage of the research it is unknown how much genetic gain in the two urine traits can be made. Thus, a ±10% change in the traits is assumed. This was done for each possible combination of trait change for each of the urine traits (Table 1). The impact of selection for urine traits on N leaching was also assessed for different stocking rates and N intakes.

Results

The potential effect of genetic selection of urine traits is shown in Table 1. As expected, the model predicted that N leaching would decrease when total urine volume increases or when volume per urination decreases. When the mean for total urine volume changed by -10% and +10%, leaching changed by 5.0% and -4.5%, and for volume per urination, leaching changed by -2.9% and 2.6% respectively. Both average N intake and average N output in urine were kept constant for each ±10% change in trait shown (Table 1). The results in Table 1 show that a change in total urine volume had a greater effect on N leaching than did an equivalent percentage change in volume per urination.

Another finding was that the impact of genetic selection for urine traits that resulted in a decrease in N leaching had less of an impact on nitrogen leaching at higher N intakes and higher stocking rates. Figure 2 shows the impact of stocking rate on the effectiveness of trait change on N leaching. The Y axis is the percentage reduction in N leaching as a result of selection for urine traits and the X axis is the change in stocking rate. The impact of stocking rate was only modelled for the selection of traits that resulted in a reduction in N leaching as shown in the legend of Figure 2. At a stocking rate of two cows/ha/yr, the reduction in N leaching for a +10% change in total urine volume was 5.3%, and 3.4% for a -10% change in volume per urination. When the stocking rate was doubled

Table 1 The mean percentage change in nitrogen leaching per hectare per 10% increase or decrease in each trait and each trait combination.

	Total urine volume per day		
Volume per urination	-10%	0%	10%
-10%	2.1%	-2.9%	-7.4%
0%	5.0%	0.0%	-4.5%
10%	7.6%	2.6%	-1.9%

Figure 2 The predicted impact of stocking rate on the effectiveness of increasing total urine volume by 10% (◆–) and decreasing volume per urination by 10% (■–)to reduce nitrogen leaching per hectare.

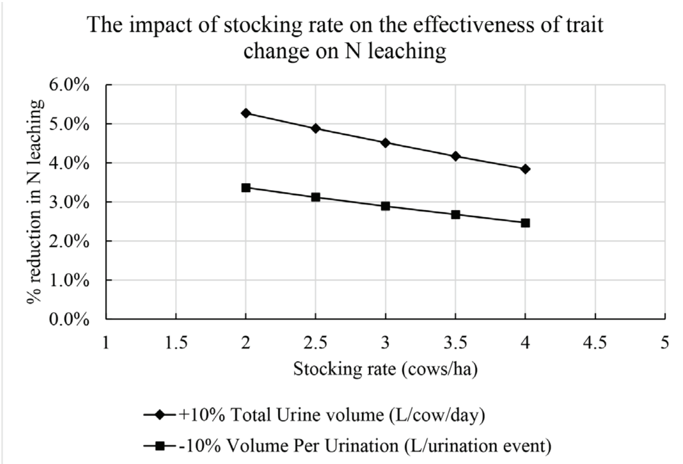
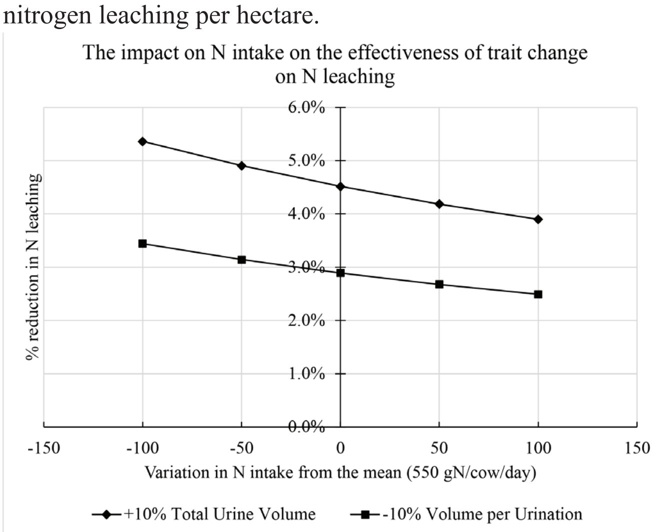


Figure 3 The predicted impact of nitrogen intake on the effectiveness of increasing total urine volume by 10% (◆–) and decreasing volume per urination by 10% (■–)to reduce nitrogen leaching per hectare.



to four cows/ha/yr the reduction in N leaching decreased to 3.8% and 2.5% for total urine volume and volume per urination, respectively.

The same trend was observed for a change in N intakes as shown in Figure 3. The axes are the same as in Figure 2, however the change in stocking rate has been replaced with a change in N intake for the X axis. The mean N intake used in the model was 550 grams/cow/day with variations modelled from the mean in 50-gram increments. As for the stocking-rate simulation, only trait changes that resulted in a reduction in N leaching were modelled. When the mean for N intake was decreased by 100 g/N/day the reduction in N leaching increased to 5.4% and 3.4% for total urine volume and volume per urination, respectively. When N intake was increased by 100 grams, the reduction in N leaching decreased to 3.9% and 2.5% for total urine volume and volume per urination, respectively.

Discussion

This study predicts that genetic selection for urine traits could result in a 3 - 5% reduction in N leaching. The realisation of this potential is dependent on further genetic analyses of phenotype and genotype data to determine how much genetic change can be achieved through selection for urine traits. As such, the results of this study are preliminary in terms of estimating the reduction in N leaching possible through genetics, however the results align with other studies. Ledgard et al. (2015) reported significant reductions in N leaching of 65% when cows were supplemented with salt. The salt caused water intake of cows to increase resulting in a greater total daily urine volume and increased urination frequencies. Although the effects of selecting for urine patch traits is not of the same magnitude, the mechanism to reduce N leaching is consistent.

The purpose of the model is to quantify the impact of changing herd average total urine volume and volume per urination on N leaching. While the model itself has not been validated, the key causal relationships and underlying principles are well established, based on data from other studies (Selbie et al. 2015). Based on the outputs of the model, cows that would have the greatest positive effect on N leaching would have a high volume per day and/or a low volume per urination, at a fixed urinary N output. This is due to the three key factors that determine the nitrogen load of urine patches; being, urinary N concentration, the urine volume per event and the surface area receiving urine (Haynes & Williams, 1993). Therefore, when cows have a high total urine volume at a fixed N output, urinary N concentration decreases due to the dilution effect. Furthermore, when urinary N output and total urine volume are fixed, but volume per urination is decreased (which is the same an increase in urination frequency), urinary N load of urine patches also decreases. This is because less urine is being deposited onto the same area of soil. It also reduces the infiltration depth of urine patches, which means a greater proportion of urinary N remains in the root zone for plant uptake (Li et al. 2012).

It was found that variation in total urine volume had a greater impact on N leaching than did variation in volume per urination. This can be simply explained by the fact that the 10% increase in urine volume has the greatest effect on N loading in single urine patches (9.1% reduction in UNloadSingle) compared with 10% decrease the volume per urination (5.9% reduction in UNloadSingle) (Li et al. 2012). As such, increasing total urine volume, while keeping UN output constant, reduces nitrogen concentration, and thus, N leaching. This means that selection pressure toward increasing total urine volume would (provided that total UN does not increase concomitantly) provide greater value when reducing N leaching per hectare compared to selecting for cows with lower volumes per urination event.

The impact of genetic selection for urine traits is reduced when stocking rate and N intake are increased. The probability of urine-patch overlaps is greater at higher stocking rates. This increases the coverage of urine-patch overlaps, which results in an increase in the weighted average urinary-N loading of the area covered in urine patches (Haynes et al. 1993; Pleasants et al. 2007). The increase in N intake reduces the impact of genetic selection for urine patch traits. This is a result of increased urinary N concentration, which increases urinary-N load and N leaching. Therefore, diluting urine by increasing total urine volume is less effective. These results would indicate that urine traits would have a greater positive impact on N leaching on farms that have low stocking rates and low N intakes per cow. However, dairy systems in New Zealand that have high N leaching generally have high stocking rates and per-cow N intakes. Genetics that reduce N leaching would potentially have the greatest value for these more-intensive farms. This paper provides a basis for further research on the genetic parameters of urine patch traits such as heritability, reliability and genetic variation to determine how much genetic progress can be made in each trait.

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