A Novel, Comprehensive Genetic and Management Initiative to Reduce the Environmental Impact of New Zealand Dairy Cattle

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"Knowing is not enough, we must apply. Willing is not enough, we must do."
- Johann Wolfgang von Goethe

Abstract

Between 1990 and 2012, the rapid expansion of pastoral dairy farming in New Zealand contributed to a 29% increase in nitrogen leaching from farms to waterways. In 2014, central government mandated that regional councils develop water quality targets and impose new regulations resulting in intense pressure to reduce the environmental impact of dairy farming that threatens the industry's social license to operate. Nitrogen leaching features prominently in this new regulatory regime, and some groups advocate reducing the numbers of cattle to meet the new targets.

DairyNZ and its genetic evaluation subsidiary, New Zealand Animal Evaluation Limited, have formed a partnership between the New Zealand Ministry of Business Innovation & Employment, commercial breeding companies, research institutes, universities, and milk processors, to provide the industry with genetic and genomic estimates of genetic merit for urinary nitrogen excretion in dairy cattle and with practical strategies to shift the NZ national dairy herd toward low nitrogen excreting genetics. It will couple these genetic benefits with management-based solutions such as alternative pasture plants and crops, and produce benefits for the beef industry because ~65% New Zealand beef production is from stock derived from dairy cows,

An integrated strategy explicitly acknowledges that even the best genetics and farm systems science can only contribute to meeting societally-driven demands for sustainability if the benefits are rigorously demonstrated, regulators have credible tools to evaluate its impacts, and practical and economic barriers to adoption and implementation are recognized and minimized.

Key words: Urinary nitrogen, selective breeding, environmental impact, environmental regulation, social license

Emerging New Zealand nitrogen regulations and dairy farming

According to government estimates, total nitrogen leaching in New Zealand increased by 29% from 1990 to 2012 (Statistics New Statistics New Zealand, 2017). This trend has generated intense public interest in water quality, widely considered the country's greatest environmental challenge. Extensive conversion of agricultural land from other uses to dairy farming over the same period led to dairy cattle urine and feces becoming the largest source of agricultural nitrogen leaching in about 2008, accounting for almost 50 million kg of nitrogen leachate out of a total of 137 million kg in 2012 (Statistics New Statistics New Zealand, 2017). Consequently, the New Zealand dairy industry is under intense societal pressure to mitigate these impacts, threatening its social license to farm.

In 2014, the New Zealand central government reacted to these trends by issuing a "Freshwater National Policy Statement" (New Zeanland Ministry for the Environment, 2017)

mandating that local and regional governments fulfill their responsibilities under New Zealand's main environmental legislation, the 1991 Resource Management Act, by setting objectives for the state of freshwater bodies and legal limits to achieve them by December 31, 2025. This shift in focus from regulating or mandating specific farming practices to setting catchment-level water quality targets puts the onus on farmers for meeting them, and thus for developing and implementing on-farm strategies to achieve compliance. Farms that do not meet targets any other way could have no choice but to reduce stocking rates or cease farming operations.

Most New Zealand dairy farmers feed mainly pasture to cows using a rotational grazing scheme, and thus, the main contributing factor to nitrogen leaching from such farms is urinary nitrogen produced by grazing cows on high protein forage. The nitrogen load within a urine patch may be as high as 1,200 kg N per hectare (Haynes, Williams, 1993), too high for pasture plants to assimilate at some times of the year.

Monitoring and mitigation tools

Obtaining direct measurements of urinary nitrogen and nitrogen leaching from individual farms to develop legal limits and monitor compliance is extremely challenging, and several regional councils have adopted or are considering a popular farm system and nutrient management model (OVERSEER®, https://www.overseer.org.nz) originally designed to help farmers optimize on-farm nutrient use for increased profitability. According to the OVERSEER® website it "was designed to model easily obtainable data which means the model uses simplifications of complex processes. This results in a level of uncertainty in the modelled estimates." Ledgard and Waller (2001) estimated this uncertainty at 25-30% for predicted nitrogen leaching, excluding errors and uncertainty associated with inputs. Furthermore, those inputs currently do not account for variation between herds with respect to genetic determinants of nitrogen partitioning and urinary nitrogen production.

Past research has produced some cost-effective nitrogen mitigation options, but they are not keeping pace with increases in nitrogen loss, particularly in nitrogen sensitive catchments. New nitrogen mitigation options with long-term benefits that are inexpensive, easy to implement, and rapidly scalable are urgently required.

Milk urea as a predictor of urinary nitrogen

Lactating dairy cattle partition dietary protein into somatic tissue, fetal growth, and milk production, with surplus nitrogen excreted via N-gases, feces, and urine (Mitchell *et al.*, 2005; Spek *et al.*, 2013). Ammonia produced in the rumen is converted into blood plasma urea by the liver, which passively diffuses to other fluid pools in the body including milk and urine (Roseler *et al.*, 1993).

Several studies have shown that milk and urinary nitrogen are proportional (Burgos *et al.*, 2007; Ciszuk, Gebregziabher, 1994; Jonker *et al.*, 1998; Kauffman, St-Pierre, 2001; Kohn *et al.*, 2002). The concentration of milk urea nitrogen should, therefore, be a useful predictor of urinary nitrogen excretion. Furthermore, milk urea nitrogen is easily and inexpensively measured using standard mid-infrared (MIR) spectroscopy. Although phenotypes based on MIR analysis might be less accurate than direct measures, this ubiquitous technology creates opportunities to collect millions of individual phenotypes from routine herd testing and thus capture genetic variation as well as variation at the farm and catchment levels.

Barriers and knowledge gaps for a genetic solution

A preliminary pedigree analysis in New Zealand found that milk urea nitrogen is moderately heritable (~0.16) and has no strong adverse genetic correlations with production traits (Beatson *et al.*, unpublished), results that roughly agree with similar studies of Danish and Canadian Holsteins (Mitchell *et al.*, 2005; Wood *et al.*, 2003). If the phenotypic correlation between milk and urinary nitrogen is indicative of a similar signed genetic correlation, milk urea

nitrogen could be a useful trait for national-scale evaluation of urinary nitrogen and the development of a breeding value for reducing urinary nitrogen excretion at the individual and herd-level through selective breeding.

A breeding value for reducing urinary nitrogen would be highly attractive to New Zealand dairy farmers for a variety of reasons. Like all genetic improvement, the farm-level benefits would be cumulative, permanent, and (assuming weak or no genotype-by-environment interactions) universally applicable and infinitely scalable. Further, selective breeding has very low barriers to adoption because it requires little or no investment in infrastructure or changes to farming practices and can be "stacked" with management solutions such as alternative pasture plants and/or farm systems (see: https://www.dairynz.co.nz/about-us/research/forages-for-reduced-nitrate-leaching/frnl-research-reports/) While potentially costly to develop and validate, genetic solutions have very low costs to farmers once implemented.

There are however several technical and implementation hurdles that must be addressed. Although there have been some studies characterising phenotypic and genetic variation in milk urea nitrogen in dairy cattle, and its relationships with other traits (e.g. Aguilar *et al.*, 2012; Hossein-Zadeh, Ardalan, 2011; Miglior *et al.*, 2007; Mitchell *et al.*, 2005; Mucha, Strandberg, 2011; Wood *et al.*, 2003), we currently do not understand the genetic architecture of urinary nitrogen excretion in the grazing systems practised in the New Zealand dairy herd. Further we do not understand the extent of any genetic antagonisms with other economically important traits. At a more practical level, to implement a routinely predicted breeding value for urinary nitrogen we must develop a data stream suitable for national animal evaluation, develop suitable analytical models, and characterise the accuracy of estimated breeding values for this difficult to measure target trait. Regarding the new regulatory regime, to incentivize farmers to adopt low nitrogen excreting genetics, we must also demonstrate and quantify how individual- and herd-level urinary nitrogen excretion translate into farm- and catchment-level impacts that satisfy new regulatory criteria. Consequently, the tools used to monitor and enforce compliance must correctly incorporate the effects of genetic change in urinary and faecal nitrogen. Finally, we must evaluate the economic value of reducing urinary nitrogen excretion so that it can be correctly incorporated into the economically-weighted New Zealand multi-trait selection index (referred to as Breeding Worth or BW).

How we will do it

To both fill the knowledge gaps and overcome the practical barriers to implementing selective breeding for reduced urinary nitrogen, DairyNZ, and its genetic evaluation subsidiary, New Zealand Animal Evaluation Limited (NZAEL) have formed a novel partnership between the New Zealand Ministry of Business Innovation & Employment, commercial breeding companies, research institutes, universities, and milk processors This 7-year, ~$NZ 21 million programme aims to provide the industry with genetic and genomic estimates of genetic merit for urinary nitrogen excretion in dairy cattle and with practical strategies to substantially shift the NZ national dairy herd toward low nitrogen genetics and to couple these benefits with management solutions such as alternative pasture plants and crops. The work plan explicitly acknowledges that even the best genetics and farm systems science can only contribute to meeting societally-driven demands for sustainability if the benefits are rigorously demonstrated, regulators have credible tools to evaluate its impacts, and practical and economic barriers to adoption and implementation are recognized and minimized. The partnership therefore includes effort to quantify the environmental benefits and economic value of low-nitrogen genetics, elucidate potential interactions between divergent nitrogen-excretion genotypes and dietary nitrogen availability, and improve the information and tools available for monitoring compliance with emerging regulations. Using the NZ Ministry of Business Innovation and Employment's terminology, the programme is divided into two "Research Aims": one focused on generating new knowledge to enable the development of national evaluations for urinary nitrogen excretion, and the other focused on

implementing routine evaluation, validating its benefits, and ensuring that the tools used to monitor compliance capture those benefits. Both Research Aims consist of a series of interlinked "Critical Steps" required to achieve them, and each Critical Step is designed to produce outputs and impacts that either contribute to downstream efforts or deliver real-world benefits. Figure 1 represents this scheme in diagrammatic form.

Critical steps under Research Aim 1 rely heavily on recently-developed automated urine sensor technology (Betteridge *et al.,* 2013; Shepherd *et al.,* 2017) to collect direct measures of urinary nitrogen, and couple those data with blood urea nitrogen, and milk urea nitrogen measurements from over 1,000 grazing cows. These data will then be used to estimate genetic parameters, and combined with SNP genotypes, search for genomic regions of large effect known as quantitative trait loci and develop genetic and genomic predictions of urinary nitrogen breeding values. We will also use these data to identify phenotypically extreme animals for more detailed feed stall experiments to study nitrogen partitioning using a factorial experimental design that feeds high and low urinary nitrogen animals with either high or low nitrogen content feeds. This work will elucidate the physiological and biochemical mechanisms underlying genetic and environmental variation in urinary nitrogen excretion, and simultaneously collected gene expression data will help identify gene networks and putative causal genetic variants. All this knowledge will be used to develop national-scale genetic and genomic breeding value predictions.

Research Aim 2 focuses on implementation and validation. We will estimate the economic value of reducing urinary nitrogen and incorporate this novel trait into our national evaluations. We will also develop practical strategies for farmers to convert their herds without sacrificing production or profit. Using experimental farm studies, we will test the key hypothesis that using low nitrogen excreting cows reduces nitrogen leaching at farm-scale, and use this information to both develop catchment-scale models and upgrade the OVERSEER® Nutrients Budget model (Selbie *et al.,* 2013) to incorporate individual- and herd-level genetic variability.

Finally, the entire programme is overlaid by a farmer-focused co-development approach that incorporates commercial partner farms at every level to ensure the outcomes and solutions are practical, adoptable and acceptable to farmers.

This work will also have implications for the beef industry because ~65% New Zealand beef production is from stock derived from dairy cows (Burgafraat, 2016).

Conclusion

DairyNZ and NZAEL are about to initiate a comprehensive, industry-good effort that goes beyond the prediction of breeding values for nitrogen excretion to quantify the environmental benefits and economic value of low-nitrogen genetics, elucidate potential interactions between divergent nitrogen-excretion genotypes and dietary nitrogen availability, adapt farm systems models widely used to monitor environmental compliance to incorporate this genetic variation, and promote the widespread adoption of both management and genetic tools by directly involving commercial farmers in co-developing on-farm strategies throughout the 7-year programme.

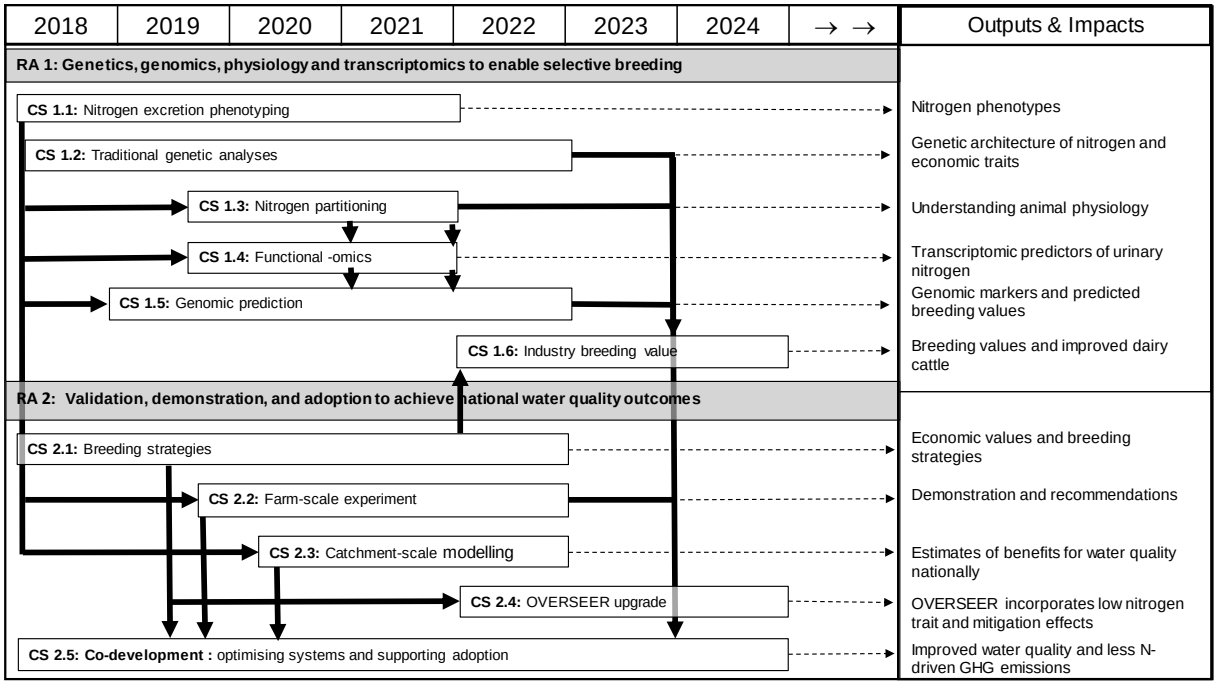

Figure 1. Diagrammatic representation of the 7-year programme. Filled arrows represent flows of information and/or biological materials between Research Aims (RA) and Critical Steps (CS). Broken arrows connect Critical Steps to Outputs and Impacts

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