Evaluation of two potential on-farm measures for reducing greenhouse gas emissions from an average dairy farm on the West Coast of the South Island of New Zealand

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Abstract

Agriculture contributes about 60% of New Zealand's total greenhouse gas emissions. Management practices for reducing these emissions will be required to meet our future international commitments. This paper presents estimates of two practical on-farm measures for reducing total greenhouse gas emissions from an average dairy farm on the West Coast of the South Island of New Zealand: 1) the incorporation of cereal silage into the diet, and 2) the strategic use of a stand-off pad in winter. Total calculated greenhouse gas emissions were reduced by about 14% if fertiliser N-boosted pasture was replaced with bought-in cereal silage grown off-farm. The estimated reduction in emissions was due to reductions in nitrous oxide and carbon dioxide emissions, whereas methane emissions were not significantly affected by this management practice. Reduced methane emissions required an increase in per animal production and a corresponding decrease in stocking rate. The use of a stand-off pad during winter did not significantly affect total greenhouse gas emissions using current inventory calculations. However, recent research suggests that it may reduce emissions by 3 to 8%, when accounting for the seasonal variation in N_2O emissions and reduced fertiliser N requirements due to reduced pasture damage. A preliminary assessment of the economic implications of the cereal silage option suggested the cost of using cereal silage is likely to be higher than any savings that could be accrued from carbon credits obtained from reducing greenhouse gas emissions. However, the costs associated with building and using a stand-off pad are likely to be off-set against a potential increase in pasture production, and carbon credits obtained from a reduction in greenhouse gas emission would represent a net cost saving.

Keywords: carbon dioxide, cereal silage, dairying, methane, mitigation options, nitrous oxide, stand-off pad

Introduction

Ratification of the Kyoto Protocol will legally bind New Zealand to reduce its greenhouse gas emissions to 1990 levels over the next 6 to 10 years. Thereafter, even more stringent greenhouse gas reduction targets could be required. The three main greenhouse gases are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Agriculture contributes about 60% of our total greenhouse gas emissions in CO_2 equivalents, with 90% of these agricultural emissions comprising CH_4 and N_2O emissions. Recent analyses indicate that national CH_4 and N_2O emissions are currently up to 9% above 1990 levels (Clark & Ulyatt 2002; Ledgard *et al.* 2002a). The principle source of agricultural methane is enteric fermentation in the digestive tract of ruminants. Nitrous oxide emissions from New Zealand agriculture arise largely as a result of the deposition of excreta nitrogen to the soil by grazing animals (de Klein *et al.* 2001). To ensure New Zealand will be able to meet its international commitments, sustainable management practices for reducing greenhouse gas emissions from agriculture need to be developed and adopted. In a previous study, de Klein & Clark (2002) estimated the impact of potential management options for reducing greenhouse gas emissions from dairy farms, on either the total CH_4 or the total N_2O emissions for New Zealand. Two options that were identified as potentially most effective for reducing N_2O emissions were reducing the amount of excreta N produced by feeding the animals lower N diets, and avoiding N excreta deposition in autumn/winter when the risk of N_2O emissions are highest (de Klein *et al.* 2001) by using a stand-off pad. However, de Klein & Clark (2002) also showed that some of the potential options for reducing emissions of one greenhouse gas could increase emissions of another. They concluded that potential options need to be evaluated at a farm scale for all greenhouse gases collectively. This paper presents an evaluation of two practical on-farm measures for reducing total greenhouse gas emissions, by estimating the CH_4, N_2O and CO_2 emissions for an average dairy farm on the West Coast of the South Island of New Zealand.

Methods

Total methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions were estimated for two greenhouse gas reduction practices on an average West Coast farm (Bailey 1997; Davis *et al.* 1998; LIC 2001);

Table 1 Details of an average West Coast dairy farm.

	Average West Coast Dairy Farm
Effective milking area (ha)	124
Stocking rate (cows/ha)	2.0
Average live weight (kg/cow)	456
Milk production (L/cow/yr)	3700
Milk solids production (kg MS/ha/yr)	650
Milk solids production (kg MS/cow/yr)	325
Pasture production (t DM/ha/yr)	13.2
Pasture utilisation (%)	70
Effluent management	Spray irrigation
Effluent area (ha)	20
N fertiliser use (kg N/ha/yr)	100 (on 104 ha non-effluent area only)
Lime use (kg/ha/yr)*	800
Fertiliser P (kg/ha/yr)*	35
Fertiliser K (kg/ha/yr)*	40
Fertiliser S (kg/ha/yr)*	50

*Assumed values (J Morton pers. comm.)

(Tables 1 and 2): 1) the incorporation of bought-in cereal silage into the diet as a replacement for N-boosted pasture to reduce the amount of excreta N returned to soil, and 2) the strategic use of a stand-off pad in winter (Chadwick *et al.* 2002; de Klein & Clark 2002). Total greenhouse gas emissions were also estimated for a combination of options 1 and 2 (Option 3).

Under option 1, fertiliser N application was reduced from 100 to 0 kg N/ha and the subsequent loss of pasture growth was compensated for by buying in cereal silage grown off-farm. The N concentrations of pasture and cereal silage were 3.6 and 1.8%, respectively.

Under option 2, the animals were kept on a stand-off pad for 60 days during winter, but allowed to graze for 4 hours each day, to minimise N excreta deposition in autumn/winter when the risk of N_2O emissions is highest. The collected farm dairy effluent (FDE) was spray irrigated onto the land during that period.

The effect of these management practices on methane emissions was estimated using the method presented by Clark & Ulyatt (2002). This method differs from the method used in the calculation of the official national methane inventory in that it uses information on animal size and productivity to estimate methane emissions rather than relying on fixed emission factors per animal irrespective of their level of productivity. The calculations are based on an average West Coast dairy cow of 456 kg liveweight, an average milk production of 3700 litres/cow (LIC, 2001), a metabolisable energy (ME) requirement of 45600 MJ/cow/year, and ME values for grass and cereal silage of 10.5 and 11 MJ/kg DM, respectively. Methane output was assumed to be 6.3% of the gross energy consumed, which is the mean value obtained from dairy cows grazing C3 pastures in New Zealand (M. J. Ulyatt; G. C. Waghorn unpublished results).

Nitrous oxide emissions were estimated using a standard international methodology for calculating N_2O emissions from agriculture, developed by the Intergovernmental Panel on Climate Change (IPCC 1997). This methodology was used in the current calculations because it is the same as used by the New Zealand government for its annual N_2O inventory reporting as required under the Kyoto Protocol. Although there are uncertainties associated with this IPCC methodology, it does provide a standard and common approach, and allows a comparison of relative differences in N_2O emissions under various management practices. This methodology estimates N_2O emissions from all sources of nitrogen from a farming system by multiplying each source with an N_2O emission factors (EFs). The nitrogen sources are divided into those that cause direct emissions on the farm (e.g. excreta N, fertiliser and FDE), and those that originate from the farm but cause indirect emissions off-farm (e.g. due to nitrate leaching and ammonia volatilisation). In New Zealand's application of the IPCC methodology the following N_2O emission factors are used: N_2O from animal excreta = 1% of N excreted during grazing; from FDE and fertiliser = 1.25% of N applied; from nitrate leaching = 2.5% of N leached; and from ammonia volatilisation = 1% of N volatilised. The N_2O emission factor for animal excreta is a New Zealand specific emission factor based on review of field studies carried out in New Zealand (Sherlock *et al.* 1997). The other N_2O emission factors are the default values set by the IPCC based on international research. Although N_2O emissions associated with the production of cereal silage did not occur on the dairy farm itself, they were a part of the total farming operation and were therefore included to estimate the total impact of this management option on N_2O emissions.

The amounts of N excreted by the grazing animals, N collected and recycled as Farm Dairy Effluent (FDE), and N leached as nitrate and volatilised as ammonium

Table 2 Details of average West Coast dairy farm and the management options for potential reduction of greenhouse gas emissions.

	Average farm (124 ha)	Option 1: Bought-in cereal silage grown off-farm	Option 2: Stand-off pad + grazing for 4 hrs/d	Option 3: Bought-in cereal silage + Stand-off pad
Winter grazing management	On pasture; grass silage or baleage fed out on pasture	On pasture; cereal silage fed out on pasture	On stand-off pad for 60 days + 4 hrs grazing/day; grass silage/baleage fed out on pad	On stand-off pad for 60 days + 4 hrs grazing/day; cereal silage fed out on feed pad
Stocking rate (cows/ha)	2.0	2.0	2.0	2.0
Pasture production (t DM/ha/yr)				
Total [2]	13.2	12.4	13.2	12.4
From N fertiliser use [3]	0.8	0	0.8	0
Total DM (t DM/yr)				
Grown on farm	1637	1538	1637	1538
Cereal bought in		100		100
N fertiliser use				
Pasture on farm (kg N/ha/yr)	100 (non-effluent area)	0	100 (non effluent area)	0
(t N/yr)	10.4	0	10.4	0
Cereal off farm (kg N/ha/yr)	0	100	0	100
(t N/yr) [4]	0	1.3	0	1.3
N flows (kg N/ha/yr)				
N excreted on pasture	287	263	263	241
N applied as FDE	18	18	42	42
Nitrate leaching	33	26 [5]	26	27 [5]
Ammonia volatilisation	26	16 [6]	27	17 [6]

[1] LIC (2001).
[2] Davis *et al.* (1998).
[3] Assumes fertiliser N response of 10 kg DM/kg N.
[4] About 12.5 ha required to grow 100 t cereal silage DM (Bailey 1997).
[5, 6] Includes estimates of nitrate leaching and ammonia volatilisation from the cereal crop of 10 and 12 kg N/ha, respectively.

were estimated using the OVERSEER® nutrient budgeting model (Ledgard *et al.* 1999). The total amount of N fertiliser used was 1.3 t N for option 1 and 3, and 10.4 t N for the average farm and option 2 (Table 2).

An assessment of the CO_2 emissions associated with fuel, electricity, lime use, fertiliser manufacture and use, and cultivation, growth, harvest and transport of cereal silage was also made. As for the N_2O calculations, CO_2 emissions associated with the production of cereal silage were included to estimate the total impact of this management option. Fuel and electricity use were based on average values from a Waikato dairy industry study (Ledgard *et al.* 2002b). Carbon dioxide emission factors for fuel, electricity, lime, fertiliser use and manufacturing, and cereal cropping were derived from Wells (2001). The estimates also accounted for a reduction in lime requirement due to a reduction in N fertiliser for the cereal silage option. This reduction in lime requirement was estimated using an updated version of a soil acidification model (de Klein *et al.* 1997).

Results and discussion

Estimated methane emissions

The inclusion of cereal silage into the diet of the cows to replace N-boosted pasture and the strategic use of a stand-off pad had little or no effect on methane emissions (Table 3). This was largely due to the fact that the assumed ME content of grass and cereal silage consumed was very similar and there was therefore very little change in the total amount of feed consumed. In addition, the calculations assume that the per animal production remains the same and that the amount of methane emitted per

Table 3 The effect of greenhouse gas mitigation options on greenhouse gas emissions from an average West Coast dairy farm (in t CO_2 equivalents/yr).

	Average farm	Option 1: Cereal silage bought in	Option 2: Stand-off pad + grazing for 4 hrs/d	Option 3: Cereal silage + Stand-off pad
Methane emissions	517	515	517	515
Nitrous oxide emissions				
Excreta from grazing animals	173	159	159	146
FDE application	14	14	32	31
Fertiliser use	63	8	63	8
Nitrate leaching	50	39	42	32
Ammonia volatilisation	16	10	16	10
Total N_2O	316	229	313	227
Carbon dioxide emissions				
Fuel and electricity use	43	47	45	49
Fertiliser use	88	32	88	32
Grow and transport cereal crop	0	9	0	9
Total CO_2	131	88	133	90
Total emissions	964	832	963	831
(% reduction from average farm)		(14)	(<1)[1]	(14)

[1] ranges from 3 to 8% if accounting for seasonal variation in N_2O emissions and reduced fertiliser N requirements due to reduced pasture damage (see text).

unit of feed intake does not change due to the introduction of cereal silage. However, if the inclusion of cereal silage in the diet increased milk production per animal, the same milk yield could be obtained with fewer animals and CH_4 would fall because the proportion of the total energy used for maintenance decreases. Using a standard IPCC methodology, de Klein & Clark (2002) estimated that for a 450 kg cow, CH_4 emissions per unit of milk decreased from 28.8 to 23.5 kg CH_4/1000 L milk when the milk production increased from 3000 to 4000 L milk/cow/year. In the current example, the methane production per 1000 L milk is 24.4 kg CH_4. An increase in milk production per cow from 3700 to 4000 L/year and a reduction of cow numbers from 248 to 229 would result in a 5% reduction in total CH_4 emissions, while maintaining the same total milk production on the farm.

Estimated nitrous oxide emissions

The use of cereal silage as an alternative to N-boosted pasture was estimated to reduce N_2O emissions by about 28%. The inclusion of cereal silage reduced the N excretion rate from 287 to 263 kg N/ha (Table 2) due to the lower N concentration of cereal compared to grass, which reduced the direct N_2O emission from animal excreta by about 8% (Table 3). The reduction in N fertiliser use from 10 t N, which produced 100 t of pasture DM on the average farm, to 1.3 t N to produce 100 t DM cereal silage off-farm, resulted in an 85% reduction in N_2O emissions from N fertiliser. Indirect N_2O emissions from leached and volatilised N were also reduced (by about 26%), even though the calculations included estimates of off-farm nitrate leaching and ammonia volatilisation losses from the cereal crop.

When the animals were kept on a stand-off pad for 20 hours per day, the reduction in N_2O emission estimated using the current inventory methodology was very small. Although N_2O emissions from excreta from grazing animals and nitrate leaching reduced by 8 and 15%, respectively, N_2O emissions from farm dairy effluent (FDE) application increased 2.5 times.

The highest reduction in N_2O emission (29%) was achieved when the two previous mitigation options were combined, which was largely a result of the inclusion of cereal silage.

Chadwick *et al.* (2002) also estimated that although the use of stand-off pads resulted in lower N_2O losses from grazed land and nitrate leaching, increased losses occurred from spreading the effluent and ammonia volatilisation, resulting in only a small reduction in total emissions. This is partly due to the fact that the IPCC N_2O emission factor for effluent application (1.25%) is higher than the New Zealand emission factor for animal excreta returned during grazing (1%). However, research shows that N_2O emissions for urine and dung are generally higher than for effluent application (de Klein *et al.* 2001). Thus, the N_2O emission factor for FDE application in New Zealand requires refinement to fully quantify the impact of this mitigation option.

The current N_2O inventory calculations also assume that the emission factor for excreta returned during grazing is constant throughout the year. However, N_2O emissions from animal excreta tend to be highest during the wet autumn/winter period (Carran *et al.* 1995; de Klein *et al.* 2001). It is likely, therefore, that the reduction in N_2O emissions from pastures that are grazed only for 4 hours per day during winter will be higher than currently estimated using a constant N_2O emission factor throughout the year. For example, Ledgard *et al.* (1996) found that denitrification losses from grazed dairy pastures showed a distinctive seasonal pattern, with about 50% of the losses occurring between June and August when soils are wet. Based on these results and assuming the N excretion rate is constant throughout the year, the N_2O emission factor for excreta deposited during grazing would be 0.6% during the 10 grazing months and 3% during the 2 months the cows only grazed for 4 hours per day. Using these emission factor values, the N_2O emissions would reduce by 10% compared to the average farm. This estimate is similar to earlier calculations by de Klein & Clark (2002).

Reduction in soil damage from animal treading in winter when using a stand-off pad is likely to reduce N_2O emissions (Oenema *et al.* 1997), but this is again not accounted for in the current methodology for calculating N_2O emissions. The use of a stand-off pad could also result in additional forage, due to reduced pasture damage and more efficient use of excreta-N (de Klein 2001). If pasture production increased by 5%, the fertiliser N requirement could be reduced from 100 to 25 kg N/ha to maintain total DM production at 13.2 t/ha, and N_2O emissions would be reduced by about 15% compared to the average farm.

Estimated carbon dioxide emissions

The estimates of CO_2 emissions include those from fuel, electricity, fertiliser and lime use, fertiliser manufacturing, and where applicable, from soil carbon release following cultivation and harvesting of cereal crop. Inclusion of cereal silage reduced total CO_2 emissions by about 33%, even though CO_2 emissions from cultivation, harvesting, fuel and fertiliser use on the cereal crop increased (87 kg CO_2/t DM cereal bought-in; Wells 2001). The reduction in N fertiliser use on pasture from 100 to 0 kg N/ha resulted in a reduction of CO_2 emissions associated with manufacturing N fertiliser by about 300 kg CO_2/ha. In addition, CO_2 emissions from lime use reduced by about 40% due to a reduction in soil acidification associated with N fertiliser use.

Using a stand-off area for 60 days during the winter months resulted in only a very small increase in CO_2 emissions. However, if pasture production increased due to reduced treading damage and N fertiliser use was reduced from 100 to 25 kg N/ha, total CO_2 emissions would be reduced by 20% compared to the average farm.

Estimated total GHG emissions

The calculations suggested that total greenhouse gas emissions were reduced by about 14% when cereal silage was used as an alternative to N-boosted pasture. This was largely due to a reduction in N_2O and CO_2 emissions (28 and 33%, respectively). The use of a stand-off pad with 4 hours grazing per day for 60 days during winter did not significantly affect total greenhouse gas emissions using current inventory calculations. Nitrous oxide and CO_2 emissions reduced only slightly, while methane emissions were the same compared to the average West Coast farm. However, the current IPCC calculations do not take account of the seasonal variation in N_2O emission of grazed pasture or the effect of animal treading on N_2O emissions during winter. When using an N_2O emission factor of grazed pasture of 0.6% during the 10 grazing months and 3% during the 2 winter months as discussed above, total greenhouse gas emissions reduced by about 3%. In addition, if using a stand-off pad increased pasture production by 5 % and reduced fertiliser N requirements in spring from 100 to 25 kg N/ha, total greenhouse gas emissions would be reduced by 8% compared to the average farm.

The cereal silage options discussed above assume that the cereal is grown off-farm and bought in. An alternative option could be to grow the cereal on-farm as part of a pasture renovation cycle. Although this would not impact on CH_4 emissions, N_2O and CO_2 emissions would change. Total greenhouse gas emissions were also estimated assuming that 10% of the farm was re-sown each year and a cereal crop was grown from spring to late summer at 8 t DM/ha/yr and new pasture re-sown in autumn, yielding 7 t DM/ha until the following spring (Davis *et al.* 1998). It was also assumed that the effluent block (20 ha) yielded 14 t DM/ha. The remaining pasture would then require about 40 kg fertiliser N/ha to ensure the total DM production remained at about 1637 t/year (Table 2). Based on these assumptions, total greenhouse gas emissions were estimated to reduce by about 9% for on-farm cereal production, which is slightly less than that for bought-in cereal.

Economic considerations

Although it was not the primary objective of this paper, a preliminary assessment of economic implications was also made. For the cereal silage option this assessment was based on a cost of $30,000 for buying-in 100 t DM cereal silage (30c/kg DM) and savings of $10,400 from reducing N fertiliser use on pasture from 100 to 0 kg N/ha ($1/kg N). Based on these figures and given that the cereal silage option could reduce greenhouse gas emissions by 113 t CO_2-equivalents, the price of carbon credits needs to be about $173/t CO_2 to break even. Although this price largely depends on the international market, it is unlikely that it will be as high as $173 (Australian Bureau of Agricultural and Resource Economics 2001). This suggests that the cost of using cereal silage would be higher than the likely savings from reduced greenhouse gas emissions.

The use of a stand-off pad will require the construction of the pad, and effluent storage facilities. de Klein (2001) indicated, however, that the associated costs can be off-set against a potential increase in pasture production due to a more efficient use of animal excreta N. If the use of a stand-off pad reduced total greenhouse gas emission by 3 to 8%, the associated carbon credits would therefore represent a net saving.

Conclusion

Replacing N fertiliser boosted pasture with cereal silage reduced total greenhouse gas emissions by about 14%. The use of a stand-off pad did not significantly affect total greenhouse gas emissions when calculated using current IPCC-based methodology, although a 3 to 8% reduction is estimated based on recent research on seasonal variation of N_2O emissions and increased pasture production due to reduced treading damage. A preliminary assessment of the economic implications of incorporating cereal silage in the diet suggested that the cost of this greenhouse gas mitigation option would be higher than the likely savings made from carbon credits. The costs associated with the stand-off pad option could be off-set against a potential increase in pasture production, and carbon credits accrued from a reduction in greenhouse gas emission would represent a net saving.

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