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Identification of cost-effective management options for reducing greenhouse gas emissions by 10% on a dairy farm in Waikato, New Zealand

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Abstract

An optimisation model of a dairy farm was built to estimate the cost of mitigation of greenhouse gas emissions (GHG-e). First, the Farmax and Overseer models were used to describe production, profitability, and emissions to the environment of a medium-input dairy farm system for the Waikato-Bay of Plenty region of New Zealand. This process allowed generation of a valid and consistent set of input data for a detailed nonlinear programming model able to optimise resource use. The optimisation model was then used to investigate how producers may best respond to the introduction of a 10% restriction on GHG-e, with and without the use of strategic changes to their farm system to mitigate GHG-e. Profit decreased by 8% when the restriction was introduced without the availability of strategic mitigation options. The variables that changed most to achieve the reduction were nitrogen fertiliser input, which was reduced by 58%, and stocking rate which was reduced by 7%. In contrast, profit increased by 5% when strategic mitigation options were used under GHG-e restrictions. Using high genetic merit cows was enough to achieve this increase in profit under the emissions constraint.

Keywords: greenhouse gases; dairy farm; profit; abatement; systems; emissions profile

Introduction

Dairy farming in New Zealand accounts for about 17% of the total country's greenhouse gas emissions (GHG-e). As a whole, New Zealand agriculture has increased GHG-e by around 10% since 1990 (Ministry for the Environment 2010). The Climate Change Response (Moderated Emission Trading) Amendment Act 2009 (New Zealand Legislation 2009) states that farmers will begin to pay for their GHG-e from 2015. Therefore, it is probable that New Zealand dairy farmers will face pressure to either reduce, or pay for their GHG-e.

Methane (CH_4) emissions are an inevitable consequence of ruminant digestion. Nitrous oxide (N_2O) emissions have risen over the last decade following increases in production intensity on New Zealand dairy farms, especially through increases in application of nitrogen (N) fertiliser and stocking rate (Ministry for the Environment 2010). One way of reducing methane emissions is to reduce the number of animals on any given farm to reduce total feed intake, but this strategy can lead to a reduction in production per ha and also reduced profit if feed efficiency is not increased and the whole farm system is not adapted (Beukes et al. 2011). Nitrous oxide emissions can be lowered through reducing nitrogen fertiliser application and stocking rate, as well as through the use of other mitigation options, such as stand-off pads, feed pads, and the application of nitrification inhibitors (de Klein et al. 2008). This highlights that cost-effective mitigation may require substantial changes to many interdependent management variables within a farming system. Computer modelling is highly suited to evaluate alternative strategies given its capacity to represent and consider these interdependencies simultaneously.

The influence of cow genetics across different feeding systems was tested for profit and GHG-e by O'Brien et al. (2010), using simulation modelling. They found that GHG-e per ha generally increased with higher stocking rate or more concentrate feeding but profitability did not always follow the same trend. For example, the New Zealand strain achieved the highest profit at an intermediate stocking rate of 2.62 cows per hectare. This suggests that medium intensity grass-based systems can achieve high profitability and decrease GHG-e simultaneously.

Beukes et al. (2010; 2011) studied the economics of different mitigation options using a mechanistic whole farm model (DairyNZ's WFM) and a nutrient budget tool (OVERSEER®). However, in those studies, mitigation options were implemented by the modeller at one pre-established level, and GHG-e reduction and profit calculated afterwards for the different scenarios. This is a time consuming process and requires a great deal of ability and farm system knowledge from the modeller to achieve the best possible use of resources. In contrast, for this paper a detailed optimisation model called the Integrated Dairy Enterprise Analysis (IDEA) framework, was employed to identify the best combination of mitigation options, and "level" for each mitigation, that would maximise operating profit while reducing total GHG-e of the farm by 10%. Given the absence of better information regarding GHG-e goals, the 10% is based on the level defined by the Climate Change Response (Moderated

Emission Trading) Amendment Act 2009 (New Zealand Legislation 2009).

The objective of this study was to determine the cost associated with a 10% reduction in GHG-e and at the same time identify the required changes to the farming system that will achieve this reduction whilst maximising operating profit.

Table 1 Comparison of model output from FARMAX and IDEA.

Variable	Model		Difference (%)
	FARMAX	IDEA	
Farm profit ($/ha)	1,098	1,053	-4.3
Stocking rate (cows/ha)	3.07	3.08	0.33
N fertiliser applied (kg N/ha)	105	119	13.3
Milk production (kg MS/cow)	328	331	0.91
Lactation length (days)	271	277	2.2
Grazed pasture eaten (t DM/ha)	9.8	11.8	20.1
Supplement eaten (t DM/ha)	2.0	2.3	13.7
Crop type	Maize	Maize	
Crop area (%)	2.2	2.00	-8.0
Silage conserved (t DM/ha)	0.46	0.43	-6.5
Replacement rate (%)	23	21	-7.4

Method

Model description

IDEA is a nonlinear optimisation model that provides a detailed description of management within a New Zealand dairy farming system. The model is defined over 26 fortnights to provide comprehensive insight into feed allocation across a typical management year. The incorporation of 26 feed periods across a single year is high compared to other optimisation models of grazing systems, such as MIDAS (Doole 2012). However, it is less precise than simulation models in which daily time steps are common. This is necessary since optimisation models of the complexity of IDEA exceed current computer memory restrictions when defined with a daily and weekly time step. Use of optimisation allows interdependencies between system elements to be considered when exogenous shocks, such as changes in price or government policy, are simulated.

IDEA incorporates the basic structure of the model introduced by McCall et al. (1999). However, this framework is extended in various ways to provide a closer description of real systems:

1. Grazing strategies involve both rotation length and post-grazing residual herbage mass as decision variables.
2. Rotation length and post-grazing residual herbage mass impact the growth and digestibility of pasture.
3. Cows can be fed below potential capacity to varying degrees.
4. Cow condition influences intake, milk production, and conception rate.
5. Pasture utilisation is conditional on stocking rate.

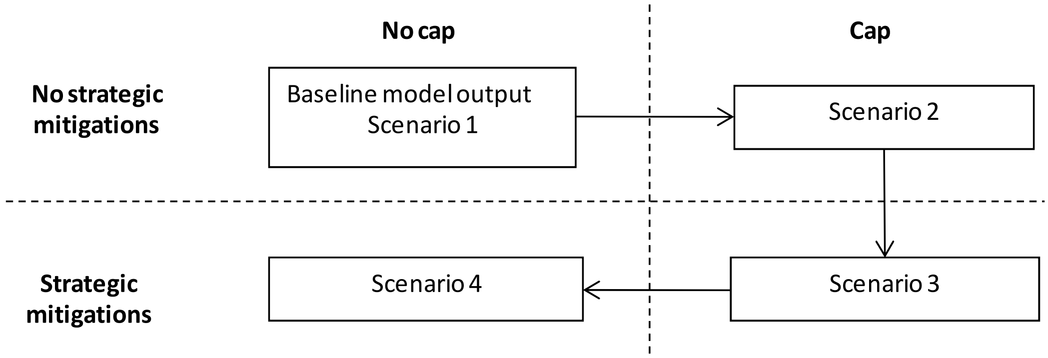
IDEA identifies the feeding strategy that maximises annual profit. Feed supply is based on grazing management that allocates pasture to stock, while silage can be produced during periods of surplus grass production. Dairy meal, maize silage, and palm kernel expeller can be purchased, while maize silage can also be produced on-farm. Kale and turnips can be grown as forage crops. Age structure, calving date, and culling policy affect temporal energy requirements. Also, individual cow attributes, such as body condition, lactation length and milk production level, influence feed demand. The genetic merit of cows is also represented in the IDEA model. Cows with high genetic merit have a mean peak milk yield one standard deviation above that of standard New Zealand cows. The levels of peak milk yield for the standard set of cows represented in IDEA are generated using data from 850,000 cows from the Livestock Improvement Corporation database. IDEA is solved using the General Algebraic Modelling Systems (GAMS) (Brooke et al. 2008).

Model comparison and validation

DairyNZ (2010) classifies dairy farm systems on a scale of 1 to 5 according to the level of imported supplements, ranging from no imported supplements (System 1) to between 25 and 40% of the total feed requirements consisting of imported supplements (System 5). The analysis presented here is based on the simulation of four scenarios for an intermediate production System 3 farm. Typically, between 10 and 20% of the total feed is imported in this kind of farm in early spring, to extend lactation and for dry cows. The representative farm is based on the mean of survey information from 30 System 3 farms in the Waikato-Bay of Plenty region extracted from the DairyBase database for the 2008-09 season (dairybase.co.nz) These farms average 125.5 ha of effective area (milking platform) and 380 cows milked at the peak with 24% of replacements reared each year. This representative System 3 farm was modelled in FARMAX, a complex simulation model of a New Zealand dairy system (Bryant et al. 2010), which was used to create a complete set of farm output beyond what is recorded in DairyBase.

Comparison of FARMAX and IDEA output was used to assess if IDEA provided a meaningful description of the farming system being studied. Table 1 show that IDEA provided a close description of the farming system described by the FARMAX model output. This allows some validation of IDEA output as FARMAX also provided a system-level description of a dairy farming system, albeit not in an

Figure 1 Four modelling scenarios investigated with the nonlinear optimisation model. Cap = GHG-e constraint of 10% reduction.



optimisation environment. There is less than 1% difference between stocking rate and milk production reported for each model. However, some deviations occur with respect to "grazed pasture eaten" and the related level of "N fertiliser applied" (Table 1). Cows represented in FARMAX where nearly 15% more efficient than those represented in IDEA in terms of kg of dry mater eaten per kg of milk solid produced. These deviations are deemed acceptable given that FARMAX and IDEA have different cow models and also were modelling different size cows. FARMAX model runs were conducted for smaller cows, which have a lower optimal intake than the Friesian cows represented in IDEA. In addition the utilisation of grass is user-defined in Farmax, while in IDEA it is a consequence of management decisions. IDEA intake results are in line with DairyNZ (2010) data. Furthermore, GHG-e of the baseline farm was in line with standard figures reported in Beukes et al. (2011) and with OVERSEER®(Wheeler et al. 2003) model output for the System 3 farm. This provided some validation that the IDEA model was predicting GHG-e within an acceptable range.

The four scenarios evaluated in the model are shown in Fig. 1. These scenarios differ in whether a cap is present that requires producers to reduce GHG-e by 10% and the possibility to implement recommended strategic mitigation practices. The mitigation practices available in the "No strategic mitigation Scenario" are reductions in production level such as restrictions of stocking rate and nitrogen fertiliser application. These strategies represent the abatement methods that a standard producer can use without the adoption of additional innovations. The abatement practices available to the "Strategic mitigation scenario" include the use of high genetic merit cows, application of nitrification inhibitors, use of forage crops grown on farm and use of a stand-off pad (Beukes et al. 2011).

Table 2 Relevant costs used in this application of IDEA. PKE = Palm kernel expeller; DM = Dry matter.

Item	Cost
Fixed ($/ha)	900
Variable ($/cow)	500
PKE ($/t DM)	350
Dairy meal ($/t DM)	650
N fertilizer ($/t urea)	500
Maize silage ($/ha)	3,300
Re-grassing ($/ha)	1,000
Nitrification inhibitors ($/ha)	150

The baseline situation in Fig. 1 provides a benchmark for the other scenarios. No additional pasture growth was assumed to be obtained with the application of nitrification inhibitors, consistent with experiments conducted on New Zealand dairy farms (Macdonald et al. 2010). Improved herd reproduction is also a potential mitigation strategy, but this was not modelled because it still has to be satisfactorily represented in IDEA.

Parameter values

The milk pay out for this exercise was fixed at $5.5 per kg of milksolids and the relevant prices used in the simulations are listed in Table 2. Fixed costs include such things as insurance, administration, rates, Accident Compensation Corporation (ACC) and dues. Variable costs include wages, animal health, breeding, electricity, and stock grazing.

Results and discussion

A profit reduction of $79 per hectare, or 8%, was found when a reduction in GHG-e per hectare of 10% was imposed without strategic mitigation options available (Scenario 2; Table 3). Two of the observed changes to the system were more important than the others; a 58% reduction in nitrogen fertiliser input, and a 7% reduction in stocking rate. These changes show that the adaptation of the farm system to achieve a reduction in GHG-e is reliant on reducing production intensity given the unavailability of more strategic options such as high genetic merit cows, application of nitrification inhibitors, and use of forage crops. These imply further farm system changes. These results are in line with those of

Table 3 IDEA model output for the four scenarios evaluated. Scenario 1 =. Baseline situation; Scenario 2 = 10% reduction in baseline emissions without strategic mitigation options; Scenario 3 = 10% reduction in baseline emissions with strategic mitigation options. Scenario 4 = No reduction in baseline emissions with strategic mitigation options. N = Nitrogen; MS = Milksolids; CH_4 = Methane; N_2O = Nitrous oxide; GHG-e = Greenhouse gas emissions; CO_2 = carbon dioxide.

Variable	Scenario			
	1	2	3	4
Farm profit ($/ha)	1,053	974	1,106	1,191
Stocking rate (cows/ha)	3.08	2.87	2.81	3.01
N fertilizer applied (kg N/ha)	119	50	51	118
Milk production (kg MS/cow)	331	331	344	344
Milk production (kg MS/ha)	1,019	950	967	1,035
Lactation length (days)	277	277	278	277
Pasture eaten (t DM/ha)	11.8	10.6	10.8	11.8
Supplement eaten (t DM/ha)	2.3	2.2	2.2	2.3
Total feed eaten (t DM/ha)	14.5	13.3	13.4	14.5
CH_4 emissions (kg/ha)	347.7	323.0	322.5	346.6
N_2O emissions (kg/ha)	13.7	11.6	11.7	13.7
GHG-e (kg CO_2-eq /ha)	11,543	10,389	10,389	11,517
Mitigation practices			High genetic merit cows	High genetic merit cows

Basset-Mens et al. (2009), who found that GHG-e per hectare increases with the intensification of the farming system in New Zealand, and GHG-e per kg of milksolids was least for the low input system and intermediate for the higher input systems.

Introducing strategic mitigation practices with the cap imposed (Scenario 3) increased profit relative to the baseline situation by 5%. This occurred because although stocking rate and total feed eaten decreased by 9% and 8% respectively, relative to the baseline situation, milk production per cow increased by 4% given the use of cows with higher genetic merit. Cows with higher genetic merit can achieve better economic performance and reduce GHG-e at the same time. No additional cost is associated with cows of higher genetic merit in this study. This follows the application of Beukes et al. (2010) and is consistent with the intuition that such herds already exist and consideration of the costs accruing to the replacement of the whole herd would greatly bias model output. In the same way, when the cap was removed and strategic mitigation options were available (Scenario 4), profit increased by 13% relative to the baseline. In this scenario, a reduction of 2% in stocking rate occurred to compensate for the higher potential intake of the high genetic merit cows and GHG-e per hectare was about the same as the baseline.

Profit does not decrease much with the cap in Scenario 2 and Scenario 3 for two reasons. First, the 10% reduction in emissions proposed by the cap is significant, but not large. Secondly, the use of strategic mitigations other than cows with high genetic merit introduces additional costs that are unwarranted at the 10% cap. For example, nitrification inhibitors would only be used in the optimal plan in Scenario 3 if their cost falls by 13% to $131 per hectare. For that reason, if high genetic merit cows are removed as an option, then optimal management in Scenario 3 would be identical to optimal management in Scenario 2.

The emissions profile changed in the mitigated systems. Most abatement occurs through a reduction in N_2O, which decreases by 15%. However, CH_4 abatement is also important, as it falls by around 7%. These results are in line with those reported by Beukes et al. (2010; 2011).

Conclusions

The IDEA model provides a meaningful description of a production System 3 dairy farm parameterised using survey data from the DairyBase database and FARMAX simulations. Optimisation of the farming system using IDEA provides a consistent and flexible means to consider its many interdependent elements while seeking to identify systems that cost-effectively reduce GHG-e.

Reducing N fertilizer is the cheapest way to reduce GHG-e from dairy farms in the Waikato-Bay of Plenty. This option will affect both nitrous oxide and methane emissions as less feed is available for the cows. This reduction in available feed not necessarily results in a reduction in profit of the same magnitude because feed efficiency gains can be achieved by increased individual cow performance, such as through using high merit cows, resulting in a lower number of cows and associated costs. This partially compensates for the lower total herd intake.

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