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FARM SYSTEMS AND DIET MODELLING OF GREENHOUSE GAS EMISSIONS, NITROGEN LOSSES AND ECONOMIC PERFORMANCE OF DIFFERING DIET AND LAND USE SCENARIOS FOR A WAIKATO DAIRY FARM

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Abstract

Whole farm systems modelling was undertaken to investigate the impacts of multifactorial alterations within a farming system to Greenhouse gas (GHG) emissions, nitrogen (N) losses, farm productivity and profitability. The control farm was created using data from a DairyNZ economic survey (DairyNZ, 2019), with the intention of representing an 'average farm' for the Waikato region for the 2018/19 season. Whilst the physical farm parameters remained constant across the scenarios, progressive alterations were made to variables such as stocking rate, cow size, genetic merit and concentrate feed input. Modelling software Udder (version 3.19.1), RedSky (version 5.04.02) plus Excel spreadsheet and Overseer (version 6.4.0) were used to predict the productive, economic and environmental outcomes of 4 scenarios each with increasingly fewer, but larger cows of higher genetic merit whilst being fed increasing amounts of a concentrate feed, to a maximum of 18.5% of the diet – the alternative scenarios utilising a pasture /forage /concentrate diet (PFC diet). Whilst maintaining the same physical parameters as the control farm, these four alternative scenarios were constructed with the express aim to keep farm milk production similar to the control scenario, whilst varying parameters such as stocking rate, cow size and cow genetic merit. A fifth alternative scenario was also modelled with the aim of reflecting current industry advice; this consisted of the same baseline farm system as the control farm, with a 15% reduction in stocking rate, without use of concentrate feeds (pasture /forage diets, PF).

Critically, the purpose of utilising concentrate feeds in this modelling was not to intensify the system by increasing the stocking rate or total farm milk production; rather, concentrate feeds were utilised to increase the per cow production compared to the lower level of production per cow that would be possible in a forage only system, allowing the total annual production to remain the same across the scenarios.

Whole farm systems modelling showed compounding effects of the multifactorial farm system alterations; by moving to a PFC diet (reducing the forage content and increasing the concentrate portion of the diet to a maximum of 18.5%), using larger cows of higher genetic merit, and maintaining the same farm milk solid production, GHG emissions (including youngstock) and N losses (leaching, volatilisation, and denitrification) each decreased by 15-16%, whilst profitability increased by 22% (at the modelled concentrate and milk prices) in the most developed scenario, compared to the control farm. Cow body condition score (BCS), an important indicator of animal welfare, was higher throughout the season in the PFC scenarios than the lower input scenarios. The most developed scenario (4) reduced total farm feed requirement by 13% which was a primary driver for reducing GHG emissions and N losses. There was an additional benefit of an 8.5% reduction in land area required on the dairy platform to maintain production in scenario 4. This retired land could be used for GHG mitigation or carbon sequestration or other revenue generating purposes. The stocking rate of 2.94 cows per hectare in the control farm was able to be reduced to 2.06 cows per hectare in scenario 4, thereby also reducing the requirement for replacement stock numbers.

Cornell Net Carbohydrate Protein System (CNCPS) modelling was undertaken to verify the trends of the results obtained by Overseer. The results from CNCPS modelling confirmed the trends observed with the Overseer modelling.

This modelling showed that by incorporating concentrate feeds into a pasture-forage diet and simultaneously increasing cow size and genetic merit, as well as reducing stocking rate, GHG emissions and nitrogen losses can be reduced substantially; area of land farmed can be reduced and profitability and productive efficiency of farm-land and animals increased.

Introduction

There has been a large amount of research into strategies to reduce GHG emissions, both domestically and internationally over the last two decades. Current advice to the dairy industry is indicating that the mechanism for reducing GHG emissions should be to reduce reliance on concentrate feeds and for the industry to move back to a lower stocked, pasture /forage-only system.

The New Zealand dairy industry has historically been a predominantly pasture-based system. However, over the past two decades, farmers have introduced concentrate feeds into their farming systems to optimise the productivity of their cows and land. Nevertheless, the New Zealand dairy industry is still largely pasture based, with approximately 85% of feed grown on farm, and 15% of feed imported from outside the farm (Ledgard et al., 2020).

Given the large contribution of enteric methane production from ruminants to New Zealand's GHG emissions, there has been particular focus on reducing enteric methane production. Methane is naturally produced during fermentation in the rumen as it is an end product in the fermentation of carbohydrate feed sources (Beauchemin et al., 2008; O'Neill et al., 2011). Nitrogen losses are also an important environmental factor requiring optimisation. Nitrogen losses from NZ dairy systems can be very high due to the high quantities of soluble and degradable protein in high quality pasture (Higgs et al., 2013).

The challenge before New Zealand dairy farmers is to reduce their environmental footprint whilst maintaining or increasing productivity and profitability. It is pertinent to the global food system that the New Zealand agricultural industry maintains its high level of land use efficiency, whilst always striving to improve current practices. Knapp et al. (2014) emphasized that GHG mitigation strategies which reduce agricultural productivity would be at least partly counterproductive as they would simultaneously increase the cost of food or reduce the availability of high-quality animal products.

The primary objective of this investigation was to use modelling software (Udder, Overseer and Red Sky) to analyse productivity and profitability, as well as GHG emissions and nitrogen outputs through modelling a series of multi-factor alterations to the average farm in the Waikato region as defined by the 2018 /2019 DairyNZ economic survey (DairyNZ, 2019).

The secondary objective of this investigation was to use CNCPS software to verify the accuracy of the trends in GHG emissions obtained from modelling through Overseer. Given the large contribution of enteric methane production to total GHG emissions in NZ dairy systems, using a separate, internationally respected model is important to corroborate the results from the Overseer model.

Materials and Methods

Whole systems analysis

Udder

A whole-farm model was developed in the farm modelling software Udder, to represent an ‘average farm’ in the Waikato, based on information from a 2018-19 DairyNZ economic survey (DairyNZ, 2019). This farm (control farm) model consisted of a 117 ha, Spring calving dairy farm with a start of calving date of 15th July, a calving period of approximately 11 weeks, an annual heifer replacement rate of 25% of peak cow numbers and a feeding system consisting of ryegrass /white clover pasture and imported silage (pasture silage was chosen for this exercise) and palm kernel expeller (PKE).

Pasture grazing decision rules are discussed in detail by Macdonald et al. (2010). The decision rules used in the current modelling was in accordance with these rules, with the aim of optimising quality and quantity of pasture production.

Rotation lengths were set in accordance with a template designed to reach the end of the first grazing round by approximately September 25. The rotation length was primarily designed with the intention to graze plants at the 2.5 – 3 leaf stage for the majority of the season, maximizing pasture harvested without impacting pasture quality. The exception to this rule was during the period of seedhead accumulation, in which the 2-2.5 leaf stage was targeted for grazing.

Initial and final average body condition score (BCS) of the herd was the same in each scenario to ensure annual milk production wasn’t at the cost of body fat reserves. Final average pasture covers (APC) were equal to the initial APC. Ensuring the average pasture cover and BCS of the herd are the same at the model start date, and end date, ensures that the model is feasible and has long term sustainability.

Financial Analysis

The economic performance of the control farm was extrapolated from Red Sky Farm Performance Financial Analysis software (version 5.04.02) which provides a platform for analysing the financial performance of a farm, and the opportunity to benchmark different farms or farm systems against one another.

The financial analysis was performed in a spreadsheet, extrapolating the expenses from the control scenario and allocating costs to a per cow or per hectare basis in accordance with the method used by Macdonald et al. (2011).

Table 1. Various costs used within the models

Milk Price	\$6.50 /kg MS
Concentrate price	\$500 /t DM
Imported forage	\$350 /t DM
Home-made forage	\$120 /t DM
Nitrogen	\$1,850 /t N

Analysis of environmental parameters

Greenhouse gas (GHG) emissions and nitrogen (N) losses were calculated using Overseer farm modelling software (version 6.4.0).

Total farm GHG emissions are calculated in Overseer by estimating methane, nitrous oxide and CO_2 emissions which are presented as CO_2 equivalents; this method is largely based on the method used by the New Zealand GHG emissions national inventory. Global warming potential (GWP) on a 100-year basis and standard Intergovernmental Panel for Climate Change (IPCC) 2007 factors were used for methane and nitrous oxide of 25 and 298 kg CO_2 equivalent /kg respectively.

GHG emissions for YS were included in the whole farm systems analysis in Overseer.

N losses calculated in Overseer take into account the N losses from leaching, volatilisation and denitrification. N losses which occurred during the rearing of the replacement heifers off the dairy platform were calculated and reported for each scenario.

More detailed descriptions of Overseer and the GHG section of the Overseer model are given by Wheeler et al. (2006) and Wheeler et al. (2008).

Nitrogen losses from land outside the farm required to grow supplementary feed (forage or concentrate) were not accounted for in the current modelling. N losses from the production of concentrate feeds should be allocated to the nutrient and environmental budgets of the farms where they are physically occurring. N losses associated with the consumption of the concentrate feeds are accounted for in the current modelling.

There was not a feed-pad or barn on the farm. Therefore, the majority of the dung and urine was deposited directly onto pasture. Liquid effluent collected from the yard is stirred and spread regularly throughout the year.

Scenario 1-4

Using the same software and methodology used to model the control farm, four alternative scenarios were modelled. For these scenarios, the physical farm parameters were kept the same as the control farm and milk production was controlled to remain very similar to the control farm model. However, variations in cow size, genetic merit, stocking rate and the level of concentrate feeding were incorporated into the systems (**Error! Reference source not found.**). After modelling in Udder to ensure the feasibility of each scenario, these alternative farm system scenarios were then modelled through the Overseer program and the financial spreadsheet. The same methodology was used as in the control scenario, in order to analyse the impacts of the variable factors on GHG emissions, N losses, productivity and profitability compared with the control farm.

The same decision rules were applied to the scenarios surrounding pasture management as were used in the control farm, and careful control of supplementation and surplus pasture conservation was practised to ensure post-grazing pasture levels didn't exceed or fall below 1,500 kg DM /ha, in order to maintain optimum pasture quality in all scenarios.

In scenario 1, the concentrate included in the ration was 100% maize grain. In scenarios 2-4, the concentrate was a blend of soybean hull (42%), maize grain (42%) and dried distillers grain (16%).

Scenario 5

Scenario five was created to represent current industry advice for reducing GHG emissions through reduced stocking rate (15% reduction) and reduced imported feed input, using pasture and forage-based supplements only. For scenario 5, the physical farm parameters were the same as control and scenarios 1-4. As a result of a 15% reduction in stocking rate and the use of forage supplements only, the production level of this scenario was 11% lower than that of the other scenarios, as modelled utilising the supply and demand of feed in Udder.

Table 2. Metrics of the control farm and the five scenarios

	Control	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Peak Cow Numbers	344	306	258	247	220	293
Farm Area (ha)	117	117	117	114	107	117
Cow LW (kg)	450	475	500	500	550	450
Kg LW / ha	1,323	1,242	1,103	1,083	1,131	1,127
Relative cow genetic merit	100%	101%	104%	105%	107%	100%
Total feed consumed (t DM) **	1,944	1,881	1,762	1,738	1,688	1,686
Feed consumed vs. control		-3.2%	-9.3%	-10.6%	-13.2%	-13.2%
Stocking Rate (cows/ha)	2.94	2.62	2.21	2.17	2.06	2.5
Comparative SR (kg LW/t DM) *	94.1	90.5	84.8	81.9	82.4	92.0
Farm production (kg MS)	124,890	124,839	124,819	124,941	124,954	111,308
Concentrate fed (% of diet)	0%	4.0%	9.9%	15.8%	18. 5%	0%

LW = Liveweight
kg MS = kilogram of milk solids
* Excluding young stock

** Including young stock

In each of the five alternative scenarios modelled in Udder, the same base pasture growth rates, total pasture production, pasture quality parameters, and level of nitrogen and fertiliser per hectare as in the control farm was applied. An important differentiation between the scenarios was the timing and area of silage harvesting, and Nitrogen applications. Where dairy platform land area was reduced, total N and fertiliser use was reduced to maintain the same application rate per hectare.

Cow size and genetic merit were important variable factors (Table 2). For each scenario, BCS at the end of the season was very similar to the beginning of the season. This was approximately BCS of 5 for scenarios 2, 3 & 4, and BCS 4.5 for scenarios 1 & 5, and control.

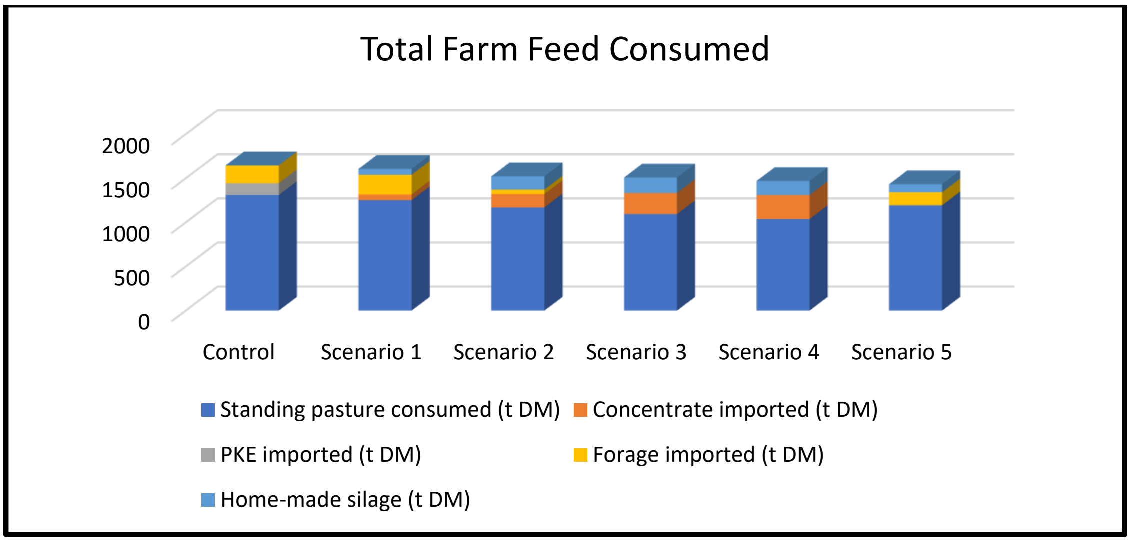

Figure 1 Illustrates the reduction in the total feed requirement when concentrates are utilised (excluding young stock)

In all scenarios (including control), the Rising 1-year-old calves grazed off-farm from 1st December, to return as Rising 2-year-old heifers on June 1 the following season. This is considered standard industry practice in the Waikato region.

Where farm model scenarios reduced land area, the area of each soil type modelled in the control Overseer model was adjusted proportionally to ensure the percentage of each soil type on the farm was maintained in each of the Overseer models.

Methane emissions CNCPS

The Cornell Net Carbohydrate and Protein System (CNCPS) was used to model the methane emissions of three of the dairy systems described in the whole farm systems analysis above (control, scenario 4 and scenario 5). CNCPS is a modelling tool to enable farmers and nutritionists to predict nutrient supply and demand of cattle in different management conditions (Van Amburgh et al., 2019).

The diet on the control farm consisted of pasture, conserved forage and PKE; approximately 80% standing pasture, 12% imported pasture silage on DM basis annually, and 8% imported PKE. This diet was designed to be representative of an average Waikato farm using DairyNZ survey data (DairyNZ, 2019). In scenario 4**,** the annual diet consisted of approx. 72 % standing pasture, 10% silage (home-grown pasture silage only) and 18.5% imported concentrates. Scenario 5 consisted of approx. 84% standing pasture, 11% imported- and 5% home-grown silage.

Results and Discussion

Whole farm systems analysis

Whilst maintaining total farm milksolids production, each of the four alternative scenarios (1-4) decreased the GHG emissions and N losses, and increased profitability in comparison with the control farm (Tables 4-6).

By progressively decreasing the stocking rate but increasing cow size and genetic merit in each of the scenarios, the total DM consumed (t) reduced gradually through scenario 1-4 (Table 2). This reduction in total DM consumed was reflected by a progressive reduction in GHG emissions and N losses from scenario 1-4 (Table 5, Table 6). As stocking rate decreased and cow size and genetic merit increased, the total energy and the percentage of total energy required for cow maintenance decreased, and the percentage of feed energy partitioned towards milk production increased, increasing the feed conversion efficiency (FCE; Table 3).

There were inverse relationships between milk production per cow as % LW and methane production, and between concentrate fed (% of diet) and methane production (Table 3, Table 4 & Table 5). There were also inverse relationships between concentrate imported (t) and total GHG (t eCO_2 /yr), and between concentrate imported (t) and total kg GHG (eCO_2) /kg MS until a plateau of methane efficiency for scenarios 3 & 4 (Table 4, Table 5 & Table 6).

Table 3. Production responses from changing system parameters

	Control	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Peak Cow Numbers	344	306	258	247	220	293
Production /cow (kg MS)	363	408	484	506	568	380
Production / cow as % liveweight	81%	86%	97%	101%	103%	84%
Production /ha (kg MS)	1,067	1,067	1,067	1,096	1,168	951
FCE - kg DM feed per kg MS *	13.2	12.9	12.2	12.1	11.8	12.9
MS per kg DMI *	0.076	0.078	0.082	0.083	0.085	0.078
Feed energy partitioned to MS**	44.6%	46.7%	50.1%	51.2%	52.6%	45.7%

MS – Milk-solid
FCE – Feed conversion efficiency
* Excluding young stock
** Including young stock

Scenario 4 showed the largest reduction in total farm GHG emissions and N losses compared with the control farm, 13.3% and 10.2% respectively excluding contribution from young stock (Table 5); 15.7% and 15.5% respectively including young stock (Table 6). Scenario 4 utilised a diet with the highest concentrate inclusion (18.5%) of the scenarios modelled and utilised larger, more genetically efficient cows, with a lower SR than any of the other scenarios and the control farm (Table 2). This also resulted in a decrease in total farm feed requirement (incl. YS) of 13.2% compared to the control farm. Due to the lower SR, the concentrate feed inputs and their higher genetic capacity, the cows in scenario 4 had the highest MS production per cow, and the lowest methane production per kg MS (Table 3 & Table 5).

Table 4. Requirement for imported feed and operating profit (OP)

	Control	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Concentrate imported (t)	0	66	150	239	272	0
Concentrate as % of diet	0%	4.0%	9.9%	15.8%	18.5%	0%
PKE imported (t)	133	0	0	0	0	0
PKE as % of diet	8.1%	0%	0%	0%	0%	0%
Forage imported (t DM)	202	224	51	0	0	148
Home grown silage (t DM)	0	66	150	175	159	91
Farm area retired	0%	0%	0%	2.6%	8.5%	0%
Operating Profit	$270,777	$291,263	$331,657	$315,970	$330,970	$250,753
OP vs. control*		7.6%	22.5%	16.7%	22.2%	-7.4%

*Milk price of $ 6.50/kg MS, concentrate cost of $ 500/t.

Table 5. Impacts on GHG emissions and N losses of control farm compared with scenarios 1-5, including footprints of concentrates*, excluding young stock as modelled in Overseer

	Control	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Methane (t eCO_2 /yr)	924.9	888.4	840.9	813.5	802.7	813.6
N2O (t eCO_2 /yr)	304.3	287.6	271.6	258.2	250.7	278.6
CO2 (t CO_2 /yr)	222.5	179.9	180.6	198.6	204.7	150.5
Total GHG (t eCO_2 /yr)	1,451.7	1,355.9	1,293.1	1,270.3	1,258.1	1,242.7
Total GHG emissions vs. control		-6.6%	-10.9%	-12.5%	-13.3%	-14.4%
Total GHG (kg eCO_2) /kg MS	11.6	10.9	10.4	10.2	10.1	11.2
N loss (kg N /yr)	5,199	5,225	4,853	4,842	4,670	4,754
N loss vs. control		+0.5%	-6.7%	-6.9%	-10.2%	-8.6%

*Overseer includes embodied emissions of imported supplements in its GHG calculations, see Appendix 9.

Table 6. Impacts on GHG emissions and N losses of control farm compared with scenarios 1-5, including footprints of concentrates*, including young stock, as modelled in Overseer

	Control	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Methane (t eCO_2/yr)	1095	1049.3	977.2	950.5	928.8	958.5
N_2O (t eCO_2/yr)	378.1	357.4	331	317.3	303.3	342.2
CO_2 (t CO_2 /yr)	245.2	202	198.8	217	217.7	170.8
Total GHG (t eCO_2/yr)	1718.3	1608.8	1507	1484.8	1449.8	1,471.5
Total GHG emissions vs. control		-6.4%	-12.3%	-13.6%	-15.6	-14.4%
Total GHG (kg eCO_2) /kg MS	13.8	12.9	12.1	11.9	11.6	13.2
Total kg GHG /kg MS vs. control		-6.3%	-12.2%	-13.6%	-15.7%	-3.9%
N loss (kg N/yr)	6,829	6,661	6,114	6,067	5,769	6,165
N loss vs. control		-2.5%	-10.5%	-11.2%	-15.5%	-9.7%

*Overseer includes embodied emissions of imported supplements in its GHG calculations, see Appendix 9.

The mechanism involved in reducing GHG emissions and N losses in the modelled scenarios was reducing the total dry matter consumed on each farm (Table 2). Reducing the total quantity of feed consumption is a commonly accepted method for reducing enteric methane production (O'Neill et al., 2011). As stocking rate was decreased, and cow size and genetic merit increased, proportionally less energy was required for maintenance, and a higher proportion of energy was partitioned towards milk production (Table 3). In the farm systems modelled, as a lower percentage of the feed energy was partitioned to maintenance and more towards milk production increasing FCE; increased production per cow resulted in similar total farm milk production with fewer cows and less total feed consumption. As total feed consumption progressively reduced, GHG production and N losses also progressively reduced. This result is in accordance with the concept described by Hristov et al. (2013) who reported that on a per cow basis, whilst methane emissions increase as feed intake increases, the efficiency of methane emissions per kg dry matter intake (DMI) also increases with increasing feed intake above maintenance level. Therefore, when there is a low stocking rate, combined with high production per cow, as is the case with scenario's 3 and 4, the maintenance energy requirements have been diluted by high DMI per cow, the efficiency of methane production per kg MS is high, and total farm methane production is low. This concept is also supported by Knapp et al. (2014) and Boadi et al. (2004) who both reported that lower methane production in scenarios where milk production remains constant with reducing cow numbers should be expected.

For scenarios 2-4, N losses were inversely correlated with concentrate feed % in the diet (Table 4 & Table 5). This is because the concentrate feed had lower average CP content than the pasture (Overseer default of 3.7% N for pasture). As concentrate proportion of the diet increased, the overall CP content of the diet decreased, which reduced the N losses. Higgs et al. (2013) reported that a primary method of reducing N losses is through reducing N content in feed. With progressively increasing levels of concentrate in scenarios 2-4, N losses progressively reduced from a 6.7% reduction from control for scenario 2, to a 10.2% reduction from control for scenario 4 (excl. YS). Scenario 1 had high N losses due to the high reliance on pasture silage as a supplementary feed.

Scenario 4 had the largest improvement in operating profit (22.2%) compared with the control farm (Table 4), notwithstanding the fact that 8.5% of the productive farmland was able to be retired from dairy production in this scenario.

Scenario 5 was designed to represent the implications of current recommendations for reducing GHG emissions on the control farm. A 15% reduction in SR was implemented, and no concentrate feed was imported. Whilst scenario 5 did reduce total farm GHG emissions by 14.4%, farm milk production was reduced by 11% (Table 2 & Table 6). This causes methane efficiency to be similar to that of the control farm; 11.6 vs. 11.2 kg GHG (e CO_2) /kg MS for control and scenario 5 respectively, whilst scenarios 2, 3 and 4 reduced total GHG emissions to 10.4-10.1kg GHG (eCO_2) /kg MS. Furthermore, profitability of Scenario 5 was approximately 7.4% lower than the control farm and 20-24% lower than that of Scenarios 2-4.

Scenarios 3 & 4 had a stronger reduction in N losses compared with scenario 5, whilst achieving 20-24% higher operating profit than scenario 5. Total land area for the milking platform was able to be reduced despite maintaining productivity in scenarios 3 & 4, whereas the full land allocation was required to produce the results of scenario 5 (Table 2).

The intensity of dairy emissions have decreased over the past three decades due to increased milk production from a reduced number of cows (Clark & Journeaux, 2021). As well as reducing the total farm GHG emissions, scenario's 1-4 progressively reduce the intensity of GHG emissions per unit of milk production through increased FCE and optimising milk production on the land area and feed available. Scenario 5 only marginally reduces the intensity of GHG emissions (e CO_2) per unit of milk produced compared to control, and still has a higher intensity than scenario 1, the least optimal of the 4 alternative scenarios in terms of GHG (kg e CO_2) /kg MS.

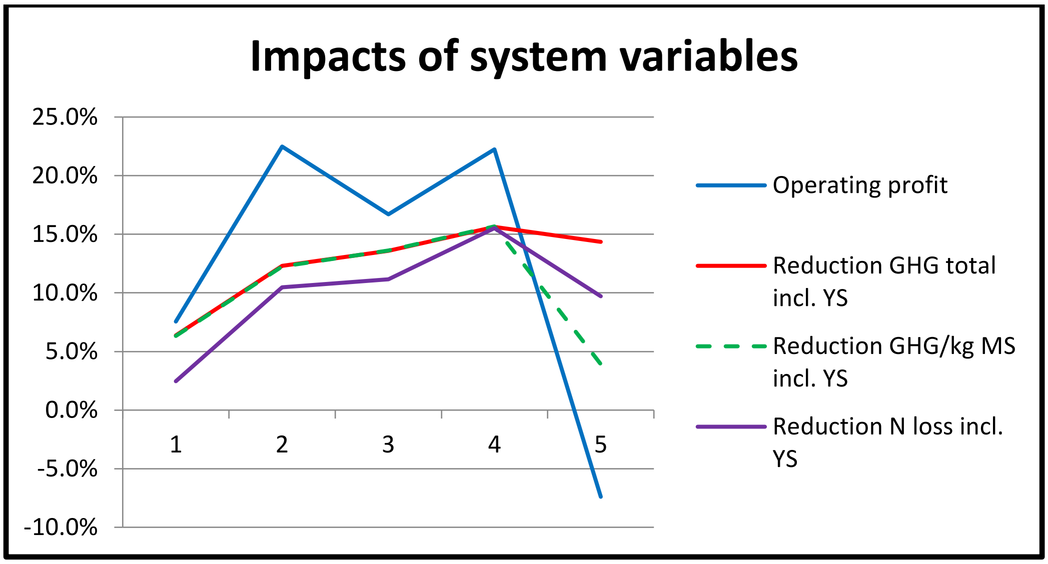

Figure 2. Relative performance of systems 1 through to 5 compared to Control.

Note: Milk pay-out of \$6.50 /kg MS and concentrate price of \$500 /t

The operating profit for scenarios 1-4 showed robust profit margins at variable concentrate prices and milk pay outs, when compared with scenario 5. Due to the low operating profit of scenario 5, scenario 1 was more profitable than scenario 5 at all calculated concentrate prices for a milk pay-out of \$5.00 and higher, and at a milk pay-out of \$4.50 until the concentrate price reached \$650 /t. Scenario 2 was more profitable than scenario 5 at all calculated milk pay-outs and concentrate prices. Scenarios 3 & 4 were more profitable than scenario 5 at most concentrate and milk prices. It was only when there was a combination of the milk price being very low and the concentrate price being very high where system 5 would challenge the profitability of scenarios 3 & 4.

An important distinction to make is that in this research, concentrate feeds are not being included in the diet to increase the stocking rate. Concentrate feeds are being utilised to optimise the per cow production compared to what would be possible in a forage only system, therefore, allowing a lower SR than the control scenario but maintaining milk production. As has been discussed, optimising the per cow production causes a dilution effect on methane produced in association with the consumption of maintenance energy (Hristov et al., 2013; Knapp et al., 2014). This optimisation of per cow production is where scenarios 3 and 4 have major advantages over scenario 5. Whilst scenario 5 does achieve environmental benefits, it is at the expense of milk production and profit. In addition, scenarios 2, 3 and 4 all have lower SR than scenario 5. In terms of the global food supply, New Zealand milk has a low Carbon footprint compared to internationally produced milk (Knapp et al., 2014; Ledgard et al., 2020), therefore, it is better to maximise our efficient milk production as is demonstrated in scenario 4, rather than achieve similar environmental goals by sacrificing milk production as shown with scenario 5.

It is pertinent to note that many feeds utilized in the stock feed industry are by-products from the manufacturing or processing of other products such as energy, human food or -food oil production. Alternative disposal of by-product feed potentially result in negative environmental implications (Russomano et al., 2012); hence it should be considered that utilizing these products as stockfeed increases efficiency of the overall food system, which means that the production of greenhouse gases from their use is for a productive purpose, rather than a wasteful purpose.

Methane emissions CNCPS

The use of a pasture, forage and concentrate system in scenario 4, with 18.5% of the diet as concentrate feed reduced the total farm methane production by 13.9% compared with the control farm. Scenario 5 resulted in a 9.6% reduction in methane production compared with the control farm, but there was also an 11% reduction in milk production (Table 2).

There was a 15% reduction in methane production per kg FCM for scenario 4 whilst in scenario 5, there was a 1.9% increase in methane production per kg FCM. The decrease in methane production per kg FCM in scenario 4 corresponded with increased levels of concentrate in the diet which resulted in an increase in milk production per cow, and decreased energy (%) partitioned towards maintenance. The level of methane produced per kg FCM is at its lowest when cows are at peak levels of milk production, consuming a diet of pasture and concentrates, without supplementary forages (Scenario 4). The increase in methane production per kg FCM in scenario 5 is due to the reduction in milk production and the low feed conversion efficiency in this scenario.

The significant reductions in methane production for scenario’s 4 & 5 compared with the control farm align with the trends observed in the Overseer modelling. The modelling of the systems through CNCPS also confirms the feasibility of the systems which were originally modelled through Udder.

Conclusions

The modelling undertaken shows that a multi-faceted approach to tackling environmental problems on dairy farms will yield the most beneficial outcomes with substantial reductions in GHG emissions and nitrogen losses whilst improving profitability and land use efficiency in New Zealand.

Progressive improvements in environmental parameters can be achieved with the incorporation of concentrates into the farm system in conjunction with reducing the stocking rate and land area employed, as well as increasing size and genetic merit of cows to optimise intake and production on a per cow basis. This resulted in lower total feed requirements for similar milk production, resulting in reduced GHG emissions and N losses. Utilising concentrates in the diet enabled high DMI and high milk production per cow, which dilutes maintenance requirements and increases the efficiency of methane production per unit of milk produced. Animal welfare may be improved compared to systems relying on forages only.

Carefully designed and executed PFC systems improved economic performance over a wide range of pay-outs and concentrate prices and increased the productive efficiency of land and animals without reducing farm production. Designing these PFC systems requires a whole-system approach, analysing various levels of concentrate feed inputs, stocking rates, cow liveweight, cow genetic merit and land use, in order to achieve the most efficient milk production whilst maintaining or improving profitability on farm.

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