Relationships between nitrogen inputs, outputs in product, and surpluses in New Zealand dairy systems

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Abstract

This paper introduces a framework for quantifying relationships between nitrogen (N) inputs (from fertiliser, imported feed and fixation), outputs in animal product, farm gate N surplus, and N use efficiency (NUE) in grazing dairy systems. Data from 380 New Zealand dairy farms categorised according to farm system type (1 to 5, representing increasing reliance on imported feed), plus a 3-year farm systems experiment comparing different N fertiliser and supplementary feed inputs, were plotted within this framework. Within each system type, as more inputs were used to increase animal production, the farm N surplus increased and NUE declined. This trend was also apparent across the treatments in the systems experiment. In general, systems reliant on moderate-to-high feed inputs resulted in more N in product and higher NUE than systems with low reliance on imported feed, but still led to high N surpluses and, therefore, high nitrate leaching risk. Systems converting total N inputs of 300 kg/ha (from all sources) to milk efficiently (NUE = 30% or higher) are well-positioned to maintain high milk production with a relatively low N surplus (~200 kg/ha) and, therefore, relatively low N leaching risk.

Key words: Dairy systems; nitrogen; nitrate leaching; milk production; environment

Introduction

Dairy farmers in many regions of New Zealand are now, or soon will be, required to reduce nitrate leaching to comply with environmental regulations. The more nitrogen (N) that is brought into the farm system, the lower the efficiency with which it is used for pasture and milk production. The fraction which is not used for production, defined as the whole farm N surplus (N inputs in N fertiliser, imported feed supplements, and biological fixation minus N in milk and liveweight of sale animals), will eventually move into the wider environment (Whitehead 1995). Thus, the annual farm N surplus is a good indicator of likely N losses to water and atmosphere (de Klein et al. 2017, Pinxterhuis et al. 2018).

The advent of environmental regulations means that dairy system requirements for N are now defined by two factors: production, and environment. Farmers have a production goal (explicit or implicit), while the public has an environmental goal of reducing the N load in freshwater (made explicit by regulation). Nitrogen in animal products (milk, meat) and N leaching into freshwater (ground or surface water bodies) are both outputs from farm systems and they are often in conflict with one another. To help resolve the conflict, it is important to quantify the relationships between the two key outputs.

The aim of this paper is to present a general analytical framework in which N in product is plotted against the farm N surplus (as a proxy for environmental losses), and from which the management requirements (chiefly total N inputs, and nitrogen use efficiency, NUE = N in product / N inputs) for achieving high production with low N emissions can be identified. Data from commercial dairy farms, and from a dairy farm systems experiment, are plotted within the framework to illustrate some general principles.
Methods

The framework is shown in Figure 1, where the x- and y-axes encompass both NUE (the diagonal lines), and N inputs (the points along the diagonal lines – some of which are labelled with kg N/ha total N input from fertiliser, feed imports and N fixation).

Physical farm data were drawn from 380 farms in DairyBase for the 2014/15 production year. An OVERSEER® simulation was created for each farm to calculate the N surplus. The data were segmented by system type, defined by the proportion of total feed supplied to the herd that was imported (Hedley et al. 2006): system 1 (no imported feed; n=12 farms); system 2 (4-14% of total feed is imported; n=91), system 3 (10-20% total feed is imported; n=156), system 4 (20-30% of total feed is imported; n=92) and system 5 (30-40% of total feed is imported; n=29). The relationship between N surplus and N output was analysed, and the best fit polynomial curve plotted in Fig. 1.

In addition, data were collated for eight treatments compared in a three-year farm systems experiment in the Waikato as reported by Macdonald et al. (2017). Five of the treatments used no imported feed (one received no N fertiliser, two received 200 kg N/ha/y and two received 400 kg N/ha/y), while pasture feed supply in the other three was supplemented by maize grain and/or maize silage (all with 200 kg N fertiliser/ha per year).

Results

In the farm data set, between 37% and 56% of the variation in the relationship between N surplus and N output was explained by a second order polynomial for all farm systems 1 to 5 (Fig. 1). Nitrogen use efficiency declined as N output increased for all system types. For example, for system 3 farms, NUE declined from 40% at total N input of 90 kg N/ha (N in product = 35 kg/ha, N surplus = 55 kg/ha) to around 22% at total N input of 300 kg N/ha (N in product = ~ 75 kg/ha, N surplus = 225). The N surplus increased by 170 kg/ha across this range.

In the farm systems experiment, NUE also declined as N in product increased from the ‘control’ treatment (zero fertiliser N input and imported supplement; 50% NUE; Fig. 1). When no supplement was used, maximum N in product (around 90 kg/ha) was reached with 200 kg N fertiliser/ha/year (with an additional ~ 100 kg N/ha coming from biological fixation). These systems were markedly more productive and efficient than the system 1 commercial farms. The systems treatments using supplements (triangles in Fig. 1) were also more efficient at using N than the corresponding system 4 and 5 commercial farms, albeit still resulting in high N surpluses (210 – 350 kg/ha).
Figure 1. Relationships between N surplus and N output in product in grazed dairy systems. Diagonal lines join points of equal nitrogen use efficiency (NUE; 50%, 33% and 25% are shown for comparison). Solid symbols on these lines indicate total N input (kg N/ha per year). Solid lines are fitted curves for commercial farms operating according to the definitions of systems 1, 2, 3, 4 or 5 in the New Zealand dairy industry (after Hedley et al. 2006). Open symbols are means for each of three years for treatments in a farm system experiment: circles = no N fertiliser or imported supplement; diamonds = 200 kg N fertiliser/ha/y, no supplements (2 stocking rates); squares = 400 kg N fertiliser/ha/y, no supplements (2 stocking rates); triangles = 200 kg N fertiliser/ha/y with supplements (three different types) (Macdonald et al. 2017).

Discussion

Whole-farm N surplus is the key nitrogen productivity variable to focus on when adapting farm systems to reduce nitrate leaching (Pinxterhuis et al. 2018). A high NUE does not necessarily lead to a low N surplus and therefore low risk of N loss. Rather, NUE is an indicator of the potential for increasing the efficiency of N use through management, and this needs to occur in tandem with a reduction in N inputs to achieve financial and environmental sustainability. Simply reducing inputs without improving the efficiency of use of those inputs leads directly to lower milk production, as shown by tracing toward the origin on the NUE lines in Figure 1. A combination of lower inputs leading to a lower N surplus, and increased efficiency of use of imported N, is required.

The farm data set used here was characterised by large variation among farms (data not shown), as noted also by de Klein et al. (2017). Hence, there is considerable potential for most farms to reduce N surplus. Farm systems where N inputs total 300 kg/ha per year from all sources (not just fertiliser; biological N fixation can contribute substantial amounts of N, e.g. Ledgard et al. 1999) and converting N and feed inputs to milk efficiently (NUE = 33% or higher) are well-positioned to maintain high milk production with a relatively low N surplus (~ 200 kg/ha) and, therefore, relatively low N leaching risk. Such systems should also be highly profitable (Macdonald et al. 2017). Nitrate leaching mitigation options such as use of feed supplements with low N content will result in only small reductions in environmental N losses if the system continues to operate with a high N surplus.
References