Greenhouse gas assessment for the Lincoln University Dairy Farm

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Abstract

The Lincoln University Dairy Farm (LUDF) is a commercial demonstration dairy farm achieving over 1700 kg MS/ha with 4.2 cows per hectare on a pasture based system. We compare greenhouse gas (GHG) emissions from such a system with the "typical dairy farm". LUDF was a first adopter of nitrous oxide mitigation technology through the use of eco-n nitrification inhibitor. A full life cycle assessment for greenhouse gases within the farm gate was completed for the 2006-07 farming year. The LUDF produced milksolids with 11% lower GHG emissions/kg MS (kg CO_2 eq/kg MS) than the typical NZ dairy farm, and when nitrification inhibitor mitigation was factored in for nitrous oxide this resulted in 21% lower emissions/ kg MS. However the per hectare output of GHG was 51% higher than for the "typical" NZ dairy farm. This suggests that properly managed dairy farms with an emphasis on pasture utilisation and per cow and per hectare production, and the use of eco-n nitrification inhibitor, can lower GHG emissions per unit of output (milksolids) even if the per hectare output is higher than average, which demonstrates improved land utilisation.
Keywords: intensive dairying, greenhouse gases, lifecycle assessment, nitrification inhibitor, eco-n

Introduction

Lincoln University Dairy Farm (LUDF) offers a unique opportunity to benchmark an irrigated dairy production system that is characterised as high production (1700 kgMS/ha). Establishing its greenhouse gas emissions (GHG) footprint and comparing this to a more "typical" NZ dairy farm gives further insights into ways of improving one aspect of the environmental and economic performance of the NZ dairy industry. The "typical" farm was modelled on the Waikato region using inputs, stocking rates and production from a combination of sources (Basset-Mens *et al*. 2007; MAF 2006)

The purpose of this paper is to:

1. Establish a detailed resource use and production inventory of the LUDF
2. Establish the LUDF's greenhouse gas emissions
3. Compare the results with previous NZ studies and a "typical" NZ dairy farm
4. Provide a technical analysis on the potential impact of the proposed agricultural emissions trading scheme (ETS).

Study Methods

Systems boundaries

The functional unit (i.e. the product unit with a similar function) is a tonne of milk solids.

The system boundary (i.e. the boundary that identifies the relevant GHG emissions and removal activities associated with the specified product) includes the impacts associated with:

- The extraction, refinement, formulation, packaging and transport to the farm of fuel, fertiliser and agrichemicals
- Fuel use on the farm: this includes all types of fuel the farmer purchases (excluding private usage), as well as the estimated fuel use by contractors for fertiliser application, weed control, cultivation, direct drilling, and infrastructure maintenance
- On farm electricity use, including irrigation, milking plant and water reticulation; electricity includes fugitive losses in conversion and distribution
- Transport of stock by truck between the farm and run-off
- The run-off production platform
- The embodied energy and emissions from on-farm capital equipment.

Greenhouse gas emissions (CO_2, CH_4, N_2O) from resource use include:

- Direct energy sources. All types of fuel used on farm, diesel used by contractors, transportation, and electricity used by the farm
- Electricity including the energy inputs to deliver it to the farm
- Fertilisers, agri-chemicals and purchased feed including manufacture and delivery
- Limestone quarrying and processing, and carbon emissions from the reaction with the soil
- Manufacture and maintenance of capital items
- Packaging and chemicals.

Greenhouse gas emissions of methane and nitrous oxide are from:

- Methane emissions from ruminant animals fermentation and manure management
- Nitrous oxide emissions from direct and indirect inputs

Table 1 Summary of fuel energy and emission factors.

Fuel type	Unit	Consumer energy (MJ/unit)	Fugitive energy coefficient	Primary energy (MJ/unit)	GHG (GWP_{100}, g CO_2 eq/ $MJ_{primary}$)	GHG (g CO_2 eq/ unit)
Diesel	litres	37.9	1.19	45.2	69.2	3,126
Petrol	litres	34.9	1.19	41.6	66.1	2,750
Avg Electricity (2005)	kW	3.6	2.23	8.03	28.9	232

Source: Barber & Pellow (2008).

Table 2 Energy inputs for various agrichemicals.

Agrichemical	Average % of active ingredient	Production of active ingredient (MJ/kg ai)	Formulation, packaging and transport (MJ/kg ai)	Total (MJ/kg of product)
Bloat oil	95%	5	110	31
Animal remedies	50%	100	110	105
Herbicide-glyphosate	36%	440	110	186
Other	50%	100	110	105

Source: Wells (2001).

Table 3 Purchased feed-embodied energy and GHG emissions.

Feed	Energy (MJ/t DM)	GHG (kg CO_2 eq/MJ)	GHG (kg CO_2 eq/t DM)
Grain (barley)	2,795	0.051	143
Silage	1,500	0.060	90
Hay	1,500	0.060	90

of synthetic fertiliser and animal waste and indirect emissions from leaching.

The components of the life cycle which have been excluded are:

- All processes in the production chain beyond the farm gate
- Carbon sequestered in soil, woody material and farm products.

The resource use and greenhouse gas emissions are based on Life Cycle Assessment methodology (ISO 14044:2006) of the Lincoln University Dairy Farm (LUDF) and its main product milk.

Allocation

Biological allocation, which is based on the feed required physiologically by the animal to produce milk and meat (calves, culled cows), has been used in this study and the results have also been compared to an economic allocation approach. Biological allocation was used by Basset-Mens *et al.* (2005) who determined allocation impacts between the co-products milk and meat to be in a ratio of 85:15.

Economic allocation is the preferred approach in the Publicly Available Specification PAS 2050 (BSI 2008) currently being developed by Defra/BSI British Standards and the Carbon Trust. However a problem with the economic allocation is that there are marked variations in price between locations and times. Farm profitability and revenue streams can be quite cyclical and often, for an exporting country like New Zealand, are very dependant on world commodity prices and the exchange rate; consequently changes in a products carbon footprint may have no correlation with changes in farm management or performance. For these reasons, and to remain consistent with other NZ studies, we used biological allocation.

Data

Table 1 describes the primary energy and greenhouse gas emissions (CO_2, CH_4, N_2O) of NZ fuels using an LCA methodology. Fertiliser use is reported in the different nutrient components and the CO_2 emission factors presented by Wells (2001) were adapted to include the CH_4 and N_2O emissions during manufacture.

The energy requirement to manufacture agrichemicals ranges between 5 and 440 MJ/kg active ingredient (ai). Energy used in formulating, packaging and transporting the chemicals adds a further 110 MJ/kg ai. Table 2 shows the energy input for various agrichemical categories.

Table 4 Resource inputs and production.

	Unit	LUDF		Typical NZ dairy farm
		Quantity/farm	Quantity/ha†	Quantity/ha
Direct Energy				
Diesel	litres	5,053	31.2	37
Petrol	litres	1,996	12.3	23
Contractors	litres	6,383	39.4	20
Electricity	kWh	348,636	2,152.1	557
Indirect Energy				
Nitrogen	kg	30,710	189.6	114
Phosphorus	kg	4,410	27.2	59
Potassium	kg	0	0.0	57
Sulphur	kg	5,635	34.8	64
Magnesium	kg	0	0.0	0
Lime	kg	80,000	493.8	295
Agrichemicals	litres	2,140	13.2	8
Minerals	kg	16,000	98.8	8
Purchased Feed	kg DM	167,140	1,031.7	1,100
Grazing off (replacements from 9 months and winter cows off)	SU	1,371	8.5	-
Capital				
Buildings	m^2	1,103	6.8	6
Dairy Shed	cups	50	0.3	40
Vehicles	kg	6,100	37.7	93
Implements	kg	5,227	32.3	80
Races	m	3,625	22.4	36
Fences	m	15,104	93.2	80
Pipes	m	16,000	98.8	-
Irrigation area	ha	179	1.0	0
Water				
Irrigation	mm	450	450	0
Area				Quantity/ farm
Main milking platform	ha	162	-	107
Run-off	ha	19	-	0
Irrigated area	ha	181	-	0
Production				
Stocking rate	Cows milked	670	4.1	300
Milksolids	kgMS	274,600	1,700	94,800

† divided by the 162 ha on the main milking platform.

Agrichemical greenhouse gas emissions are 0.064 kg CO_2 eq/MJ.

The total embodied energy and GHG emissions of purchased feed are shown in Table 3. In addition to the purchased feed, stock are grazed off the farm which also needs to be taken into account. The resource use (total energy) and their associated GHG emission coefficients are assumed to be 380 MJ/SU/yr and 30 kg CO_2 eq/SU/yr respectively (Barber & Pellow 2008). These values were based on Meat & Wool NZ's All Class Average sheep and beef farm and then adjusted for the length of time the animals were off the LUDF.

An inventory of farm equipment (length, size and type of pipes, description of fences and their proportion) and the area of buildings were collected in the farm survey and energy and emission coefficients (Barber & Pellow 2008) were applied to these capital items.

To calculate methane emissions, the AgResearch programme Overseer® version 5.2.6.0 was used. The model was tailored to the LUDF using the advanced functions and included the animals wintered off the farm and the replacements, from 9 months, grazing elsewhere.

Nitrous oxide comes from both direct and indirect sources. Direct sources include soil emissions from synthetic nitrogen fertiliser and animal waste excreted in the paddock. Indirect sources include the volatilising and leaching of synthetic nitrogen fertiliser and animal excretion. Overseer® was used to determine these emissions.

Global warming potentials (GWPs) are based on the ability of different gases to trap heat in the atmosphere and the decay rates, relative to that of carbon dioxide. The GWPs we used in this study are 1, 21 and 310 for CO_2, CH_4 and N_2O respectively (IPCC 1996). These values are consistent with those used in New Zealand's GHG Inventory report. All results are expressed in CO_2 equivalents (CO_2 eq.).

Results and Discussion

Resource inputs

Table 4 presents the average inventory of resource inputs for the whole farm, including run-off. The resource inputs incurred by replacement stock raised off the farm between 9 months of age and when they return as in-calf cows, plus those cows that winter off the farm for an average of 9 weeks are accounted for in the grazing-off stock units. The total inputs have also been divided by the area of the LUDF's main milking platform (162 ha) to determine the inputs per hectare.

Lifecycle assessment

Life cycle impact assessments evaluate resource use and emissions based on the life cycle inventory. Two impact categories have been chosen – total energy use and greenhouse gas emissions. These results do not account for any sequestered carbon credits from trees or the soil carbon. Table 5 shows the total energy use of the LUDF.

The total energy inputs per tonne of milk solids based on biological allocation is 21,750 MJ/t MS. Economic allocation, based on 93% of the income being generated from milk, has an energy input of 23,770 MJ/t MS. Table 6 presents the greenhouse gas emissions for the LUDF per tonne of milksolids using both biological and economic allocation.

Mitigation and emissions trading scheme

There are limited opportunities to significantly reduce the greenhouse gas emissions from agricultural production. One of the few viable and commercially available tools to lower animal and field emissions is the use of nitrification inhibitors to reduce both N_2O emissions from urine patches and nitrate leaching. LUDF uses the commercially available nitrification inhibitor eco-n™ (Ravensdown Fertiliser Co-operative). This is applied by spray application in May and August. In 2006/07, it was applied to half the farm and across the whole farm in the 2007/08 season.

In a study by Clough *et al.* (2007) use of nitrification inhibitors were found to reduce average emissions of N_2O and nitrate leaching by 72% and 61% respectively. They consequently recommended lowering the NZ specific emission factors for EF1 (0.01)[1], $EF3_{PRP}$ (0.01)[2] and $Frac_{LEACH}$ (0.07)[3] where nitrification inhibitors were used to the conservative values of 0.0058, 0.0058 and 0.0455 respectively.

Table 5 Total energy use by Lincoln University Dairy Farm.

	Energy use (MJ/ha)
Direct energy inputs	
Diesel	1,410
Petrol	510
Contractors (diesel)	1,780
Electricity	17,275
Indirect energy inputs	
Nitrogen	12,320
Phosphorus	410
Potassium	0
Sulphur	175
Magnesium	0
Lime	295
Agrichemicals and Minerals	3,125
Purchased Feed & Grazing-off	5,025
Capital inputs	1,045
Total	**43,370**

Table 6 Total on-farm GHG emissions (kg CO_2 eq/t MS)

	Biological allocation	Economic allocation
Direct energy		
Diesel	49	53
Petrol	17	19
Contractors	62	68
Electricity	251	274
Total direct energy	**378**	**413**
Indirect energy		
Nitrogen	321	351
Phosphorus	13	14
Potassium	0	0
Sulphur	6	6
Magnesium	0	0
Lime	107	117
Total fertiliser	447	489
Agrichemicals & minerals	100	110
Purchased feed & grazing-off	182	199
Total indirect energy	**729**	**797**
Capital inputs	53	57
Animal emissions		
Methane	4,768	5,212
Nitrous oxide	2,947	3,221
Total	**8,875**	**9,701**

As the Overseer version available at the time was not adapted to include the effect of eco-n, the farm was modelled using the IPCC methodology and NZ emission factors. These emission factors were then changed to reflect the effect of using eco-n™ and then the percentage change in each of the nitrous oxide emission categories was applied to the farm's baseline Overseer® result. This simplified approach assumed that

[1] EF1 emission factor for direct emissions from N input to soil
[2] $EF3_{PRP}$ emission factor for direct emissions from waste in the pasture range and paddock animal waste management system
[3] $Frac_{LEACH}$ fraction of nitrogen input to soils that is lost through leaching and run-off

Table 7 Impact of eco-n™ on GHG emissions.

	No Eco-n kg CO_2 eq/ha	Eco-n kg CO_2 eq/ha	No Eco-n kg CO_2 eq/t MS	Eco-n kg CO_2 eq/t MS	Percentage change
Resource Use	2,315	2,330	1,160	1,170	< 0.1%
Methane	9,510	9,510	4,770	4,770	0.0%
Nitrous Oxide	5,875	3,805	2,945	1,910	35.2%
Animal waste – direct	4,470	2,600	2,240	1,305	41.8%
Animal waste – indirect	430	370	215	185	14.4%
N fert – direct & indirect	975	610	490	305	37.4%
Total	17,700	15,645	8,875	7,845	11.6%

Table 8 Emissions trading scheme farm costs.

Emission source	Allocation of 90% of 2005 emissions			Full price of emissions		
Carbon price >	$15	$25	$50	$15	$25	$50
Methane emissions	$1,860	$3,105	$6,205	$18,615	$31,030	$62,055
Field nitrous oxide emissions	$1,150	$1,915	$3,825	$11,480	$19,130	$38,265
Total farm carbon cost	$3,010	$5,015	$10,030	$30,950	$50,160	$100,320
Eco-n carbon credit	$4,045	$6,740	$13,480	$4,045	$6,740	$13,480
Total farm carbon cost using eco-n	-$1,035	-$1,725	-$3,450	$26,050	$43,420	$86,840

Table 9 Carbon footprint of the Lincoln University Dairy Farm vs. a "Typical" NZ dairy farm.

	kg CO_2 eq/t MS		kg CO_2 eq/ha		kg CO_2 eq/cow	
	Lincoln	Typical	Lincoln	Typical	Lincoln	Typical
Direct Energy	380	360	755	375	185	135
Indirect Energy	730	780	1,455	815	350	290
Capital	50	140	105	145	25	50
Methane	4,770	5,570	9,510	5,805	2,300	2,070
Nitrous Oxide	2,950	3,070	5,875	3,200	1,420	1,140
Total	8,875	9,920	17,700	10,340	4,280	3,690

Table 10 Comparison of "typical NZ dairy farm" and LUDF energy and GHG emissions.

	MJ/t MS	kg CO_2 eq/ha	kg CO_2 eq/t MS
Typical farm (this study)	21,143	10,340	9,920
LUDF – no eco-n	21,750	17,700	8,875
LUDF – with eco-n	21,885	15,645	7,845

there is no effect of eco-n on pasture and animal production, and therefore no change in methane production; which may then have been offset by higher production. The use of eco-n™ increased GHG emissions by 2.5% (two spray applications), due to more fuel being used, but lowered the GHG emissions of animal and field emissions of nitrous oxide by 13%.

Table 7 describes the impact of modelling these changes using Overseer® and the percentage change in each emission category. Nitrous oxide emissions have been reduced by 35%, and overall farm emissions (including CO_2 and CH_4) have decreased by 12%. Eco-n™ has reduced total farm nitrous oxide emissions by 270 t CO_2 eq; total farm emissions have decreased by 267 t CO_2 eq due to the small increase in energy use for applying eco-n™ twice a year.

A technical analysis of the likely measures to be included in the NZ Emissions Trading Scheme was conducted. The Agricultural ETS will likely be applied to the animal and field emissions of methane and nitrous oxide. While the final mechanisms to be used in the ETS have yet to be decided, it was assumed that the emissions from the replacements and those animals wintered off the farm were excluded. These emissions were assumed to be accounted for on the farm that the animals are moved to. Total LUDF animal and field emissions that will attract the agricultural ETS are 2006 t CO_2 eq (20% lower than the LCA result). At $25/t CO_2 the additional cost in the first year based on 90% of the emissions being allocated for free and assuming there have been no significant changes since the 2005 base year, will be $5,015. By the time the free allocation is phased out this will have increased to $50,160. Any change in carbon emissions either above (e.g. increased stock numbers) or below (e.g. by using a mitigation strategy like eco-n™) the 2005 base year will be charged at the full cost of carbon from the outset of the agricultural ETS. Consequently the farm receives the full benefit from implementing a mitigation strategy, like eco-n™, from the outset. Table 8 describes the impact of different carbon prices, the free allocation of GHG emissions, and the use of eco-n™.

Conclusions

The Lincoln University Dairy Farm energy and resource inputs per unit of production were found to be almost identical to what this study determined for a "typical" NZ dairy farm, despite being an irrigated property that pumps water from a depth of 90 metres. The LUDF is significantly more intensive than the "typical" NZ farm so consequently resource inputs per hectare were 130% higher.

This study also determined the GHG emissions footprint of a "typical" NZ dairy farm to enable the results to be compared with the LUDF and ensure that this was done using the same methodology and emission factors. Table 4 describes the resource inputs and production of the LUDF and a "typical" NZ dairy farm and Table 9 compares the resulting GHG emissions on a production, per hectare and per cow basis.

As shown in Table 10, the LUDF GHG emissions were found to be 11% lower on a production basis than the typical NZ dairy farm. If the use of eco n™ was also taken into account (assuming it was applied across the whole LUDF as it was in the 2007-08 season and not on the "typical" NZ farm) then emissions per tonne of milk solids were 21% lower.

The Agricultural ETS will be applied to the animal and field emissions of methane and nitrous oxide. Unlike the LCA approach the emissions from the replacements and those animals wintered off the farm are excluded. These emissions are accounted for on the farm that the animals are moved to. Total LUDF animal and field emissions that will attract the ETS are 2006 t CO_2 eq (20% lower than the LCA result). At \$25/t CO_2 the additional cost in the first year based on 90% of the emissions being allocated for free and assuming there have been no significant changes since the 2005 base year, will be \$5,015. After the first year an annual reduction in the percentage of free emissions will eventually mean the full cost will be \$50,160 (at \$25/t CO_2). Table 8 describes the impact of different carbon prices, free allocations and the use of eco-n™.

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