Strategies for increasing dairy production while controlling environmental footprint on dairy farms in Canterbury, New Zealand

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Abstract: Regional Councils across New Zealand are currently setting nutrient limits for groundwater, lakes and rivers in their catchments to preserve water quality. For the dairy industry, nitrogen (N) is the most pressing issue because nitrates from excreta and fertilisers can readily leach below the root zone of pasture into receiving waters. If the New Zealand dairy industry wants to continue to increase production, it has to at least hold, or preferably reduce, total N leaching from land contributing to milksolids production . Several management strategies and tools could be used for this purpose, but they have not been integrated into New Zealand farm systems to measure the production and environmental outcomes. The Pastoral 21 programme in Canterbury is comparing two farming systems taking two different approaches to future industry development. One (HSE) is based on a stocking rate (SR) of five high genetic merit cows/ha with up to 400 kg N applied as fertiliser per year, plus up to 800 kg DM/cow bought-in feed. This system produced 2290 kg milk solids (MS)/ha and was highly profitable (operating profit $NZD5061/ha) but had a relatively high predicted nitrate leaching (35 kgN/ha). The second (LSE) has a SR of 3.5 high genetic merit cows/ha, up to 150 kg N/ha applied as fertiliser, and 40% of the pasture area in a diverse pasture mixture containing herbs and legumes. It was also highly profitable ($NZD 4860/ha) and leached 45% less nitrogen, but produced 500 kg MS/ha less than HSE. Traditionally dairy farm performance per hectare in New Zealand has been assessed using milking platform area only. A comparison between the HSE and LSE systems, including both the milking platform and all other land contributing feed used for milk production, shows that this traditional performance metric over-estimates milk production and underestimates the potential environmental impact of the system. This paper reports on an approach to consider all hectares contributing to the dairy system when calculating physical performance or estimating the potential environmental impact of a dairy farm.

Keywords: dairy, farm system, environment, nitrogen, ground water, productivity

Introduction

The New Zealand Government's National Policy Statement on Fresh Water Management 2011 (https://www.mfe.govt.nz/publications/rma/nps-freshwater-management-2011/docs/nps-freshwater-mgnt-2011.pdf) requires Regional Councils throughout New Zealand to set quality limits for all surface and ground waters in their region. The main nutrients of concern are nitrogen (N) and in some instances phosphorus (P). Nitrogen is more difficult to manage as it moves freely through the soil into water, whereas P usually stays bound to particles within the soil and mainly enters waterways through surface runoff and erosion. Regional nutrient plans will require farmers to reduce N losses in many catchments. What is likely to emerge is a 'target' nitrate leaching limit to be achieved for different categories of farms within the catchment, such as 'x' kg N per hectare per year. Depending on the catchment, soil type and farm system the target could be lower than what many farms are currently achieving. For the dairy industry and for regional economies it is important that potential negative implications of these changes on milk production and farm profitability are minimised.

Nitrogen cycling via the animal is the key point of focus for controlling N losses from New Zealand grazing systems. In grazed systems containing ryegrass and white clover, nitrogen intake far exceeds N output in products, with up to 75% being excreted either in dung (25% of total N eaten) or urine (50% of total N eaten) (Pacheco and Waghorn, 2008). In the urine patch N loadings vary between 500 and 1000 kg N/ha (Whitehead, 1995). These N loadings are in excess of the capacity of the pasture in and around the patch to take up the available N. Urinary N is readily transformed to nitrate in the soil. Nitrate is highly soluble and if not taken up by the plant roots can be carried below the root zone by drainage water. The higher the concentration of N in the diet, the higher the total amount of N excreted per day, the higher the N concentration per urination event and the greater the risk of nitrate leaching.

The risk of nitrate leaching from the urine patch is higher for urine deposited in late summer and autumn than for urine deposited at other times, because plant growth is often restricted and the urinary N is deposited close to the winter drainage period (Shepherd et al. 2010). Consequently plant uptake is low, and because winter and spring rainfall usually exceeds the water holding capacity of the soil, drainage occurs, taking with it the nitrate.

There are a number of strategies that can be adopted to manage nitrate leaching (e.g. reduced stocking rate; cow genetic merit; alternative pasture species; diet manipulation, autumn stand-off) however many of these strategies have implications for the management of the key interactions between pastures and grazing animals that drive production efficiency and lower costs of production. No on-farm research had been undertaken in New Zealand to determine the combined effect of several strategies on productivity and environmental outcomes, plus the associated system management requirements and risks.

Traditionally in New Zealand, physical, financial and environmental performance of dairy farms has been based on the milking platform area only, without considering the areas growing crops, grazing young stock and wintering cows. As dairy systems have intensified, increasing quantities of feed (grain, silage, crops) are being imported onto the milking platform and more winter grazing is occurring off the milking platform. The increased diversity in farm system implementation has resulted in the industry questioning the metrics against which dairy farming businesses are benchmarked. The current 'milking platform hectares only' approach has the potential to overestimate milk production per hectare (Glassey, 2007) and underestimate the potential environmental impact of the whole farm system. Increasing public pressure to achieve nutrient loss targets and improve water quality requires an understanding of the environmental impact of all parts of the dairy business.

The objective of this project was to measure whole-system outcomes of different management strategies for irrigated Canterbury dairy farms that improve production and reduce N leaching and investigate the metrics against which the physical and environmental performance of farming businesses are reported. The paper reports on the first 2 years of physical production results and estimations of environmental impact.

Materials and Methods

In September 2011 two experimental farmlets were established on the Lincoln University Research Dairy Farm, Canterbury, New Zealand (longitude 172°27'E; latitude 43°38'S; 10 m above sea level) using the results of pre-experimental modeling to set targets for productivity and environmental outcomes (Burggraaf et al. 2011; Beukes et al, 2011). Each farmlet had a set of farm management decision rules (MacDonald & Penno, 1998) designed to remove subjectivity from the management of the individual farm systems. Associated with the milking platform was a support block (approximately 3.5 Ha) for each farmlet where cows were wintered on forage crops for 70 days, young stock grazed and from which surplus pasture was conserved.

An overview of the two systems being compared is provided in Table 1. Both farmlets had a strong focus on management efficiency; one based on the traditional pathway of intensification through more cows and more inputs (High Stocking Efficient; HSE) and the second based on reducing stocking rate, focusing on high per cow production through increased pasture intake, and incorporating N loss mitigation strategies such as diverse pastures and reduced N fertiliser inputs (Low Stocking Efficient; LSE).

Table 1: Key management features of the HSE and LSE systems in Canterbury

	Low Stocking Rate Efficient (LSE)	High Stocking Rate Efficient (HSE)
	Milking Platform	
Number of cows	34	29
Area (ha)	6.75	8.25
Stocking rate (cows/ha)	3.5	5.0
Cow genetic merit	Breeding worth 140	Breeding worth 133
N fertiliser base	Up to 150 kg N/ha/year	Up to 400 kg N/ha/year
Pasture base; % area of farm by pasture type	36% diploid ryegrass/white clover; 36% tetraploid ryegrass/white clover; 28% diverse pastures (chicory, plantain, prairie grass, ryegrass, white clover, red clover)	56% diploid ryegrass/white clover; 44% tetraploid ryegrass
Supplementary feed	Up to 100kg DM/cow imported barley	Up to 800 kg DM/cow imported barley
	Wintering support block	
Winter feed	Kale + green chop silage	Fodder beet + pasture silage

Both farmlets were stocked with mixed age, Holstein Friesian x Jersey cross animals. Pasture mass in each paddock was measured weekly by calibrated pasture plate meter and this information was used to help manage pastures and feeding. Nitrogen fertiliser was generally applied after each grazing in the HSE system but less frequently in the LSE system. Milk volume was measured at each milking for all cows. Milk fat and protein were measured fortnightly from separate afternoon and morning milking samples. Nitrate leaching was monitored continuously at each site (milking platform and wintering block) using lysimeters (Di and Cameron, 2007) during periods when drainage water could be collected for analysis of N concentration. Nitrogen leaching and farm-gate N surplus were estimated using the OVERSEER® nutrient budgeting model (Overseer) (Wheeler et al. 2003) for individual blocks in each farm system with the exception of the winter forage crop blocks where leaching results from lysimeter measurements were scaled up and applied to the percentage of the forage crop block covered by urine patches. Operating profit was calculated using a standardised financial template with 2011-12 benchmark costs derived from Canterbury dairy farms in DairyBase®[248] to make the calculation easier to extrapolate to commercial situations.

[248] http://www.dairynz.co.nz/page/pageid/2145871201/DairyNZ_Economic_Survey#779

Results

Physical performance

Key production, profit results and estimated N leaching, average for the first 2 years' of the project, are shown in Table 2 (expressed relative to the milking platform area only) and compared to the outputs from the pre-experimental computer modeling.

Table 2: Average physical and financial performance and estimated nitrogen leaching losses for the LSE and HSE systems from 2011 to 2013, compared to pre-experimental model predictions.

	LSE (actual)	LSE (modeled)	HSE (actual)	HSE (modeled)
Total pasture harvested (t DM/ha)	15.3	16.0	18.3	18.1
Total supplements eaten (t DM/cow)	0.27		0.88	
Silage (t DM/cow)	0.21		0.55	
Grain (t DM/cow)	0.06	0.1	0.33	0.8
N fertilizer used (kg N/ha)	160	150	324	400
Days in milk (days)	269	-	257	-
Milk solids produced (kg/cow)	511	453	458	437
Milk solids produced (kg/ha)	1789	1588	2290	2184
Farm working expenses (NZ$/kg MS)	3.93	-	4.43	-
Operating profit (NZ$/ha)	4860	4334	5061	4810
N leaching (kg N/ha) [Overseer]	19	24	35	38

During the 2011-12 and 2012-13 production seasons both systems exceeded modeled per cow and per hectare milk production targets and returned high operating profits. On average the LSE herd achieved 12 more days in milk than the HSE herd and was less reliant on bought-in supplementary feed. In the LSE herd, N use in year 1 exceeded expected usage by 21 kg N/ha. Pastures were visibly N deficient in late summer/early autumn prompting the decision to apply an 'extra' round of N fertilizer to ensure pasture cover targets at drying off were met. Nitrogen leaching estimates from the milking platform were lower than the pre-experimental predictions for both farm systems.

Accounting for additional hectares

The two systems have different footprints generated by differences in stocking rate, feed inputs and wintering system, prompting the need to consider all land and other inputs into each system to generate a true comparison of performance and environmental impact. For ease of comparison the information from each research farmlet was scaled to represent an average Canterbury dairy farm with a 150 ha milking platform. Total resource use under the 'all hectares counted' scenario is presented in Table 3. Predictions are also provided for the alternative wintering system within each farm system i.e using fodderbeet in the LSE system or kale in the HSE system to allow farmers to consider the likely impact of a change in wintering practice on their farm. The land area required for each block ie winter crop support, winter support-pasture etc was estimated based on measured crop yields, winter feed requirements and supplementary feed inputs.

Table 3: Estimated total land resource requirement (ha) and tonnes of nitrogen fertiliser required for a 150 hectare Canterbury dairy farm based on resource use in the LSE and HSE farmlets.

	LSE (525 cows)		HSE (750 cows)	
Hectares (ha)	**Kale (actual)**	**Fodderbeet (modeled)**	**Fodderbeet (actual)**	**Kale (modeled)**
Milking platform	150	150	150	150
Winter support – crop	34	12	18	49
Winter support – pasture	23	25	35	33
Grain production# (purchased)	3	3	26	26
Silage* (purchased)	6	18	64	29
TOTAL	**216**	**209**	**294**	**287**
N fertiliser used (tonnes)	**Kale**	**Fodderbeet**	**Fodderbeet**	**Kale**
Milking platform	24.1	24.1	48.5	48.5
Winter support – crop	9.7	2.1	3.1	13.8
Winter support – pasture	4.7	5.4	7.3	6.8
Grain production (purchased)	0.6	0.6	4.6	4.6
Silage (purchased)	0.4	1.3	4.8	2.2
Total tonnes N	39.5	33.5	68.3	75.9

assuming 9 T DM/ha yield; * assuming 6 T DM/ha yield from 3 harvests

Based on the information in Table 3 the performance relative to total land resource use ('all hectares counted') can be estimated (Table 4). The milksolids per hectare performance reversed when all hectares were included such that the LSE system produced at a higher level, however the difference between the systems was markedly reduced. The LSE system maintained a lower nitrate leaching loss, although the difference reduced from 16 kg N/ha to only 5 kg N/ha when all hectares were considered. A farm system incorporating fodderbeet for wintering resulted in lower estimated N leaching losses (Table 4). Operating profit per kg of N leached was higher for the LSE kale system than the HSE fodderbeet system.

Table 4: Estimated performance, relative to total land resource use, for a 150 hectare Canterbury dairy farm based on resource use in the LSE and HSE farmlets.

	LSE		HSE	
	Kale (actual)	**Fodderbeet**	**Fodderbeet (actual)**	**Kale**
Milk solids (kg/ha)	1245	1302	1174	1201
N surplus[1] (kg/ha)	103	78	200	208
N conversion[2] efficiency (%)	46	54	29	29
Nitrate leached[3] (kg N/ha)	33	24	38	49
Operating profit (NZ$/ kg N leached)	147	-	133	-

[1]((total fertilizer N plus N imported in purchased feed)-(N exported in milk))/total hectares

[2]((N exported in milk)/ (total fertilizer N plus N imported in purchased feed))x 100

[3]Overseer® for milking platform and arable area; lysimeter data for wintering area scaled for % grazed area covered by urine patches.

Discussion

Management challenges

Two management challenges identified prior to the project (Clark et al. 2011) were encountered.

1. Achieving high per cow production from pasture while maintaining pasture quality

The traditional development pathway in New Zealand dairy farms has been to maximize pasture harvested by increasing stocking rate (MacDonald et al. 2008). In the context of New Zealand dairy farms, stocking rate is a combination of cows/hectare, cow liveweight and cow genetic merit as all these factors contribute to total feed demand. At five high genetic merit cows per hectare feed demand relative to supply in the HSE system was high and high rates of pasture utilization were easily achieved. In contrast, at 3.5 cows per hectare the feed demand in the LSE system was much less. Despite the reduced feed demand being offset by lower annual pasture harvested (3 t DM/ha, Table 2) in the LSE system, the challenge was to minimize pasture wastage at the same time as ensuring pasture quality was not compromised. Diverse pastures (with chicory, plantain and legumes) were incorporated into the LSE system to help maintain pasture quality and maximize pasture intake during summer. Regular assessment of pasture cover and grazing residuals was required to allow timely and accurate decisions regarding rotation length, N fertilizer use, silage conservation, pre-graze mowing and supplementation feeding. As a result of active management pasture growth and quality was maintained at a high level throughout the season. For farmers considering such a system the management tools are available to support them in their decision making, however a higher degree of management input and skill is required for successful implementation of the LSE system.

2. Nitrogen fertilizer management

Nitrogen fertilizer use on dairy farms in New Zealand has increased sharply since 1990 (MPI 2012) to support the increases in stocking rate and feed demand. In 2010/11, average N fertilizer use on Canterbury dairy farms was 247 kg N/ha (DairyNZ, 2010). A notational 'limit' of 150 kg N/ha per year was set for the LSE system because pre-experimental modeling and previous research (Ledgard et al. 2006) indicated that total nitrate leaching is very sensitive to the amount of N fertilizer applied. The issue is not direct leaching from the applied fertilizer, but rather the increase N flowing through cows consuming pasture with higher N% in the dry matter, resulting in a greater amount of surplus N being excreted in the urine.

For the HSE system with no notational N limit the N fertilizer application policy was straightforward, with approximately 30-35 kg /ha being applied, as urea, after every grazing from early September to late April, plus an early season (August) application of ammonium sulphate. For the LSE system, N was withheld for significant periods, leading to visible signs of N deficiency in pasture, especially early in the season. Developing decision rules for optimizing pasture grown from amounts of N fertilizer that are significantly less than farmers have become accustomed to using is a key requirement from this project.

Farm system footprint

Traditionally, New Zealand dairy farms were based on grazed pasture with pasture silage made from the milking platform as the main source of supplementary feed. However, intensification of the industry has resulted in major changes in the feedbase on many farms, with increasing amounts of maize silage, cereal grain, palm kernel expeller and winter grazing being used to support higher stocking rates. Farms are now classified on a 1-5 scale based on the amount of additional feed brought into the system as either supplementary feed or grazing off farm either as young stock or during winter.[249] A system 1 farm is all grass self-contained, with all stock on the

[249] http://www.dairynz.co.nz/page/pageid/2145861231/The_5_Production_Systems

dairy platform while a system 5 farm imports 25-40% of feed for use throughout lactation and for dry cows. As a result of the increased diversity in farm system operation, using the milking platform area as the unit for benchmarking physical and environmental performance e.g. milksolids/ha, kg N leached/ha does not fully reflect the performance of the total dairy system. For farms , importing significant quantities of feed, benchmarking against milking platform area has the potential to overestimate milk solids production per hectare and underestimate the environmental impact of the dairy system.

As Regional Councils across New Zealand start setting nutrient limits for groundwater, lakes and rivers in their catchments it is important to understand the environmental impact of the whole farm system, not just the milking platform. This is particularly important in farm systems where cows are wintered off farm on forage crops as research has reported that nutrient losses from grazing winter forages are significantly higher than from grazed pastures (Smith et al. 2012). To allow farmers to react to potential regulatory changes they need to understand the performance and impact of their total dairy system. The project reported in this paper provided an ideal opportunity to introduce to the Canterbury dairy industry and the notion of including all hectares required for a full year of dairy operation, ‘all hectares counted’, for benchmarking physical and financial performance.

Based on the milking platform hectares the HSE system produced 28% more milk solids and was $201/ha more profitable than the LSE system. However, when the hectares associated with growing the grain and pasture for silage and grass and crop for wintering were included the performance ranking changed. Glassey et al. (2007) also reported a change in the ranking of six farms when performance was re-calculated using all hectares. The farm where the ranking shifted most was the farm with the highest total feed supply, the highest proportion of imported feed and the most varied types of supplementary feeds. On an ‘all hectares counted’ basis the LSE system produced 6% more milk solids per hectare with a lower environmental footprint. Estimated nitrate leaching from the milking platform of the LSE farmlet was 16 kg N/ha less than the HSE milking platform and 5 kg/ha less when all hectares were included. However, including the leaching losses from the cropping and support areas of the system increased the total loss for both systems. The inclusion of fodderbeet as the winter forage source in the HSE system resulted in a smaller increase relative to the milking platform due to the smaller area required to grow the higher yielding fodderbeet crop and the lower dietary N intake with the fodderbeet diet. Incorporation of fodderbeet into the LSE system could be a strategy to reduce the environmental footprint of this system to meet potential N loss limits.

The choice of system and implications for whole-of-resource use within catchments is region and time dependent. A higher stocked system may only be viable where additional land is available, catchments can absorb more nitrate-N and communities agree that the impact on water quality is acceptable. For catchments approaching their limits for N loading or in communities wanting to improve water quality the LSE system could allow continued industry growth. Extrapolating the results of this study and assuming the dairy system was being supported by land within a single catchment, 15% more area could be dedicated to dairying, for the same estimated N losses, if all farms were achieving the estimated losses of the LSE system, compared with the HSE system.

By understanding the physical and environmental performance of all parts of the dairy system farmers can make informed decisions to ensure their business remains productive while also meeting the regulatory and community expectations for the catchment within which they operate.

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