Can low input dairy systems be economically and environmentally sustainable? Results from a farmlet study.

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Abstract

A two-year dairy study was conducted under irrigation at Lincoln, Canterbury, comparing 1. Moderate stocking rate (MSR, 3.9 cows/ha; comparative stocking rate (CSR) of 89 kg live weight (LWT)/t DM (dry matter) offered; 150 kg nitrogen (N) fertiliser/ha/year; grain supplementation of 0.55 t DM/cow/year; wintering cows off- farm); or 2. Low stocking rate (LSR, 2.9 cows/ ha; CSR of 91 kg LWT/t DM offered; grazing diverse pasture (Italian ryegrass, plantain, red- and white clover); 103 kg N fertiliser/ha/year; wintering cows on-farm). The Lincoln University Dairy Farm (LUDF; 3.4 cows/ha; CSR of 76 kg LWT/t DM offered; 169 kg N fertiliser/ha/year) was the benchmark. Milk yield, pasture production and quality data were modelled in FARMAX and OverseerFM to estimate financial and environmental performance of each farm. Performance was similar for MSR and LUDF. LSR gave the best environmental outcome across 2018/19 and 2019/20, leaching approximately 31% less N compared with MSR and LUDF. However, annual milk solids per ha were 28% less for LSR relative to MSR and LUDF. Correspondingly, the annual operating profit per ha was 35% less for LSR compared with LUDF. These financial losses can be mitigated in an LSR system if the farmer adopts more complex pasture management.

Keywords: N leaching, stocking intensity, farm profit, diverse pasture

Introduction

Farming sustainably with low nutrient losses and greenhouse gas emissions will require large shifts in farming practices in some regions. Regulatory change around nitrate leaching from farmland (Ministry for the Environment 2011) has forced farmers to consider reducing the environmental impact of their businesses while minimising any loss in profitability. Research has shown the efficacy of a range of strategies that have the potential to reduce the environmental impact of farming. Mitigations include reducing N input with possible consequences for stocking rate and feeding forages and supplements that reduce methane and improve N use efficiency (Beukes et al.*,* 2017). However, many of these mitigations may lead to reductions in profitability (Howarth and Journeaux 2016) and there is uncertainty whether the mitigations are additive when adopted in practice (Chapman et al.*,* 2021). Future advances in technology, such as the application of sensors and digital or modelling tools to improve management of stock or nutrient cycling, may improve farm efficiencies to the extent that intensive farming can continue without detriment to environmental, economic or animal welfare targets. The difficulty in making comparisons between commercial farm systems may be due to differences in the environment and/or cost of testing multiple mitigation combinations; hence, the use of modelling tools is required to narrow down suitable options. Farm systems research using farmlets provides an opportunity to validate modelling and identify any pitfalls or benefits when implementing alternative systems before adoption at scale.

In the Pastoral 21 research programme (2011/2012–2014/2015), a low input (3.5 cows/ha, 150 kg/N/ha, 85 kg LWT/t DM offered) and high input (5.0 cows/ ha, 400 kg/N/ha, 93 kg LWT/t DM offered) Canterbury dairy system were investigated in a farmlet experiment and compared with a commercial demonstration farm (LUDF, 4.0 cows/ha, 313 kg N/ha; Chapman et al.*,* 2021). The results indicated that a low input system could achieve better environmental outcomes with little effect on profit. To understand the impact of nutrient input, it is important to consider whether farmers can continue what is now considered moderate input systems (described in Chapman et al.*,* (2021) as low input) with acceptable environmental outcomes. Alternatively, farmers may have to follow a low input pathway, leading to further reductions in stocking rate while adopting forage innovations that are likely to reduce profit (Al-Marashdeh et al.*,* 2021) as they strive to meet new regulatory environmental targets to reduce nitrate leaching further by 40-60% (Ministry for the Environment 2011).

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The objective of this study was to determine those factors influencing the physical, financial, and environmental success of Canterbury's potential low and moderate input future dairy farm systems by analysing data from two years, 2018/19 (year 1) and 2019/20 (year 2) of farmlet research. This work was most relevant to Canterbury dairy farms, but there is potential to extrapolate and apply the findings to dairy farms across New Zealand.

Materials and Methods

Farm Systems Design

A farm systems comparison was carried out under irrigation at the Lincoln University Research Dairy Farm in Canterbury (43°38′S, 172°28′E; 10 m above sea level) between June 2018 and May 2020 on free draining Templeton silt loam soil. During the period of the study, total annual rainfall was 639 mm in 2018/19 and 463 mm in 2019/20.

Two farm systems were established, one with a 15% increase compared to the average regional stocking rate (3.9 cows/ha, moderate stocking rate, MSR compared to 3.4 cows/ha, (DairyNZ 2018)) and the other with a 15% decrease in stocking rate (2.9 cows/ha, low stocking rate, LSR). Lincoln University Dairy Farm (LUDF), a high producing (500 kg milk solids[MS]/cow/year) commercial dairy farm (DairyNZ 2018), was used as a benchmark farm system for comparison. LUDF grazes 3.4 cows/ha on 144 ha of perennial ryegrass (*Lolium perenne*, *cv*. Bealey and Trojan) and white clover (*Trifolium repens*, *cv*. Sustain) pasture with 10% of the milking platform (16 ha) sown in diverse pasture (perennial ryegrass and white clover plus plantain (*Plantago lanceolata* L.), and chicory (*Cichorium intybus*)). Nitrogen fertiliser was applied at 169 kg N/ha/year in the LUDF system. The feed supply for the MSR farm system included permanent perennial ryegrass (*cv.* Arrow) and white clover (*cv.* Legacy and Tribute) pastures, fertilised with 150 kg N/ha/year. During lactation (August to May), cows were offered crushed barley grain supplement (0.55 t DM/cow/year bought in) and during the non-lactation period (June and July) they were wintered off-farm on a kale crop. The LSR farm system had 45% of the farm area in diverse pasture, which contained plantain (*cv.* Ecotain), Italian ryegrass (*Lolium multiflorum*, *cv.* Asset), red clover (*Trifolium pratense*, *cv.* Relish) and white clover (*cv.* Tribute), with the remaining area as perennial ryegrass and white clover pasture. The LSR farmlet was fertilised with 100 kg N/ha/year. The LSR farmlet wintered non-lactating cows off-farm on kale during year 1 due to feed shortage but the cows remained on-farm in year 2 to reduce costs and maintain profit. Winter grazing on the LSR farmlet occurred over 100 days with pastures grazed again in spring.

Management

Animal Management

Allocation and management of the cows and pastures have been described previously (Bryant et al., 2021). Briefly, 80 crossbred Holstein-Friesian x Jersey dairy cows (16 primiparous and 64 multiparous) were blocked according to genetic merit and LWT and age and randomly assigned to one of the two farm systems. Cows calved in spring, from 1 August, and calving was spread over 10 weeks in both years. Due to a higher number of non-pregnant cows on both farmlets, the heifer replacement rate increased from 20% in year 1 to 25% in year 2.

Grazing Management

Twenty-four hectares, consisting of 1.5 ha blocks, were subdivided into ~0.5 ha paddocks (0.4-0.6 ha) and allocated to LSR (14 ha) and MSR (10.4 ha). The herbage mass in each paddock was determined weekly from the compressed height of a rising plate meter (Jenquip F150 Electronic Pasture Meter, Fielding, New Zealand) using the manufacturers equation for mass for all pasture types:

$$\text{kg/DM/ha} = 140 \times \text{height reading} + 500$$

Each paddock was then ranked according to pasture mass from highest to lowest to allow decisions regarding grazing management. Grazing decision rules, supplement management, mating and drying-off management followed the criteria outlined by Macdonald and Penno (1998). Pre-grazing covers ranged between 2800-3000 kg DM/ha with target post-grazing compressed residual of approximately 4 cm (1500 kg DM/ha). Cows in the MSR system were offered 2.5 to 3.0 kg DM/day crushed barley grain split evenly between morning and afternoon milking during every day of the milking season using an in-shed feeding system.

The LSR and MSR farmlets were irrigated using a centre pivot irrigator with overhead sprinklers. Irrigation frequency varied according to rainfall and ability to irrigate due to mechanical issues with the irrigation system. Water application ranged between 4-6 mm per application with a target application of 375 mm applied during each year. Effluent application was similar across LSR and MSR at a rate of <12 mm per application for both years; however, total effluent application per year was not recorded.

Measurements

All animal measurements were carried out with the approval of the Lincoln University Animal Ethics Committee (AEC2019-43). Cows were milked twice daily, in the morning (06:00) and afternoon (14:30). Individual cow milk volume was automatically measured at each milking (Delpro, De Laval) and milk composition was determined approximately fortnightly by sub-sampling 20 ml of milk from herd test flasks at consecutive afternoon and morning milkings. Subsamples were analysed for percentages of fat and protein, by mid-infrared spectrophotometry (MilkTestNZ, Hamilton) for determination of MS production. Cow live weight was recorded daily by an automatic walk-over weighing system (DeLaval) and body condition score (10-point scale, where 1 is emaciated and 10 is obese; (Roche et al., 2009) was determined monthly.

Herbage was sampled fortnightly by hand plucking random samples across a paddock just prior to grazing to the previous grazing residual (annual average residual compressed height of 6.7 cm), totalling approximately 500 g fresh weight herbage, and analysed for botanical and nutrient composition. Herbage samples were separated into sown and unsown species and dead material, and then oven dried for 24 h at 60°C prior to weighing. Samples for nutrient analyses were freeze dried and ground to pass through a 1 mm sieve and analysed for: organic matter, soluble sugars and starch, neutral and acid detergent fibre, crude protein, and digestible organic matter in the dry matter, (DOMD) by near infrared spectrophotometry (NIRS, Model: FOSS NIRS Systems 5000, Maryland, USA). Metabolisable energy content (MJ ME/kg DM) was estimated from DOMD x 0.16.

Modelling

The economic performance of each farmlet was simulated using a commercial modelling tool (FARMAX DairyPro, Version 8.1.0.54, Hamilton, New Zealand; https://www.farmax.co.nz/) using actual milk production, milk composition, pasture production and quality data for the years studied (Bryant et al., 2010). The FARMAX default database for dairy farming operating costs and farm expenditure in the Canterbury area was used to estimate farm working expenses for both years. Milk price was set at NZD 6.75 per kg MS, which was the average milk price set by Fonterra Co-Operative Group Limited (Interest 2022) across the two years. FARMAX predicted profitability (measured as farm operating profit) by calculating total revenue from net milk sales to a milk company relative to cow production, livestock sales and net change in feed inventory minus total farm working expenses (Bryant et al., 2010). Total farm working expenses, assumed to be the same across both farm systems, were the sum of labour/wages, livestock and feed expenses, cost incurred for grazing livestock replacements and wintering cows off farm, expenses such as fertiliser, irrigation, weed and pest control, vehicle expenses, repairs and maintenance, and overhead expenses including administration, insurance, ACC, rates and depreciation.

The environmental footprint of each farmlet was simulated using OverseerFM (version 6.3.4; Wellington, New Zealand; https://www.overseer.org.nz/; Science Advisory Panel 2021). The model estimated farm gate nitrogen (N) surplus (inputs including symbiotic fixation minus outputs in products), drainage, nitrate leaching losses and greenhouse gas emission based on production input and output, soil type and climate (Wheeler et al., 2006). The model version used accounted for the effect of plantain on urinary N excretion and subsequent N load (Shepherd 2020).

Results and Discussion

Despite differences in N fertiliser inputs and pasture composition (Tables 1 and 2), modelled annual pasture production of the MSR and LSR farmlets on the same soil type were similar (16.3 t DM/ha/year, Table 1), and comparable to 16.5 t DM/ha/year, as recorded by Chapman et al., (2021) at the same site.

Pasture composition (Table 2) comprised 90 and 75% sown species in the first and second year respectively, the remainder comprised unsown species and dead material.

The MSR and LSR farmlets differed in distribution of seasonal feed supply (Figure 1). Diverse pastures containing deep rooted legumes and herbs are known to have improved summer growth (Nobilly et al., 2013) and the cool season activity of the Italian ryegrass component likely supported the winter growth in year two (Woods et al., 2018). At a lower stocking rate, rapid late spring growth presented challenges with managing feed quality during peak pasture growth. The lower pasture utilisation in spring reduced pasture quality and coupled with subsequent low autumn growth resulting in poor pasture performance in autumn. Even though decision rules around pasture conservation were in place, delayed contract services in spring prevented surplus LSR pasture being harvested in a timely manner to maintain a consistent rotation length, which resulted in cows grazing lower quality pasture, as shown in Table 2.

The balance between pasture allocation and utilisation and short- and long-term animal production is complex. Early season gains in animal performance from the generous pasture allocation were likely offset by lower utilisation and reduced sward quality and animal performance at subsequent grazings (Hoogendoorn et al., 1992). Low utilisation can reduce pasture production through increased age of leaf material and low net assimilation rate (Brougham 1957). Low utilisation likely contributed to differences in pasture yield between the farmlets and the LUDF farm, whereby annual pasture yields across both years were 17% lower for both farmlets (Table 1). Other factors contributing to these differences included soil fertiliser, irrigation and cultivar sown. Further, given that most of the variation was explained by increased pasture growth in the autumn on LUDF relative to the MSR and LSR farmlets, this indicated better recovery of pasture post-flowering. In addition to grazing management, lower stock numbers in the LSR farmlet, and challenges with the irrigation system in the two farmlets explained the low pasture growth rates during summer relative with LUDF (Moot et al*.,* 2008).

Milk production

On a per ha milking platform basis, MS production was similar between LUDF and MSR, but 28% lower for LSR. The lower MS production per ha on the LSR farmlet was likely due to a combination of lower stocking rate and lower production per cow (Clark et al*.,* 2020). Milk solid production per cow was 9% and 13% less for MSR and LSR, respectively, compared with LUDF. Lower production (MS per cow) between the MSR and LSR farmlets and LUDF can in part be

Table 1 A physical and farm production summary of each farm system; a high performing commercial dairy farm (Lincoln University Dairy Farm [LUDF]; 3.4 cow/ha); a low stocked farmlet (LSR; 2.9 cows/ha) with diverse pasture; and a moderate stocked farmlet (MSR; 3.9 cows/ha) using grain supplement.

Parameter		2018/2019			2019/2020		
	Units	LUDF	LSR	MSR	LUDF	LSR	MSR
Pasture Yield	t DM/ha	19.7	15.8	16.5	19.4	16.6	16.1
Nitrogen fertiliser	kg N/ha	166	94	150	172	111	150
Herd							
Peak Cows Milked	cows	552	40	40	555	40	40
Days in Milk	days	278	261	259	283	242	243
Average BCS at calving	BCS	4.9	5.2	5.1	4.9	5.0	5.2
Total Liveweight per ha	kg/ha	1,665	1,367	1,914	1,666	1,422	1,833
Feeding							
Pasture offered	t DM/cow	5.2	4.2	4.1	5.1	4.5	3.8
Silage fed	t DM/cow	0.23	0.37	0.15	0.49	0.01	0.02
Barley grain fed	t DM/cow	0	0	0.54	0	0	0.55
Production*							
Milk solids	kg/ha	1,721	1,308	1,870	1,757	1,185	1,574
Milk solids	kg/cow	499	458	481	506	415	433

*Excludes milk fed to calves.

Table 2 Average annual botanical composition and nutritive value (% of dry matter, DM) of herbage for a moderately stocked farmlet (MSR; 3.9 cows/ha) using grain supplement and a low stocked farmlet (LSR; 2.9 cows/ha) with diverse pasture.

Parameter	2018/2019				2019/2020			
	LSR		MSR		LSR		MSR	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Grass (%)	64.8	0.2	79.9	0.1	42.4	21.0	58.5	19.6
Legume (%)	10.3	10.6	8.4	7.2	13.4	10.2	12.0	8.2
Plantain (%)	16.7	20.9	2.7	6.4	20.1	11.6	5.0	21.0
Crude protein (%)	20.4	4.2	21.9	3.3	20.4	0.4	22.0	2.1
Neutral detergent fibre (%)	42.6	5.3	43.8	4.0	44.1	1.3	46.3	1.8
Metabolisable energy (MJ /kg/DM)	11.7	0.7	11.8	0.5	10.8	0.2	11.2	0.5

Botanical composition and pasture quality for year 1 have been presented previously by Bryant et al., (2021)

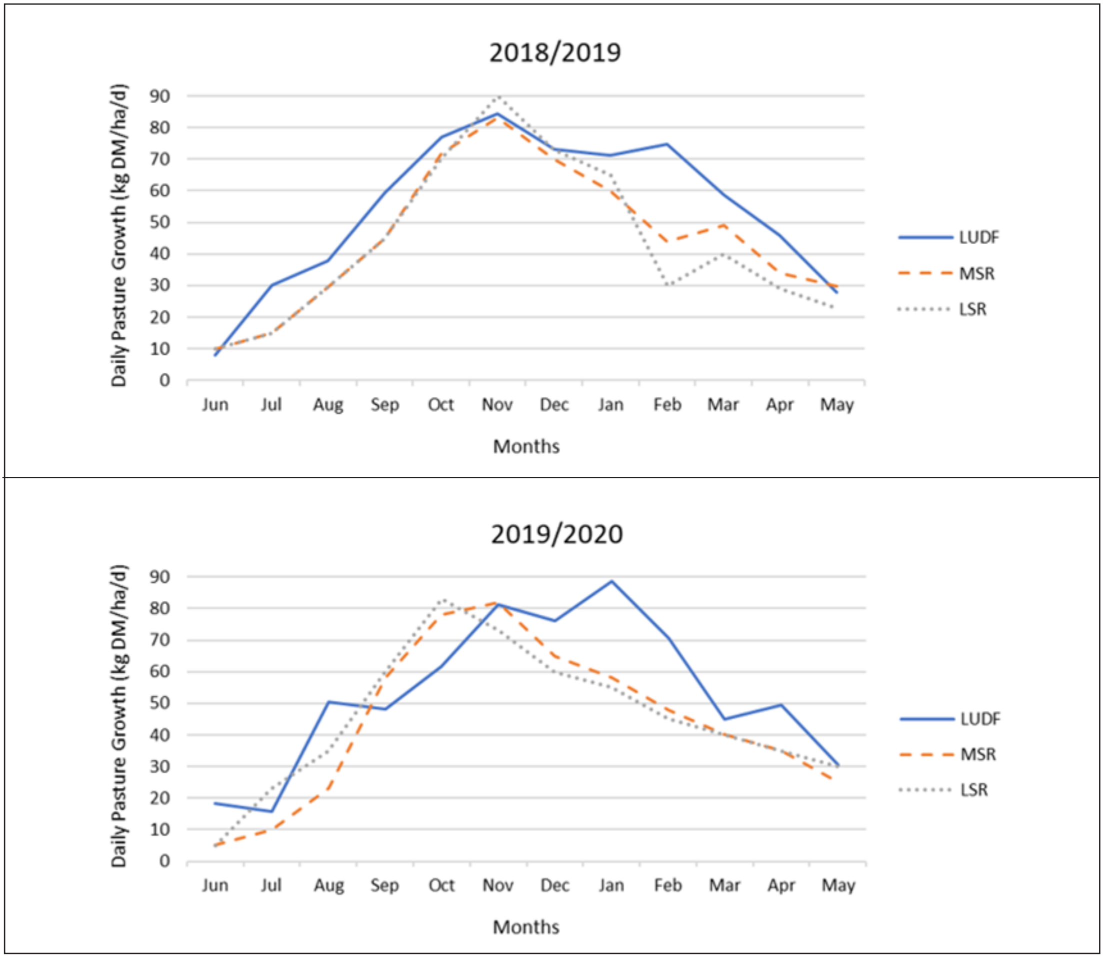

Figure 1 Average monthly pasture growth (kg DM/ha/d) estimated using a rising plate metre across different months of the year (June to May) for a high performing commercial dairy farm (Lincoln University Dairy Farm [LUDF]; 3.4 cows/ha) compared with a low stocked farmlet (LSR; 2.9 cows/ha) with diverse pasture and a moderate stocked farmlet using grain supplement (MSR; 3.9 cows/ha).

attributed to the difference in CSR, where every unit decrease in CSR could be linked to an increase of 4.5 kg MS/cow (Glassey et al., 2012). Achieving high per cow production in the LSR system was challenging due to lower feed quality in year 2 (Table 2) and the late season drop in pasture growth in both year 1 and 2 (Figure 1), which led to higher supplements requirement and/or earlier dry off. At the lower stocking rate of 2.9 cows/ha for LSR, maintaining consistent pasture utilisation during surplus periods was difficult and, as a result, pre-graze pasture mass exceeded targets, resulting in a decline in quality (Bryant et al., 2021). During the second year, the autumn decline in pasture growth was anticipated and cows were dried off earlier than the other systems, to build pasture cover for wintering cows on farm.

Foremost, the lower milk production (within and across years) for LSR and MSR relative to LUDF was driven by fewer days in milk. A decrease in milk production (to the factory) for LSR and MSR in year 2 relative to year 1 is mainly due to fewer days in milk as mentioned above but could, in part, be due to increasing the milk allocation to heifer calves from 5 L to 8 L.

Economics

Modelled farm revenues and working expenses (Table 3), averaged over the two years, were 28% and 29% lower for LSR compared with MSR on a $/ha basis, but relatively similar when compared on a $/kg MS basis (less than 1.6% difference). As a result, the operating profit (Table 3) generated was 30% greater for MSR than LSR. Relative to LUDF, farm revenue and farm working expenses were 22% and 12% lower for LSR, on a $/ha basis. In contrast, MSR generated an 8% greater revenue, with 24% higher farm working expenses incurred compared with LUDF on a $/ha basis. When compared on a $/kg MS, the two farmlets (LSR and MSR) generated 9% and 10% more revenue than LUDF, but with higher farm working expenses (24% and 26%). Thus, average farm operating profits over the two production years for the LSR and MSR farmlets were $1,971 and $411 (35% and 7% respectively) less on a per hectare basis and 7% and 4% less on a per kg MS basis, compared with LUDF.

Environmental footprint

Lower fertiliser application and grazing diverse pasture in the LSR farmlet resulted in a 27% lower N surplus at the farmgate compared with either MSR or LUDF (Table 4). Modelling estimated that the LSR system had 31% less N leached and emitted 27% less GHG compared with MSR and LUDF (Table 4). A similar farm systems study with dairy cows grazing diverse pasture, containing plantain and Italian ryegrass, had a predicted 35% reduction in the relative risk of N leached and 8% less GHG emitted (Al-Marashdeh et al., 2021). These results were consistent with previous research that demonstrated the positive impact of plantain in reducing urinary N load and the relative risk of N leaching (Mangwe et al., 2019). However, further research is required to determine how monthly and seasonal differences in N inputs and outputs can improve these farm systems. In addition, further work is required to examine the long-term effects of using

Table 3 Estimated farm economics (from Farmax model) for a commercial dairy farm (Lincoln University Dairy Farm [LUDF]; 3.4 cows/ha); and two future dairy farm systems, a low stocked farmlet (LSR; 2.9 cows/ha) with diverse pasture and moderate stocked farmlet (MSR; 3.9 cows/ha) using grain supplement.

	2018/2019			2019/2020		
Units	LUDF	LSR	MSR	LUDF	LSR	MSR
Farm Revenue						
$/ha	11,355	9,139	13,154	12,883	9,787	13,024
$/cow	3,291	3,199	3,387	3,734	3,425	3,581
$/kg MS	6.60	6.99	7.04	7.33	8.26	8.27
Farm Working Expenses						
$/ha	5,515	5,017	7,133	6,182	5,310	7,327
$/cow	1,599	1,756	1,837	1,792	1,859	2,015
$/kg MS	3.20	3.84	3.81	3.52	4.48	4.65
Farm Profit						
$/ha	5,202	3,484	5,384	6,063	3,839	5,059
$/cow	1,508	1,219	1,386	1,757	1,343	1,391
$/kg MS	3.02	2.66	2.88	3.45	3.24	3.21

Table 4 The environmental outcomes of each farm system (from Overseer model) for a commercial dairy farm (Lincoln University Dairy Farm [LUDF]; 3.4 cows/ha); and two future dairy farm systems, a low stocked farmlet (LSR; 2.9 cows/ha) with diverse pasture and a moderate stocked farmlet (MSR; 3.9 cows/ha) using grain supplement.

		2018/2019			2019/2020		
	Units	LUDF	LSR	MSR	LUDF	LSR	MSR
Farmgate N Surplus	kg N/ha/year	267	201	305	277	196	246
N leached	kg N/ha/year	31	21	35	31	22	27
GHG emitted	kg CO_2-equivalents/ha/year	16,210	12,207	17,801	16,522	11,674	15,043
N leached	kg N/kg MS	0.018	0.016	0.019	0.018	0.019	0.017
GHG emitted	kg CO_2-equivalents/kg MS	9.42	9.33	9.52	9.40	9.85	9.56

*Total GHG (Greenhouse gas) emissions include methane, carbon dioxide and nitrous oxide predicted using the Overseer Model (version 6.3.4).

diverse pastures with plantain in conjunction with strategic and tactical strategies targeting N leaching at critical periods when the risk of N leaching is high. Such longer-term work is critical to assist farmers to understand and manage the implications of using diverse pastures combined with other mitigation strategies, to limit any adverse effects on operating profit.

The difficulty in maintaining good economic outcomes whilst lowering environmental impacts is well recognised (Howarth and Journeaux 2016). Howarth and Journeaux (2016) investigated the environmental and profit impact of adopting three different mitigations; reduced N fertiliser, low N supplements and stand-off. They showed that adopting these strategies to achieve N leaching reductions greater than 20% resulted in large negative shifts in profitability. Previous dairy farm systems research using farmlets has demonstrated that Canterbury dairy farms could potentially reduce nitrate leaching by 30% relative to regional benchmarks, without negative effects on farm profit (Chapman et al., 2021). While the LSR system indicated that farmers can achieve further reductions in nitrate leaching (>30%) compared with MSR and LUDF through lower N input and the use of diverse pastures. The current results suggested that this will come at a significant cost of profitability. The difference in operating profit between the figures reported by Chapman et al. (2021) and the LSR system in the current study was attributed to the use of diverse pastures. This highlighted the importance of implementation of mitigation strategies in conjunction with effective and efficient use of pasture and supplements. The LSR system achieved a lower modelled environmental footprint per ha compared with MSR and LUDF, hence, the only way to reduce the environmental impact as currently modelled, is to reduce N inputs and production per hectare, unless a breakthrough technology is developed.

Conclusion

The purpose of this study was to demonstrate if current Canterbury farm systems could continue to reduce N input through lower fertiliser application and the use of diverse pastures (plantain and Italian ryegrass) to reduce the environmental footprint of dairy farming. This study highlighted the importance of implementing correct management decisions at critical periods to ensure pasture growth matches animal demand. The main challenges farmers face when de-intensifying their farming practices to meet regulatory compliance around nitrate leaching, are reduced production and operating profit. Implementation of the current LSR system warrants further investigation, to determine how farm management decision rules can be improved to reduce N surplus with minimal impact on operating profit.

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