

## Resource use efficiency and environmental emissions from an average Waikato dairy farm, and impacts of intensification using nitrogen fertiliser or maize silage

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### Abstract

A life cycle assessment (LCA) approach was used to estimate whole-system (dairy farm + grazing and forage land) resource use and environmental emissions for an average Waikato dairy farm enterprise. Effects of increased production from 850 to 1020 kg milksolids/ha using more nitrogen (N) fertiliser (+200 kg N/ha/yr) or forage (+2 t DM/ha/yr maize and oats silage) were also assessed. Fertiliser N increased production and economic efficiency, but decreased environmental efficiency through a predicted increase in N leaching and greenhouse gas (GHG) emissions. In contrast, using forage increased the use of land but increased milksolids/ha and with no loss in environmental efficiency (per kg milksolids).

A preliminary comparison of the average Waikato farm system and an example Swedish dairy farm system showed small differences in environmental efficiency (GHG or N leaching/m<sup>3</sup> milk) but much higher (5-fold) energy efficiency on the Waikato farm. This is important to maintain, particularly as farms intensify, if “food-miles” (energy use in transporting produce to markets) become a component of our “eco-label” for supplying produce to overseas markets.

**Keywords:** dairy farm, efficiency, environment, intensification, maize, nitrogen, resource use

### Introduction

Milk production on dairy farms in New Zealand has been steadily increasing over time (Livestock Improvement 2003). A number of factors including increased supply of feed from greater use of nitrogen (N) fertiliser and increased use of supplementary feeds have contributed to this trend. In this paper, we use a Life Cycle Assessment (LCA) method to estimate the total impacts of these changes on the use of the resources: land, nutrients and energy.

Evaluation of efficiency indices must go beyond consideration of the dairy farm unit only, and

incorporate the **total** area of land and use of resources e.g. including grazing off-farm and producing supplements. Ideally, a whole-system evaluation should account for other indirect contributors (e.g. energy used for fertiliser production). A whole system evaluation should also consider the impacts of intensification on air and water quality.

Life Cycle Assessment is a methodology which can be used to estimate whole-system resource use and environmental emissions (e.g. Cederberg 1998). In this study, LCA was applied to an average Waikato dairy farm system to examine total resource use and environmental emissions associated with intensification of dairying via N fertiliser use or forage cropping (maize/oats). A comparison of Waikato and Swedish dairy farms is also presented.

### Methodology

The average Waikato dairy farm system (for 2000/2001) is based on land used for dairying, grazing and forage production as outlined below.

Productivity data for the average 83 ha dairy farm was derived from the Dexcel ProfitWatch database, including estimates of pasture requirements for grazed-off animals and brought-in forage. An “average” beef farm was assumed to be used for grazing-off cows and dairy heifers, based on MAF Monitor Farm data for the Waikato/Bay of Plenty intensive model beef farm (MAF 2002). From animal intake estimates for the beef farm it was calculated that 15 ha was required to meet grazing-off requirements of the 83 ha dairy farm. Similarly, the average brought-in feed was assumed to be supplied from 2 ha of a “typical” forage cropping block. This block was based on Waikato land used for double-cropping with maize silage and oats silage, and average yields of 22 and 4 t DM/ha, respectively (J Gavin pers. comm.).

Three whole-farm systems were evaluated, being the average farm system and two intensification

options to achieve a 20% increase in milk production:

1. Base farm system of 83 ha dairy farm producing 850 kg milksolids/ha and supported by 15 ha of 'beef' property and 2 ha of forage block.
2. Base farm system plus extra 200 kg N/ha on the dairy farm which was assumed to produce 1020 kg milksolids/ha.
3. Base farm system plus extra 2 t DM/ha of maize/oats silage (from an extra 6.4 ha of forage block) and assumed to produce 1020 kg milksolids/ha on the dairy farm.

All options were assumed to carry 2.8 cows/ha on the dairy farm. Milksolids responses from fertiliser N were based on data from Dexcel Number 2 dairy, and from forage were based on average research data of 85 g milksolids/kg DM (Kidd 2001).

Farm economic and nutrient use data for the average Waikato dairy farm (for 2000/2001) was obtained from the Dexcel ProfitWatch database. Fuel and electricity use was based on average New Zealand dairy farm data from Wells (2001). Fuel and electricity use for the beef farm were based on data obtained from the MAF Monitor farms, while average fertiliser nutrient use data was supplied by Ballance Agri-Nutrients Ltd. Fuel, electricity and nutrient use for forage cropping was based on data supplied by Gavin Grain (a large Waikato contracting company). The OVERSEER<sup>®</sup> nutrient budget model (Wheeler *et al.*

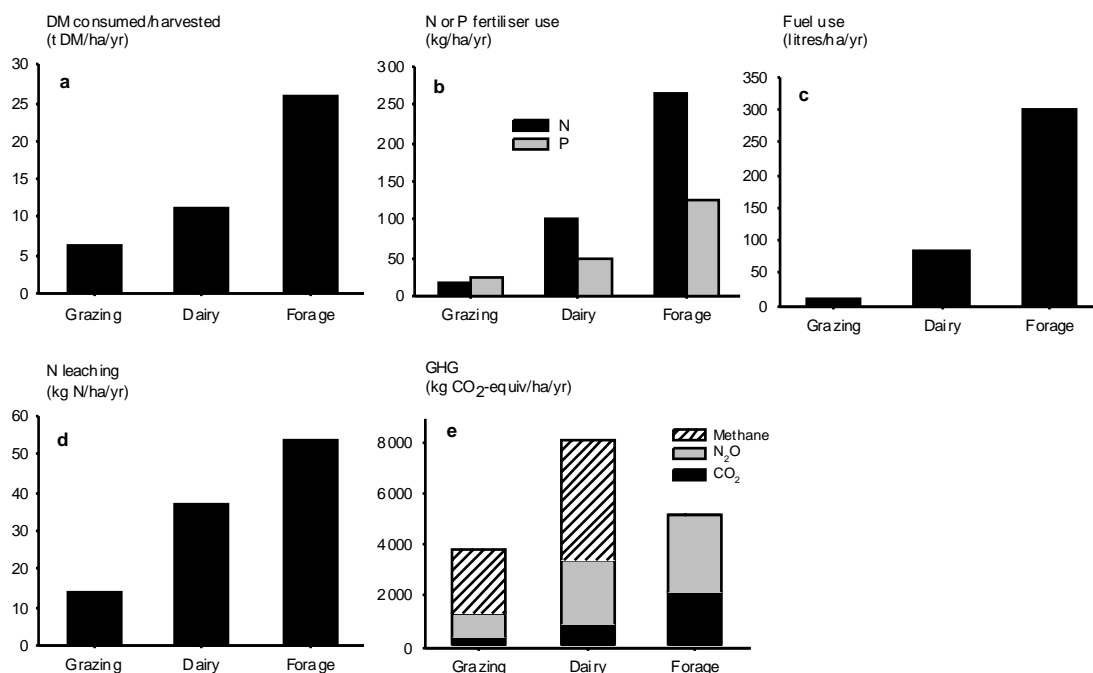
2003), was used to estimate N leaching and total N emissions to waterways for the three different land uses. It was also used to estimate emissions of the greenhouse gases, methane and nitrous oxide, with IPCC-based NZ emission factors. Farm emissions of CO<sub>2</sub> were estimated using fuel and electricity data, and emission factors from Wells (2001). In keeping with international reports on use of LCA (e.g. Cederberg 1998), estimates of energy use and GHG emissions refer to total embodied estimates i.e. include indirect contributions associated with production of fuel, electricity and fertilisers (Wells 2001).

## Results and discussion

### Dairy farm intensification

Dairying enterprises are comprised of contributions from three constituent units i.e. the dairy farm, and land used for grazing young stock and for forage supply. For the "average" Waikato dairy farm enterprise, the typical average amounts of DM consumed or harvested on the component grazing, dairying and forage blocks (Figure 1a) were estimated at 6.2, 11.4 and 26 t DM/ha, respectively (sources: MAF 2002, Dexcel ProfitWatch and J Gavin). Fertiliser P use showed a similar relative pattern, while N fertiliser and fuel use were relatively low on the grazing block and relatively high on the forage block (Figure 1b,c). Conversely, calculated N leaching loss

**Figure 1** Comparison of grazing land, dairy farm and forage land for a) the amount of pasture grazed or forage harvested, b) nutrient use, c) fuel (diesel+petrol) use, d) N leaching and e) GHG emissions.



**Table 1** Effect of intensification from 850 (base) to 1020 kg milksolids/ha, using extra N fertiliser (+200 kg N/ha/yr) or forage (+2 t DM/ha/yr as maize + oats silage), on efficiency of resource use and environmental emissions. Data for the dairy farm only and the whole-system (dairy farm + grazing + forage land) are compared.

	Dairy farm			Whole-system		
	Base	+200N	+ Forage	Base	+200N	+ Forage
Milksolids (kg/ha/yr)	850	1020	1020	706	847	796
EFS (\$/ha) <sup>1</sup>	1037	1373	1297	861	1139	1012
N leached (kg/ha/yr)	36	74	38	32	64	35
GHG (kg CO <sub>2</sub> -equiv/ha/yr)	8590	11970	10780	7790	10590	9940
Efficiency indices						
g N leached/kg milksolids	41	73	36	45	75	44
g N leached/\$EFS	35	54	29	37	56	35
Litres fuel/kg milksolids	0.10	0.09	0.09	0.11	0.10	0.12
GHG kg CO <sub>2</sub> -equiv/kg milksolids	10.1	11.7	10.2	11.0	12.5	11.3

<sup>1</sup> Assuming \$4.00/kg milksolids, \$1/kg N applied and 20c/kg forage DM.

on the forage block was only one-third higher than on the dairy farm, although forage estimates have large uncertainty because of the lack of data for validating model estimates. Total GHG emissions per ha were relatively low on the forage block due to negligible methane emissions with animals absent (Figure 1d).

The data from the constituent units were used in calculating the whole-system estimates for the dairying enterprises. Two farm systems intensification options were examined based on increased use of N fertiliser or forage. In terms of land use efficiency, N fertiliser was the most efficient at increasing productivity per unit of land area, particularly when the whole-system land use was accounted for (Table 1). The forage option increased whole-system production/ha by 13% due to the high productivity/ha from the forage block. Economic analysis showed highest profitability from N fertiliser use, whereas the economic benefit from forage cropping was sensitive to milk returns and forage yields and costs (not presented), as found in other studies (e.g. Kidd 2001).

Fuel (diesel and petrol) use efficiency was similar across all scenarios (Table 1). However, fuel use per ha was relatively high for the forage production component (Figure 1c) and therefore fuel use efficiency in the forage-supplemented dairy farm system is strongly influenced by forage management practices (e.g. cultivation, spraying, harvesting) and forage yields.

Effects of the intensification options on environmental efficiency indicators varied between environmental indices. For N leaching, the emissions/t milksolids increased by about 60% for the +200N option and was similar on a dairy farm or whole-system basis. In contrast, the forage option decreased N leaching/t milksolids by 10% on the dairy farm, due to high conversion of N in low-protein forage

into milk and relatively low N excretion and leaching compared to that from high-protein pasture (Ledgard *et al.* 2000). However, this increase in efficiency was diminished on a whole-farm system basis because it includes relatively high N leaching from the forage-cropped land (Figure 1d). Nitrogen leaching/\$ Economic Farm Surplus (EFS) showed a similar relative pattern to that per unit milksolids.

Greenhouse gas emissions per kg milksolids (and per \$EFS) were similar for the base farm and +forage options, but increased by about 15% for the +N fertiliser option. The latter was mainly due to increased nitrous oxide emissions.

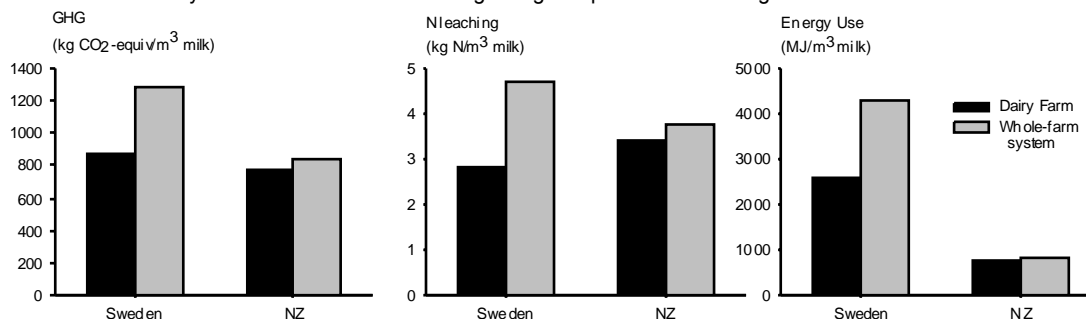
This evaluation highlights that the choice of intensification method influences the potential for gain in dairy farm system efficiency. Fertiliser N increased production and economic efficiency but decreased environmental efficiency in terms of potential effects on water and air quality. In contrast, increased forage cropping provided smaller potential economic gain but had little effect on environmental efficiency when expressed as emissions per unit of milk production.

#### How do we compare with dairying overseas?

As well as evaluating the total potential benefit from land intensification or improved management practices, LCA methodology can be used to benchmark farm systems within New Zealand or overseas. An example of a preliminary comparison of the resource use and environmental efficiency of the average Waikato dairy farm with an example Swedish dairy farm (Cederberg 1998) is given in Figure 2.

Greenhouse gas emissions per unit of milk production from the Swedish dairy farm were only slightly higher (11%) than that estimated for the average Waikato dairy farm. This refers to direct

**Figure 2** Comparison of an average Waikato dairy farm and an example Swedish dairy farm (Cederberg 1998) for GHG emissions, N leaching and energy use (fuel+electricity) based on the dairy farm unit or the whole farm system which includes land for grazing and production of forages and concentrates.



emissions associated with fuel and electricity, and accounts for emissions from on-farm crop production and feeding of housed dairy cows. While the energy-related CO<sub>2</sub> emissions were greater for the Swedish farm, this was countered by lower methane emissions per unit of milk production from Swedish cows. The latter is a product of high feed quality and the much higher milk production from Swedish cows than Waikato cows (7050 versus 3650 litres/cow/year). However, if estimates are examined on a whole system basis to account for replacement animals and all land used to produce forage and concentrates, the total GHG emissions were 50% higher for the Swedish farm system.

Estimated N leaching per unit of milk production from the pastoral component of the Swedish farm was 25% lower than that from the Waikato farm, but when all land (including cropping) was included it was 25% higher for the Swedish farm system, due to relatively high N losses from cropped land. The per-hectare estimate of N leaching to groundwater was higher for the Waikato farm than from the Swedish pastoral land (36 versus 23 kg N/ha/year), because the Swedish farm used crops to optimise dietary protein, had a lower effective stocking rate than the Waikato farm (1.0 versus 2.7 cows/ha), and excreta deposited in autumn/winter was collected, stored and applied in spring/summer thereby increasing N use efficiency.

Total farm energy use per unit of milk production on the Swedish farm was over 3 times that of the Waikato farm and over 5-fold higher on a whole-system basis. The main difference was in diesel and oil use which was over 6 times higher for the Swedish farm system due to requirements for crop production, feed transfer and heating the farm dairy. It is interesting to speculate that this large difference in fuel use could compensate for the energy cost associated with shipping dairy produce from New Zealand to Europe. The “food-miles” concept being

examined in Europe, attempts to account for the total energy costs of food production including transport of produce to markets (Paxton 1994). Our current research is examining total resource use, environmental emissions and implications of “food-miles” in more detail.

In future, it is important that the intensification practices used on New Zealand dairy farms do not diminish our overall efficiency. We should look to improve some aspects of our environmental efficiency to at least be at a similar level to our overseas competitors, while maintaining or enhancing our current high energy efficiency. This is likely to involve a combination of N fertiliser use, forage integration and improved management practices to reduce environmental impacts and increase energy efficiency. Those efficiencies could then be highlighted on “eco-labels” to enhance our marketing opportunities where high product prices exist such as in Europe.

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#### REFERENCES

- Cederberg, C. 1998. Life cycle assessment of milk production – a comparison of conventional and organic farming. SIK report. The Swedish Institute for Food and Biotechnology. SIK, Gothenburg, Sweden.
- de Klein, C.A.M.; Sherlock, R.R.; Cameron, K.C.; van der Weerden, T.J. 2001. Nitrous oxide emissions from agricultural soils in New Zealand – a review of current knowledge and directions for future research. *Journal of the Royal Society of New Zealand* 31: 543-574.
- Ledgard, S.F.; de Klein, C.A.M.; Crush, J.R.;

- Thorrold, B.S. 2000. Dairy farming, nitrogen losses and nitrate-sensitive areas. *Proceedings of the New Zealand Society of Animal Production* 60: 256-260.
- Livestock Improvement 2003. *Dairy statistics 2001-2002*. Livestock Improvement Corporation Ltd, Hamilton. 45 pp.
- MAF 2002. Waikato/Bay of Plenty intensive. pp. 26-33. *In: North monitoring report*. Ministry of Agriculture and Forestry, Wellington.
- Paxton, A. 1994. The Food Miles Report: The Dangers of Long Distance Food Transport. SAFE Alliance, London.
- Ulyatt, M.J.; Lassey, K.R.; Martin, R.J.; Walker, C.F.; Shelton, I.D. 1997. Methane emission from grazing sheep and cattle. *Proceedings of the New Zealand Society of Animal Production* 57: 130-133.
- Wells, C. 2001. Total energy indicators of agricultural sustainability: Dairy farming case study. Report to MAF; Technical Paper 2001/3. 79pp.
- Wheeler, D.M.; Ledgard, S.F.; deKlein, C.A.M.; Monaghan, R.M.; Carey, P.L.; McDowell, R.W.; Johns, K. 2003. OVERSEER® – moving towards on-farm resource accounting. *Proceedings of the New Zealand Grassland Association* 65: 191-194.