Relationships between farm productivity, profitability, N leaching and GHG emissions: a modelling approach

D.C. SMEATON[1], T. COX[2], S. KERR[3] and R. DYNES[1]
[1] *AgResearch, Private Bag 3123, Hamilton*
[2] *NIWA,*
[3] *MOTU*
dsmeaton@xtra.co.nz

Abstract

The financial and environmental performance of a typical dairy and sheep/beef farm under contrasting inputs and systems were modelled to test associations between productivity, profitability, nitrogen (N) leaching and green house gas (GHG) emissions. GHG emissions and N leaching were found to be closely correlated (R^2 > 0.90) but the correlation between these two emissions items and production and/or profit was less so, suggesting that systems that are both profitable and have a modest emissions output should be possible. The reasons why farmers have not already adopted these systems are complex but could include any of: requirement of higher level of managerial skill, incompatibility with farm soil type or contour, increased risk and capital cost to convert to the new system. Any system that involves improvements in animal efficiency is associated with a reduction in emissions per kg of saleable product.

Keywords: productivity, profit, N leaching, GHG emissions, modelling

Introduction

Farmers are increasingly encouraged to run their businesses in a manner that constrains nitrogen (N) leaching, and reduces GHG (green house gas) emissions intensity (CO_2 equivalents/kg output), and are faced with the possibility of a carbon emissions trading scheme being implemented in 2015.

These same farmers are endlessly striving to increase the productivity and profitability of their farms. Are all these objectives mutually exclusive, or are there combinations that deliver high profitability and low emissions?

We tested associations between farm productivity, profit, N leaching and GHG emissions across sheep/beef and dairy farms. This project was a part of a larger project (Anastasiadis *et al.* 2011; Tim Cox, NIWA, pers. comm.) regarding the Lake Rotorua catchment.

Materials and Methods

Models

The financial and environmental performance of a typical dairy and sheep/beef farm under contrasting inputs and systems were modelled. The dairy farm model (Table 1) was based on the 2008/09 Waikato/Bay of Plenty Monitor Farm. The sheep/beef farm model (Table 2) was based on the 2008/09 Central North Island King Country Monitor Farm (MAF 2009), a relatively low intensity sheep and cattle breeding system with limited beef finishing. These monitor farms represent regional average farms (Phil Journeaux, MAF, pers. comm.).

Farmax Dairy (Bryant *et al.* 2010) and Farmax Pro (sheep and beef; White *et al*. 2010) farm systems models were used to model each farm (the Base scenario) against which all other scenarios were compared.

Nitrate leaching and GHG emissions were estimated using the OVERSEER® nutrient budgets model (Wheeler *et al*. 2003). Rainfall and soil type information typical of the Rotorua area were applied to the OVERSEER® models.

Scenario testing

Scenarios were tested to explore the impacts of changing key management decisions on farming systems on productivity, profit and N leaching loss. Changes in the dairy model included: alterations to stocking rate, use of N fertiliser, use of DCD, wintering cows on the dairy farm or not, use of imported feed and combinations of these. In the sheep/beef model, changes included stocking rate, use of N fertiliser, alterations in the mix of stock classes, use of very high fertility ewes and combinations of these. The Farmax and OVERSEER® models are not directly linked and do not provide an optimised solution, so an iterative process was required to achieve a "best" outcome for a particular system. In total, 18 dairy and 14 sheep/beef farm systems were compared.

Table 1 Key parameters for the Base dairy farm model, annual basis. ms = milk solids.

Parameter	Value
Effective area (ha)	109
Cows wintered	314
Peak cows milked	302
Production (ms/ha)	883
Production (ms/cow milked)	319
Dairy payout ($/kg ms)	5.00
Farm working expenses ($/kg ms)	3.74
Profit ($/kg ms)	1.28
Profit ($/ha)	1152
Feed conversion efficiency (kg DM/kg product)	13.5
Pasture eaten (t DM/ha)[1]	9.5
Imported feed eaten (t DM/ha)	2.2
Area of farm cropped (ha)	0
Nitrogen fertiliser used (kg N/ha)	100
Nitrate leaching (kg N/ha)	47
GHG emissions (t CO_2 equivalent/ha)	9.3
Young stock grazed off the milking area, cows wintered on the milking area	

[1]Pasture eaten is a proportion of pasture grown. For the Base model, pasture grown amounted to 11.6 t DM/ha under optimum conditions and exclusive of decay

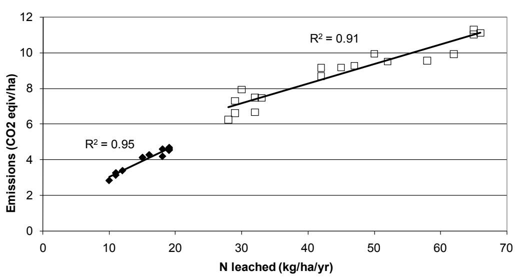

Figure 1 Relationship between GHG emissions (kg CO_2 equiv/ha) and N leached (kg N/ha) for dairy (open points) and sheep/beef (closed points) scenarios: separate trend lines fitted.

Table 2 Key parameters for the Base sheep/beef farm model, annual basis. 1 stock unit (SU) consumes 550 kg DM/head/year.

Parameter	Value
Effective area (ha)	635
SU carried	6248
SU sheep	3921
SU beef	2327
Proportion of beef animals as males (%)	38
Lambing performance (LW/EM)[1]	120
Production (product/ha)	185
Indicator bull beef schedule ($/kg carcass)	3.40
Indicator lamb schedule ($/kg carcass)	4.49
Profit ($/kg product)	2.16
Profit ($/ha)	398
Feed conversion efficiency (kg DM/kg product)	29
Pasture eaten (t DM/ha)[2]	5.2
Imported feed eaten (t DM/ha)	0
Area of farm cropped (ha)	0
Nitrogen fertiliser used (kg N/ha)	7
Nitrate leaching (kg N/ha)	12
GHG emissions (t CO_2 equivalent/ha)	3.4
No stock grazed off the farm area	

[1]LW/EM = lambs weaned/ewes mated
[2]Pasture eaten is a proportion of pasture grown. For the Base model, pasture grown amounted to 7.5 t DM/ha under optimum conditions and exclusive of decay

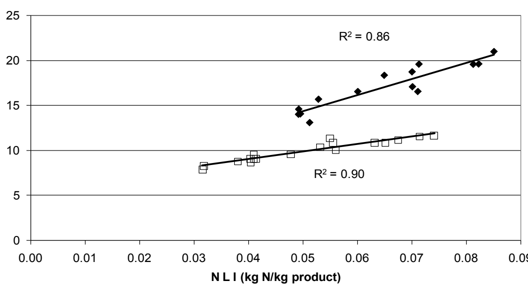

Figure 2 Relationship between GHG emissions intensity (EI: kg CO_2 equiv/kg product) and N leaching intensity (NLI: kg N leached/kg product) for dairy (open points) and sheep/beef (closed points) scenarios: separate trend lines fitted.

Results and Discussion

Relationships between N leaching and GHG emissions

N leaching and GHG emissions per hectare were highly and positively correlated (Figure 1) for both dairy (R^2 = 0.91) and sheep/beef systems (R^2 = 0.95). The relationship was similar across the dairy and sheep/beef sectors combined (R^2 = 0.95, combined trend line not shown). This was a similar result to that obtained by Ledgard *et al.* (2010)

Similarly, the intensity of GHG emissions per kg of product was highly and positively correlated with the intensity of N leaching per kg product (Figure 2).

GHG emissions intensity (CO_2 equivalent/kg product) was loosely associated with feed conversion efficiency (FCE; Figure 3): improved FCE (lower values) was usually but not always associated with a lower CO_2 equivalent footprint. Dairy systems had better FCE than the sheep/beef systems, probably driven by the ratio of feed eaten for maintenance compared with feed used for production. Note that the dairy FCE calculation did not include stock while they were grazed off the farm (Table 1). Other studies

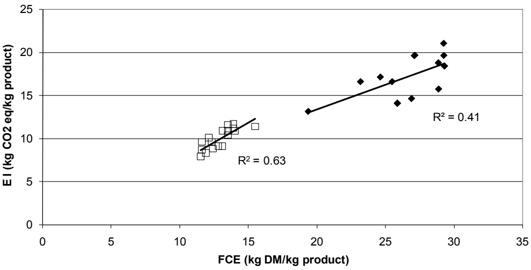

Figure 3 Relationship between GHG emissions intensity (EI; kg CO_2 equiv/kg product) and Feed Conversion Efficiency (FCE; kg DM/kg product) for dairy (open points) and sheep/beef (closed points) scenarios: separate trend lines fitted.

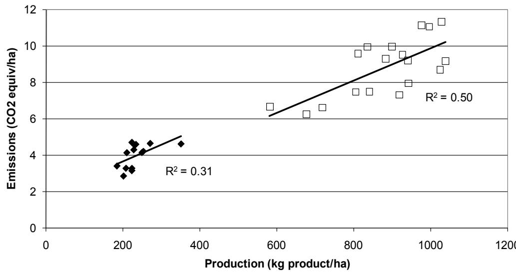

Figure 4 Relationship between GHG emissions (kg CO_2 equiv/ha) and production (kg product/ha) for dairy (open points) and sheep/beef (closed points) scenarios: separate trend lines fitted.

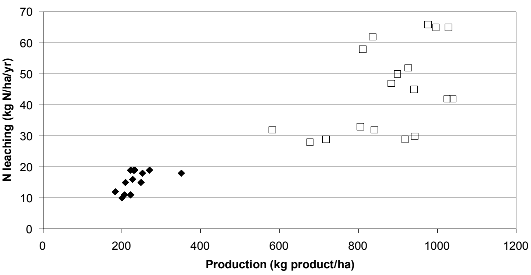

Figure 5 Relationship between N (nitrate) leaching (kg N/ha) and production (kg product/ha) for dairy (open points) and sheep/beef (closed points) scenarios.

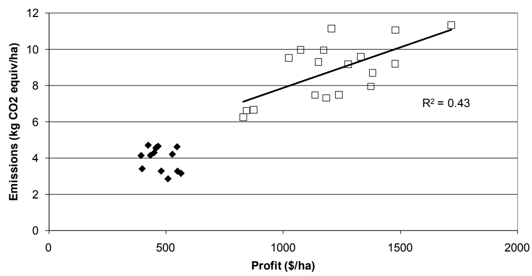

Figure 6 Relationship between GHG emissions (kg CO_2 equivalent/ha) and profit ($/ha) for dairy (open points) and sheep/beef (closed points) scenarios: separate trend lines fitted.

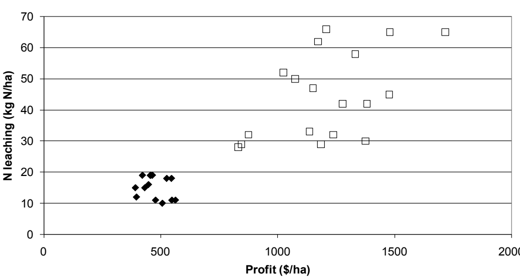

Figure 7 Relationship between nitrate leaching (kg N/ha) and profit ($/ha) for dairy (open points) and sheep/beef (closed points) scenarios.

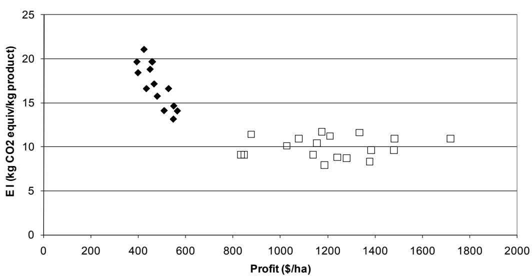

Figure 8 Relationship between emissions intensity (EI: kg CO_2 equiv/kg product) and profit for dairy (open points) and sheep/beef (closed points) scenarios.

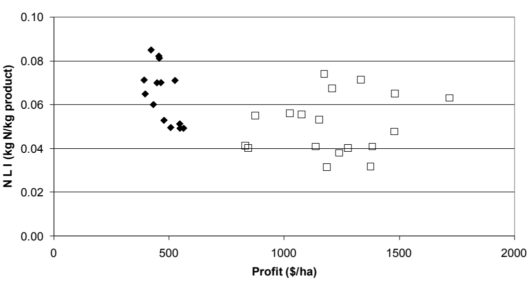

Figure 9 Relationship between nitrate leaching intensity (NLI: kg N leached/kg product) and profit ($/ha) for dairy (open points) and sheep/beef (closed points) scenarios: separate trend lines fitted.

(Dynes *et al.* 2011) using case study farms throughout New Zealand, observed that improving dairy cow FCE was associated with a reduction in carbon emissions.

Production per hectare was only moderately associated with GHG emissions per hectare ($R^2 = 0.50$ and 0.31 for dairy and sheep/beef, respectively; Figure 4) and not associated with N leaching per hectare (Figure 5). Although there is a trend for more intensive production in both dairy and sheep/beef to be associated with a greater level of emissions, our results indicate that systems exist such that production can be increased with little or no increase in emissions as previously identified by Smeaton *et al.* (unpublished report) and by Ledgard *et al.* (2010).

In *absolute terms*, the sheep/beef scenarios showed less range in both production and GHG emissions/N leaching than the dairy scenarios. Smeaton & Blackman (2007) observed a similar effect regarding variation in N leaching based on three case study sheep/beef farms in the Lake Rotorua catchment.

Profitability

GHG emissions (Figure 6) and N leaching (Figure 7) per hectare were only weakly associated with profit per hectare for the dairy scenarios, and there appeared to be no association between the two emission parameters and profit for the sheep/beef scenarios. This was probably due to the fact that all dairy scenarios were similar ("cows producing milk") whereas the sheep/beef scenarios involved a range of quite different systems, for example: finishing cattle, compared with beef cows, compared with breeding ewes. Profits near the high end of the range of profit possibilities tested (Figure 6, 7) can be achieved at the low end of the emissions range with careful choice of system.

GHG emissions and N leaching *intensity* per kg of product were not significantly associated with profit (Figures 8, 9). This implies that high profit per hectare can be achieved with a low GHG emissions intensity or N leaching intensity. In fact, over time, it would be expected that sheep/beef farmers would migrate to the high profit low footprint scenarios indicated to the bottom right of their cluster of points. Similarly, Dynes *et al.* (2011) noted that high profit dairy scenarios were often associated with lower GHG emissions intensity farm systems. In the wider study, only partially reported by Dynes, where 14 case study dairy farms were analysed, the average GHG emissions intensity was of the order of 9.7 with the highest at 11.7 and the lowest at 8.4 kg CO_2 equivalents/kg product. In that study, the sample of farmers investigated, were often, *but not always*, operating their farms at the most profitable level, or at the lowest emissions intensity level, a result similar to the monitor farm base models in this study. Why is this? Our explanation is that the most profitable farm systems, combined with a low GHG and N leaching emissions always involve all or some of:

- Lower stocking rate, combined with high per head performance
- Much higher than average breeding worth (BW) herd
- Restrained, but not nil, use of N fertiliser
- Use of DCD
- Lower replacement rates (Beukes *et al*. 2011)
- Maximum ratio of growing rather than breeding stock classes (sheep/beef farms)
- Very high fecundity ewes (200% lambs weaned/ewes mated: based on one real life example).

Some of the above criteria are either difficult to achieve in practice, require significant capital expenditure, a significant increase in managerial skill, or all three. This makes their implementation difficult and in some cases, they also run the risk of low profit due to risk of loss of pasture quality.

The "best" systems

In the present study, the dairy farms with the *lowest emissions intensity* were those where:

- Stocking rate was 14% lower than the base farm
- The cows were wintered off (clearly some of the emissions were therefore exported)
- No N fertiliser was used.

This particular scenario had production 4% higher than the base, was 3% more profitable, had an N leaching figure of 29 kg N/ha/year, compared with the base at 47 kg N/ha/year and had an emissions intensity of 7.9 (24% less than the base). This scenario also had the lowest N leaching intensity. The *most profitable scenario* used 200 kg N fertiliser/ha compared with100 for the base, produced 49% more profit/ha, leached 65 kg N/ha and had an emissions intensity 5% higher than the base.

For the sheep/beef farm, the optimum system was less obvious. The most GHG efficient farm had an emissions intensity 29% less than the base, was 37% more profitable, leached 50% more N than the base value of 12 kg N/ha, but had nearly the lowest N leaching *intensity* (22% less than base). This system involved switching all the beef SU to a bull finishing system with 80 kg N fertiliser/ha used. The next lowest emissions *intensity* (a similar value to the scenario above) was achieved by a system involving very high fertility ewes. This system had N leaching 8% less than the base, was as profitable, used no N fertiliser and had no beef cattle. These two widely different systems achieved their low emissions *intensity* through two different animal efficiency pathways, but they had quite different total emissions and N leaching *per hectare*. The first system had total emissions 35% higher than the base; the second system had emissions 9% lower than the base.

Note that although the systems above are apparently possible in practice, we have never observed them. The most emissions efficient dairy farm we have observed (unpublished data from the study reported by Dynes *et al.* 2011) had an emissions intensity of 8.4 kg CO_2 equivalent/kg ms.

Conclusions

The finding that GHG emissions and N leaching are closely linked but only weakly associated with production and or profit is useful in that it indicates that it should be possible to operate systems that are profitable yet have modest levels of emissions. The reasons why farmers have not already adopted these systems (for profit reasons) are complex, including requirements of a higher level of managerial skill, increased risk or a requirement for significant capital investment e.g. buying a very high fecundity sheep flock or high BW dairy herd. Also, high proportions of finishing bulls may be incompatible with hill country sheep/beef farming.

Any system that involves improvements in animal efficiency is associated with a reduction in undesirable emissions per kg of saleable product. The objective is to ensure that as much energy as possible, grown and consumed on the farm, goes into animal product rather than animal maintenance.

This work demonstrated that it is possible to reduce N leaching/ha and GHG emissions intensity from pasture-based farming and while increasing profitability, although the level of variation indicates that care in choice of system is required to ensure the desired outcome is achieved.

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REFERENCES

Anastasiadis, S.; Nauleau, M-L.; Kerr, S.; Cox, T.; Rutherford, K. 2011. Water quality management in Lake Rotorua: A comparison of regulatory approaches using the NManager model. Proceedings of the 52nd Annual Conference of the New Zealand Association of Economists.

Beukes, P.C.; Gregorini, P.; Romera, A.J. 2011. Estimating greenhouse gas emissions from New Zealand dairy systems using a mechanistic whole farm model and inventory methodology. *Animal Feed Science and Technology 166-167*: 708-720.

Bryant, J.R.; Ogle, G.; Marshall, P.R.; Glassey, C.B.; Lancaster, J.A.S.; García, S.C.; Holmes, C.W. 2010. Description and evaluation of the Farmax Dairy Pro Simulation Model. *New Zealand Journal of Agricultural Research 53*: 13-28.

Dynes, R,A.; Smeaton, D.C.; Rhodes, A.P.; Fraser, T.J.; Brown, M.A. 2011. Modelling farm management scenarios that illustrate opportunities farmers have to reduce GHG emissions while maintaining profitability. *In*: Continuing to increase productivity while maintaining our clean green image. *Proceeding of the New Zealand Society of Animal Production 71*: 167-171.

Ledgard, S.F.; Judge, A.; Smeaton, D.C.; Boyes M. 2010. Greenhouse gas emissions from Rotorua dairy farms: Summary report. Report to MAF. AgResearch, Hamilton. 5p. Ministry of Agriculture and Forestry, PO Box 2526, Wellington 6140, New Zealand.

MAF. 2009. MAF Monitor Farm Reports. http://www.maf.govt.nz/mafnet/rural-nz/statistics-and-forecasts/farm-monitoring/

Smeaton, D.C.; Blackman, J. 2007. Lake Rotorua Catchment Project. A report to Meat & Wool NZ on three case study farms. Beef + Lamb New Zealand, PO Box 131, Wellington.

Wheeler, D.M.; Ledgard, S.F.; DeKlein, C.A.M.; Monaghan, R.M.; Carey, P.L.; McDowell, R.W.; Johns, K.L. 2003. OVERSEER® nutrient budgets –moving towards on-farm resource accounting. *Proceedings of the New Zealand Grassland Association 65*: 191 – 194

White, T.A.; Snow, V.O.; King, W.McG. 2010. Intensification of New Zealand beef farming systems. *Agricultural Systems 103*: 21–35.