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Methane and carbon emissions from conventional pasture and grain-based total mixed rations for dairying

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ABSTRACT

Comparisons between cows grazing pasture or fed total mixed rations (TMR) show on average less milk production from pasture but a higher methane yield per milk or milksolids production from the pasture diet. The implication that TMR are associated with relatively lower greenhouse gas (GHG) emissions than pasture required an assessment of all production costs associated with both systems because TMR requires extensive cultivation and processing of grains and silages which form the bulk of the diet. A partial life cycle analysis of GHG (excluding nitrous oxides) was carried out for separate 250 cow herds located in Waikato (pastoral grazing) and Canterbury (cropping land for the TMR). This demonstrated much higher methane and carbon dioxide emissions, (kg CO_2 equivalents/kg milk) from cows fed TMR (1.53) relative to pasture (0.84). The principal cause of the high value for TMR were carbon losses from soil cultivation which accounted for 64% of emissions, expressed as CO_2 equivalents compared to 24% from pasture. Enteric methane accounted for 28% of GHG from TMR and 64% from pastoral systems. The remaining 8% and 12% from TMR and pastoral grazing respectively, were attributed to fertilisers, cultivation and processing.

Keywords: Dairy production; greenhouse gases; methane; carbon dioxide; total mixed rations; pasture.

INTRODUCTION

Greenhouse gases (GHG) have been linked to global warming and under the terms of the Kyoto protocol New Zealand has agreed to limit total annual emissions in the 2008-2012 period to 1990 levels. The Kyoto protocol stipulates that GHG emissions above 1990 levels incur penalty costs, so it is essential to have accurate GHG inventories and a good understanding of the sources of carbon dioxide, methane and nitrous oxides as soon as possible. New Zealand's GHG profile is unique; when expressed as carbon dioxide equivalents 55% of emissions arise from agriculture, in contrast to 'typical' values of 5-20% for industrialised countries, and methane accounts for about 44% of total New Zealand emissions. The dairy industry accounts for about 23% of agricultural methane (Clark & Ulyatt 2002) and its contribution to agricultural GHG is increasing as dairy numbers rise.

New Zealand's low cost dairy farming differs from that in many industrialised countries, with about 90% of nutrients derived from pasture. However recent trends show the dairy industry is becoming more reliant on supplementary feeding, especially of maize and other silages to complement pasture and improve cow nutrition and milk production. The movement away from low input, low cost dairying by increasing the use of feed supplements is an attractive option for dairy farmers because it buffers effects of climate on grass growth and quality and can prolong lactation during autumn.

Intensive dairying, where cows are housed and fed total mixed rations (TMR) doubles or triples cow milk production through improved nutrition (Waghorn, 2002). These diets comprise grains, silages and protein or energy supplements, which require annual cultivation, high fertiliser inputs and a substantial energy input for tillage, harvesting, transport and feeding. Movement toward more intensive pasture based dairying using supplements to complement pasture and minimise effects of forage short falls to improve production, fertility and welfare may improve profitability for the New Zealand dairy farmer but may also increase emissions of GHG. This paper provides a partial life cycle analysis of GHG emissions by calculating methane and carbon dioxide emissions from a conventional pastoral dairying system and those from a grain and silage based TMR system.

METHODS

Life cycle assessment (LCA) is a process for analysing and evaluating the impact that an activity or product has on the environment. This analysis takes into account all aspects of production, in this case the extent of carbon dioxide and methane emitted per unit of milk or milksolids production and can be used to identify more sustainable systems. In an ideal situation all inputs and outputs to dairy farming would be defined and emissions associated with each process quantified in terms of carbon dioxide and methane fluxes. The results presented here identify the major inputs and outputs to dairy farming but some processes have not been defined in terms of GHG emissions because values were of minor significance or because the costs in one system (pastoral grazing) could be balanced against equivalent costs in the other (TMR) system. The information presented here provides a basis for more intensive analysis and measurement, for example cost benefit analyses to consider economic factors associated with ration composition or impacts of ration composition on GHG emissions.

The LCA is based on two model farms; a conventional pasture based (with silage supplements) Waikato dairy farm and a hypothetical Canterbury farm where TMR are fed. These situations were chosen because of the prominence of Waikato as a dairying region, the availability of data concerning farming in the Waikato (Livestock Improvement Corporation, 2001) and annual crop production in Canterbury used for the TMR feeding system. Inputs for TMR feed components were obtained from Kolver *et al*. (2002) who undertook studies with

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TABLE 1: Herd characteristics of the model Waikato pasture and Canterbury Total Mixed Ration (TMR) farms used to calculate annual methane and carbon dioxide emissions.

	Waikato pasture	Canterbury TMR
Number of milking cows	250	250
Dry matter intake (kg/cow per annum)	4560	6049
Days in milk	240	300
Milk yield (kg/cow per annum)	3650	7304
Milksolids (kg/cow per annum)	310	602
Methane (kg per annum)	90	142.4
Methane/milk (g/kg)	24.6	19.5
Methane/milk (g/kg milksolids)	290	237

New Zealand Friesian cows fed TMR and included methane measurements which enabled annual methane production to be calculated (Robertson & Waghorn, 2002). Data for conventional pastoral farming were based on a stocking rate of 2.9 cows/ha and cow performance in the Waikato and annual methane production for New Zealand dairy cows reported by Clark & Ulyatt (2002).

Comparisons between Waikato pasture and TMR (Table 1) show mean milk yields of 3,650 and 7,304 kg/cow/annum from 240 and 300 days of lactation. Although mean herd size in Waikato was 226 in the year 2000, all data in this presentation are based on herd sizes of 250 cows. The number of cows and their feed requirements, together with crop yields defines the land area required to provide feed constituents for both models. These values were used for estimating soil carbon loss associated with cultivation. The Waikato dairy farm is assumed to replace pasture every 15 years and produce a maize silage crop as part of the pasture renewal programme.

Principal assumptions

- The Waikato farm has an effective area of 96 ha and TMR land requirements are based on feed requirements for a 250 cow herd and forage yields in Canterbury
- Herd replacements will be reared off the farm and replacement costs are not considered
- The area used for farm buildings, including the farm dairy and races on the conventional farm and the feeding pad and feed storage area for the TMR cows are considered equivalent for both systems
- No calculations have been made for components that are assumed to be the same for both systems. For example, costs of farm dairy manufacture, and the cost of the feed bunker and mixing wagon for the TMR have been considered equivalent to the costs for races, fencing and water reticulation etc on a conventional farm.

Detailed cost accounting may be undertaken in future assessments for items considered to be equal for the two systems in this study, with some assessments already undertaken by Wells (2001). He calculated total energy inputs to the dairy industry and concluded that capital inputs (e.g. manufacture of machinery, construction of buildings, races etc.) accounted for 19% of total energy inputs to pastoral dairying.

Components for TMR would be obtained from the least expensive source, and although cotton seed (available from Australia or the United States of America) could be substituted with linseed grown in Canterbury, there was insufficient information concerning linseed production for it to be used in this study. Calculations of GHG emissions have been made for feed components used in the trials reported by Kolver *et al* (2002) irrespective of their source.

Feed and land requirements

In calculating feed intakes of cows grazing in the Waikato it was assumed 84% of dry matter intake (DMI) was from grazed pasture. Maize silage accounted for 70% of the supplement and grass silage the remainder. Intakes were 4,560 kg DM/cow/annum (Holmes *et al*., 2002). Dry matter production was 14 t/ha/annum for pasture and 20 t/ha/annum for maize. The area of grazed pasture was 85.3 ha with production from a further 4.4 ha conserved as pasture silage and 6.4 ha cultivated annually for maize silage production and pasture renewal (Table 2). In practice, pasture silage would be made from a larger area closed for a small portion of the year, but the forage harvested would be equivalent to production from 4.4 ha.

Similar calculations were made for cows fed TMR.

TABLE 2: Feed requirements, yields, cultivation and soil carbon losses associated with feeding 250 cows either Total Mixed Ration (TMR) or pasture based diets. Data are per annum.

Component	DM/250 cows (tonne)	Yield /ha (tonne)	Area (ha) required	Soil carbon loss[a] (tonne)
TMR diet				
Maize grain	235.9	10.3[b]	22.9	74.4
Maize silage	371.3	20.0[c]	18.6	60.3
Grass silage	364.6	14.0	30.6[d]	8.2[e]
Hay	48.6	14.0	3.9[f]	1.0[e]
Barley grain	81.1	4.9[b]	16.6	54.0
Cottonseed	138.9	1.0[g]	138.9	149.0[h]
Soybean meal	104.6	2.8[i]	37.4	121.6
Molasses	38.8	13.5	2.9	1.9[j]
Corn gluten[k]	36.7	(10.3)	(3.6)	11.5
Fish meal	34.5	-	-	0
Oil, vitamins, mineral	57.1	-	-	-
Total:			**275.4**	**481.9**
Pasture diet				
Pasture	957.5[l]	14.0	85.3[e]	-
Maize silage[m]	127.5	20.0	6.3	50.4
Pasture silage	55.0	14.0	4.4[f]	-
Total:			**96.0**	**50.4**

[a] TMR production assumes 4 tonne carbon loss from first cultivation and a 4 year average of 3.25 t/year from soils in Canterbury and cotton producing regions
[b] Petrie & Bezar (1998)
[c] yields from Genetic Technologies (pers comm.)
[d] 15% loss from harvest to ensiling
[e] Assumes pasture establishment at 15 year intervals
[f] 10% loss to bailing
[g] production of 1.14 t/ha less 0.11 t oil
[h] carbon losses are one-third of true values because seed is one third of whole crop
[i] production of 2.8 t/ha less 0.5 t oil
[j] sugar cane replaced every 5 years, based on 60 t of DM yield and 10% sugar in the DM
[k] values in parentheses are calculated from corn grain
[l] 80% of DM is harvested
[m] assumes a 6 t carbon loss after first cultivation and a further 2 t loss when returning maize to pasture

Although intakes were measured (Kolver *et al*., 2002), estimates of cropping area required are dependent upon soil type, crop yields, climate etc. Inputs to model calculations assume good farming practice, based on data from Waikato and Canterbury (Livestock Improvement Corporation, 2001; Petrie & Bezar, 1998). Data for imported feedstuffs, such as cotton seed, soybean meal or molasses were derived from the country of origin and adjustments were made to the land requirement when only part of the crop were used for livestock feed. For example, a cotton crop yields about 35% cotton fibre and 65% seed (weight basis) and about 10% of the seed is extracted as oil. The seed yield is about 1t/ha, and in economic terms is worth about 20% of the total crop, with cotton fibre accounting for the remaining 80% (U.S. cotton costs and returns, 2003). The values vary with commodity prices and yields. For the purpose of apportioning GHG costs, the cotton seed meal could account for as much as 59% (weight of seed less oil) to as little as 20% of the total. For the calculations presented here we have assumed 33% of the GHG emissions from cotton production should be attributed to the seed, with full knowledge that values may change in future models

Apportionment of GHG emissions have been made for soybeans (because of oil extraction) and molasses, which is a by-product of the sugar industry. Principal assumptions are indicated in Table 2 and defined in Coubrough, (2002).

Soil carbon losses

Substantial losses of soil carbon occur with cultivation. Losses are proportional to soil carbon content, with greatest losses in the first year of cultivation and diminishing over time (Jenkinson, 1988). Kairanga and Manawatu silt loams contain about 50t carbon/ha and have formed the basis for calculation of annual losses during production of TMR rations, because losses have been measured during cropping and can be applied to Canterbury and overseas situations. Initial losses to cultivation have been about 4 t/ha in the first year of cultivation and 3 t/ha in succeeding years (Crush *et al*., 1992; Jenkinson, 1988). However, losses will be greater from Waikato soils which are likely to contain 70-80t carbon/ha. Carbon loss from Waikato soils are assumed to be 6t/ha during cultivation for maize silage production and a further 2 t/ha when the stubble is cultivated prior to sowing new pasture (Carran, pers. comm.).

Energy costs and GHG emissions for feed components

Fuel use associated with agricultural activities (ploughing, harrowing, harvesting etc.), fertiliser use and CO_2 equivalents associated with fertiliser manufacture has been compiled for the New Zealand dairy industry by Wells (2001). This information, supported by energy costs associated with machinery manufacture, fishing (for the fish meal components of TMR), agrichemical manufacture and provision of seeds (Pimental & Pimental, 1996) has enabled carbon dioxide emissions to be calculated for feed components (Table 3). The costs associated with machinery manufactured for use in crop production and farming operations (but excluding fuel use for machine operation) is based on Wells (2001) and Pimental & Pimental (1996) to give a mean carbon dioxide emission of 161 kg/ha as described by Coubrough, (2002).

Data are presented as CO_2 emissions from soil carbon, production inputs (fuel, fertilisers, agrichemicals) and machine manufacture. Enteric methane emissions have been expressed as CO_2 equivalents by multiplying the mass of methane produced by 22, which is midway between the conversion factor at the time of writing IPCC (1996) and current IPCC (2003) recommendations. All the GHG 'costs' presented for the two systems are given as CO_2 equivalents unless indicated.

RESULTS

Tables 2 and 3 define feed requirements, yield/ha, land area for cropping and grazing as well as soil carbon losses and CO_2 emissions associated with production for the TMR and pastoral systems. Data are presented for each 250 cow herd on a whole herd basis. Soil carbon losses are expressed as CO_2 equivalents to determine carbon balances (Table 3) with allowance for costs of machinery manufacture. Cow methane emissions do not include emissions from dung which are poorly defined and low under both pastoral grazing and where slurry from TMR

TABLE 3: Carbon dioxide emissions from inputs and machinery costs associated with feeding 250 cows either Total Mixed Ration (TMR) or pasture based diets. Production costs include fuel for cultivation, harvesting, fertiliser and agrichemical costs whereas machinery costs are the costs of manufacture for implements required for production. Data are per annum.

Component	DM/ 250 cows (tonne)	Area (ha)	Production (kg/ha)	CO_2 Emissions Production (t/250 cows)
TMR diet				
Maize grain	235.9	22.9	890	20.4
Maize silage	371.3	18.6	1010	18.8
Pasture silage	364.6	30.6	115	3.5
Hay	48.6	3.9	990	3.9
Barley grain	81.1	16.6	697	11.6
Cottonseed	138.9	(46)[a]	412	18.9
Soybean meal	104.6	37.4	417	15.6
Molasses	38.8	3.0	702	2.1
Corn gluten	36.7	3.6	890	3.2
Fish meal	34.5	[f]		75.9
Machinery costs		151.5[b]	161	24.4
Total				**198.3**
Pasture diet				
Pasture maintenance	957.5	85.3	876[c]	74.7
Maize silage	127.5	6.3	1010	6.4
Pasture silage	55	4.4	991[d]	4.4
Pasture renewal[e]		6.3	703	4.4
Machinery costs		6.3	161	1.0
Total				**89.9**

[a] 33% of 139 ha because seed is about 33% of total crop
[b] adjusted for infrequent renewal but frequent harvest of pasture for hay and silage production
[c] elevated values due to CO_2 emissions from lime
[d] includes costs of pasture maintenance
[e] renewal every 15 years with cultivation to maize followed by new pasture establishment
[f] Greenhouse gas costs associated with fishmeal production of 2.2kg CO_2/kg have been calculated from energy costs associated with harvest and processing (Pimentel and Pimentel, 1996)

TABLE 4: Carbon dioxide and methane emissions and production from 250 cow herds fed either Waikato pasture or Total Mixed Rations (TMR) over one year

	Waikato pasture	**TMR**
Total production (CO_2 equivalents; tonnes)	771.9	2765
CO_2 from inputs (incl. machinery; tonnes)	90.9	198.3
CO_2 from cultivation (soil carbon loss; tonnes)	186	1784
Methane from 250 cows (tonnes)	22.5	35.6
Cow methane as CO_2 equivalents (tonnes)	495	783
Milk yield (tonnes)		
Total	912	1826
Milksolids	77.5	150.5
CO_2 equivalents per total milk production (kg CO_2 equiv/kg milk) from:		
Cow methane	0.54	0.43
Methane + inputs	0.64	0.54
Methane + inputs + soil carbon	0.84	1.51
CO_2 equivalents per milksolids (kg CO_2 equiv/kg MS) from:		
Cow methane	6.39	5.20
Methane + inputs	7.53	6.52
Methane + inputs + soil carbon	9.94	18.4

feeding is spread on pastures.

Comparison between the two systems has included expression of emissions from enteric methane, soil carbon and other inputs as a proportion of total emissions and in relation to milk or milksolids production (Table 4). Cow enteric methane production remains a significant proportion of CO_2 equivalents in both systems, accounting for 0.64 of the total for pasture and 0.28 of TMR emissions. Inputs of fertiliser, fuel, seeds etc. accounted for only 0.12 and 0.08 of the emissions for the respective systems whilst soil carbon losses accounted for 0.24 of pasture and 0.64 of TMR emissions (Table 4).

The quantity of methane and CO_2 emissions associated with each herd (Table 4) can be expressed in terms of milk production. Methane alone (kg CO_2 equivalents/kg milk) was higher for cows grazing pasture (0.54) than those fed TMR (0.43) but when production and soil carbon emissions were included in the calculations, cows fed pasture produced only 0.84 vs. 1.51 kg CO_2 equivalents/kg milk. A similar relationship was evident for milksolids production (Table 4).

DISCUSSION

These data show the danger of simplistic interpretation of GHG emissions based on enteric methane production alone. Further research needs to incorporate costs associated with nitrous oxides emissions from the two systems, but the extensive land area required for provision of the TMR components, relative to pastoral grazing is unlikely to improve the TMR system relative to pasture in terms of GHG/unit milk. Linear programming could indicate responses to alternative sources of feed components or to altered cultivation practices but all predictions will require well defined assumptions for feed sources from cotton, soybeans, molasses and fish meal.

Soil carbon loss represents the principal contribution to GHG for TMR production but the extent of carbon loss from soils varies with soil type, organic matter content and cultivation practice. Net emissions from soils are a balance between yield and area required to meet cow requirements. Losses can be reduced by direct drilling but crop yields are lower relative to conventional cultivation so larger areas are required to meet cow requirements. In practice, direct drilling is often used as a means for moisture or soil conservation and is associated with low yielding environments. Many crops are not amenable to direct drilling.

Peaty or high organic matter soils lose more carbon than light soils with cultivation (A Carran pers. Comm.) but are often high yielding so a lesser area is cultivated. If direct drilling could be used in high organic matter soils, soil carbon losses may be significantly reduced. The contribution of soil carbon to the GHG costs is likely to vary ± 30% depending on soil organic matter content and cultivation practice (Crush *et al*., 1992; McLaren & Cameron, 1996).

Greenhouse gas emissions from inputs are a small proportion of total emissions for dairy farms but nevertheless are substantial at 90.9 and 198.3 tonne CO_2/annum for pastoral and TMR systems. The difference in emissions is due primarily to fertiliser use. Fertiliser accounted for about 65% of inputs for the TMR system and about 85% of GHG from the pasture system inputs (with lime accounting for nearly 30% of pasture maintenance costs). Production of nitrogenous (urea) fertiliser incurs a high emission cost relative to phosphorus or potassium (3.0 vs. 0.9 vs. 0.6 kg CO_2/kg element; Wells, 2001) because of both the energy requirement for urea synthesis and a loss of carbon from urea hydrolysis in the soil. For TMR systems, costs associated with cultivation, agrichemicals and seeds make a substantial contribution to costs. Fertiliser input can, however, be substantially lowered with legume crops such as soybeans. These factors suggest a variance of ± 20% might be appropriate for the estimates of inputs to these systems.

Measurements of enteric methane production, expressed as a percentage of dietary gross energy range between about 6.0 and 7.2% for forage and TMR diets (Robertson & Waghorn, 2002; Woodward *et al*., 2002; Ulyatt *et al*., 2002) depending mainly on diet quality and level of intake. Yields of methane from cows fed diets similar to those used in this study are unlikely to vary by more than ± 5%, but emissions can be lower when diets contain very high proportions of grain or high quality forages including legumes and herbs (Waghorn *et al*., 2002).

This analysis showed cows fed a grain based TMR produced 58% more methane and twice as much milk as cows grazing pasture. When CO_2 costs associated with soil carbon losses during cultivation and inputs of fuel, fertiliser etc. were included in estimates of GHG emissions the TMR diet resulted in nearly twice as much CO_2 and methane production as pasture (1.53 vs. 0.84 kg CO_2 equivalents/kg milk). Evaluations of GHG emissions from contrasting situations are best defined by life cycle analyses and future work must account for nitrous oxide emissions from the two systems. These data do not support any movement away from pastoral dairy farming and suggest more consideration be given to soil carbon losses to lower GHG emissions resulting from an increased use of supplements.

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