

Greenhouse Gas Production from Dairying: Reducing Methane Production

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■ Take Home Messages

- ▶ Methane is 21 times more potent than CO₂ as a greenhouse gas (GHG), and dairy cows typically produce 118 kg methane/year, which is over twice that produced by other non-lactating cattle.
- ▶ Evaluation of strategies to reduce methane production should consider the effects on total farm greenhouse gas emissions.
- ▶ Increasing productivity per cow will reduce methane emissions per kg of milk and total farm GHG emissions where milk production is fixed, although the effect on total farm emissions needs further clarification.
- ▶ A lower culling rate will reduce farm methane and total GHG emissions.
- ▶ Diets with a high proportion of concentrates that promote a high propionate type of ruminal fermentation are conducive to reducing ruminal methane production, but the effect on total farm GHG emissions may be less.
- ▶ Selecting forages and concentrates high in non fiber carbohydrates could reduce methane emissions.
- ▶ Breeding forage crops with high concentration of propionate precursors such as malate may be a long-term solution to reducing methane emissions.

■ Introduction

Although methane production from enteric fermentation in ruminants has been studied for many years, it is only recently that research has focused on reducing it in order to combat global warming. Methane from enteric fermentation is a large component of livestock related greenhouse gas emissions. This paper gives a short outline of how methane arises during the

process of ruminal fermentation, and outlines the typical emissions of dairy cattle. Then, possible mitigation strategies are examined. While this paper focuses on methane emissions from enteric fermentation, overall farm system emissions of total greenhouse gases must be taken into account to get a comprehensive picture. These will include methane and nitrous oxide emissions from animal manures, nitrous oxide emissions from soils, and CO₂ emissions from energy consumption. The data of Johnson et al. (2002) showing the relative contribution of these sources from the contrasting situations of Wisconsin and New Zealand dairy farms, indicate that the type of production system can have a major impact on the relative importance of each source (Figure 1).

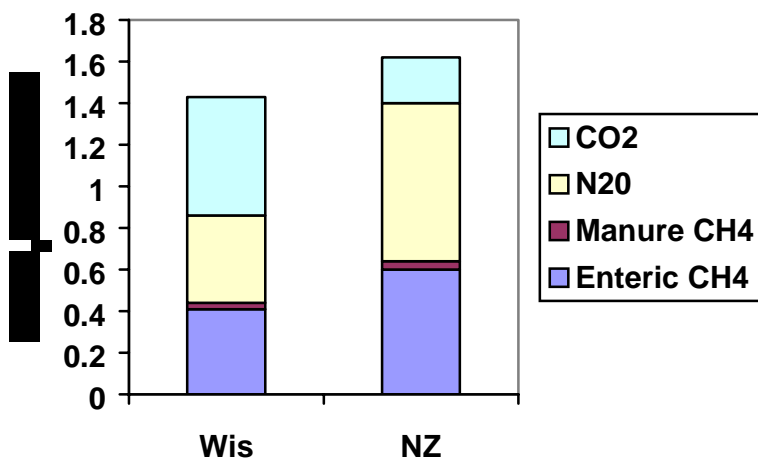
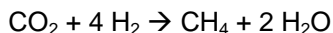


Figure 1. Total farm emissions of greenhouse gases per kg milk from a Wisconsin or New Zealand dairy farm (Johnson et al., 2002)

■ Ruminal Fermentation and the Production of Methane

Methane is produced as a result of anaerobic fermentation in the rumen and the hind-gut. Microbial enzymatic activity in the rumen (and salivary enzymes), hydrolyses much of the dietary organic matter to amino acids and simple sugars. These products are then anaerobically fermented to volatile fatty acids (VFA), hydrogen and CO₂. Some of the CO₂ is then reduced through combination with hydrogen to produce methane:

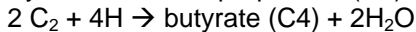
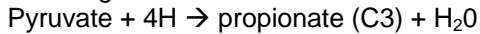


Alternatively, hydrogen can be used in the formation of some VFA or incorporated into microbial organic matter. The stoichiometry of the formation of the main VFA is shown in the following equations:

2H producing reactions:



2H using reactions :



From this it can be concluded that if ruminal fermentation patterns are shifted from acetate to propionate, both hydrogen and methane production will be reduced. This relationship between methane emissions and the ratio of the various VFA has been well documented (Hungate, 1966), and it provides opportunities to reduce methane emissions. Herein also lies the explanation as to why fibrous diets produce more methane than non-structural carbohydrate diets: the fibrous diets promote higher acetate, resulting in more hydrogen and thus more methane.

The methane in the rumen is produced by methanogenic bacteria and protozoa. The role of protozoa in methane formation is interesting. It has been established that virtually all of the bacteria attached to protozoa are methanogens (Vogels et al., 1980) and that these bacteria are responsible for between 0.25 and 0.37 of the total methane produced (Finlay et al., 1994; Newbold et al., 1995). By removing the protozoal population through defaunation, the ruminal bacterial population is modified, VFA production is shifted from acetate and butyrate towards propionate, and methane emissions are decreased. There is also a negative impact on fiber digestion (Demeyer et al., 1982) so care must be taken not to unduly disrupt rumen metabolism by this route.

The hind-gut has been reported to account for between 0.13 and 0.23 of the total emissions by sheep (Murray et al., 1976; Kennedy and Miligan, 1978). However, it appears that most (0.89) of the methane produced in the hind-gut is absorbed through the gut wall and excreted via the lungs (Murray et al., 1976). In the hind gut, protozoa are absent, and methane is produced by methanogenic bacteria. Methane emissions from the hindgut are lower than from the rumen and it has been speculated that this could be due to hydrogen removal by reductive acetogenesis rather than methanogenesis (De Grave and Demeyer, 1988).

■ Methane Production of Dairy Cows

High yielding dairy cows generally produce over 100 kg of methane/year from enteric fermentation. In the absence of country specific emission factors, the IPCC (1996) recommend that a default value of 118 kg/year be used for highly productive commercial North American dairy cows. As methane is considered to have a global warming potential 21 times that of CO₂ (IPCC, 1996), 118 kg of methane is equivalent to 2.478 tonnes of CO₂ in inventories of greenhouse gas production. Figure 2 illustrates that the emissions from dairy cows are over twice that from other cattle (beef cows, bulls, calves, growing steers/heifers, and feedlot cattle). Typically, methane emissions from enteric fermentation represent about 6% of dietary gross energy, but this varies with diet from about 2% (cattle in feedlots) to 12% (animals eating very poor quality forage) according to Johnson and Johnson (1995).

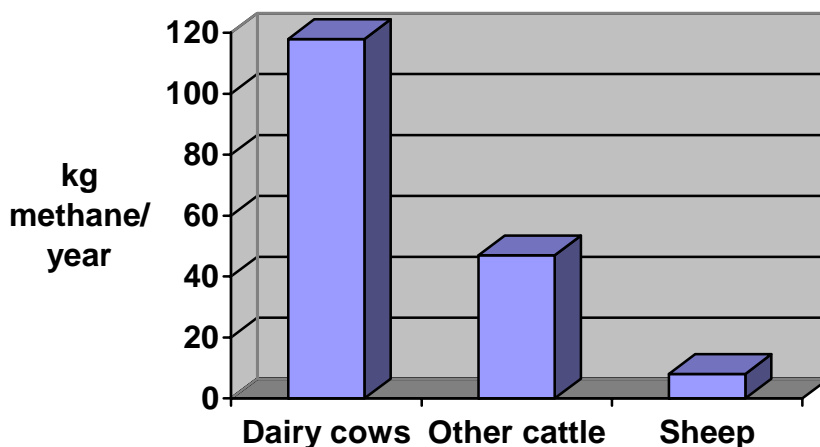


Figure 2. Default annual methane emissions of North American dairy cows, other cattle and sheep (IPCC, 1996)

■ Strategies to Reduce Methane Emissions

There have been many strategies proposed that could reduce methane emissions and these have been comprehensively reviewed by Moss (1994). This paper will discuss some of the most pertinent strategies to high producing dairy herds, and will review some of the more promising developing strategies.

Increased Animal Productivity

Increasing animal productivity will generally reduce methane emissions per kg of product (milk or meat) because the emissions associated with maintenance are spread over a larger amount of product. However, daily emissions and thus emissions per animal per year are usually increased because the higher productivity is usually associated with higher intake. Methane production is closely related to dry matter (DM) intake. Kirchgesser *et al.* (1995) reported that increasing milk yield from 4000 to 5000 kg/year increases annual methane emissions, but will decrease emissions per kg of milk by 0.16 for a 600 kg cow. A further increase to 6000 kg/year would decrease emissions per kg of milk by a further 0.128 (Table 1). Thus, there are quite significant reductions in methane emissions to be made by improved productivity in dairy cows as long as the number of cows is reduced to compensate for the increased milk yield. It should also be noted that the decline in methane emissions per kg of milk in response to increasing milk yield is curvilinear because the maintenance cost becomes increasingly diluted. Thus in high yielding herds, the reduction in methane emissions from further increases in milk yield will be relatively small.

Table 1. Estimates of methane emissions (kg/year and kg/kg milk in parentheses) from dairy cows as affected by annual milk yield and body weight) (Kirchgessner *et al.*, 1995)

Body weight (kg)	Milk yield (kg/year) ¹		
	4000	5000	6000
500	95 (0.0238)	100 (0.02)	105 (0.0175)
600	103 (0.0258)	108 (0.0216)	113 (0.0183)
700	111 (0.0278)	116 (0.0232)	121 (0.0202)

¹ 310 days of lactation combined with a 55 day dry period

When one considers total farm emissions and not just methane, the situation is less clear as the increased productivity is often associated with increased nitrous oxide emissions from soils, and increased energy consumption. In addition, the extra purchased concentrates used in the higher productivity system have a CO₂ cost of production. For example, grain up to the point of harvesting is itself associated with an emission factor of between 0.57 and 2.21 kg CO₂ per kg (Howden and O'Leary, 1997). Where the purchased feedstuffs are by-products (e.g. of brewing, distilling, etc) it is an issue as to how much of the CO₂ cost of production should be ascribed to the farm on which they are fed. However, the data of Johnson *et al.* (2002) in Figure 1 for Wisconsin and New Zealand dairy herds demonstrate that there is still a reduction in total farm emissions from higher animal productivity after all these factors have been taken into account. A degree of caution must be exercised when examining the

effect of productivity using two such contrasting systems, as there could be confounding effects other than productivity responsible for some of the differences (e.g. the CO₂ cost of energy generation).

Effect of Longevity in Dairy Cows

The longer that cows stay in a herd, the lower the number of replacements required, and thus the lower the total farm methane emissions. An example of a 100 cow farm is presented in Figure 3, where the average number of lactations varies from 2.5 to 5. It is assumed that dairy cow emissions are 118 kg/yr while the rearing of a replacement heifer to calve at 2 years old results in methane emissions of 100 kg. Figure 3 shows that total farm emissions of CH₄ from enteric fermentation decline from 15,800 kg/yr to 13,800 kg/yr (0.127 less) as the average number of lactations increases from 2.5 to 5. This does not factor in the higher yield of the older cows which would further reduce emissions per kg of milk. Thus any measures which reduce involuntary culling should be encouraged. There will also be corresponding reductions in methane and nitrous oxide emissions from manure, and in nitrous oxide emissions from soil (less fertilizer N usage due to lower stocking rate). Reducing the replacement rate will also leave more calves available for beef production (instead of cull cows).

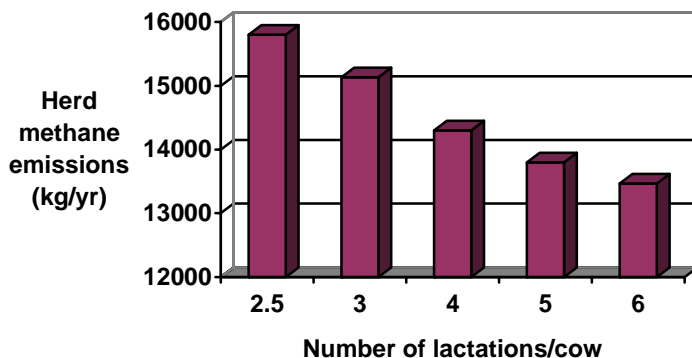


Figure 3. The effect of number of lactations per cow on annual total herd (100 cows plus replacements) emissions of methane from enteric fermentation

Effect of Concentrate Proportion in the Diet

The proportion of concentrate within the diet has been reported to be negatively correlated with methane emissions (Holter and Young, 1992; Kurihara *et al.*, 1998; Yan *et al.*, 2000; Figure 4). Concentrates contain less structural

carbohydrates than forages, and the effect of increasing the proportion of concentrates in the diet on ruminal VFA concentrations is well documented, with an increase in the proportion of propionate and a decrease in the proportion of acetate (and sometimes butyrate). This would be expected to impact on methane production. Also, increasing the proportion of concentrate in the diet will generally reduce rumen pH, and as methanogens are pH sensitive, this will also tend to reduce methane emissions. Sometimes the effect of concentrate proportion is compounded by increases in total intake, but when expressed as a proportion of gross energy intake, reductions in methane production are generally found as the proportion of concentrate increases, with these reductions being most dramatic when concentrates form the major proportion of the diet (Johnson and Johnson, 1995). Increased use of concentrates also increases animal performance and this will further reduce emissions as outlined above.

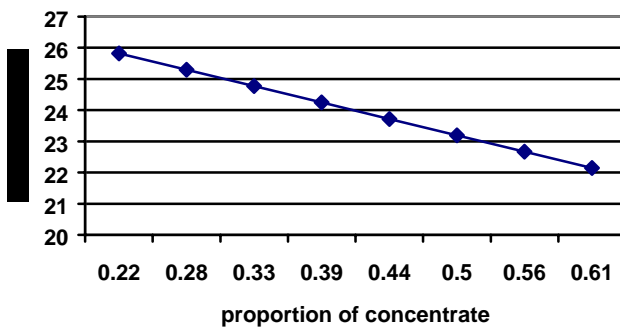


Figure 4. The effect of increasing the proportion of concentrates in the diet on methane output when total digestible energy intake, dry matter intake and feeding level are kept constant (adapted from Yan et al., 2000)

However, difference in the CO₂ cost of production per kg of feedstuffs must also be taken into account. The values of Howden and O'Leary (1997) for concentrates of between 0.57 and 2.21 kg CO₂ per kg concentrate are likely to be higher than for most forages. This may negate some of the advantage of increasing the proportion of concentrates in the diet. It is an issue that requires further clarification.

Effect of Concentrate Type

Moe and Tyrrell (1979) reported that for every gram of cellulose digested, methane emissions are nearly three times that of hemicellulose and five times that of the soluble residue. However, there has been little work to compare methane production on different concentrates. This could be of interest as there is a large selection of concentrate ingredients available, ranging from

cereals (low in fibre, high in starch) to cereal-by-products (high in fibre, low in starch), pulps (high fibre), molasses (high sugar), oilseed meals (high in protein, variable in fibre), etc. Ovenell-Roy et al. (1998) reported differences in methane production from 4 cultivars of barley fed to lambs. The higher methanogenic potential of fibrous feedstuffs has been mentioned. Johnson and Johnson (1995) noted that soluble sugars have a higher methanogenic potential than starch. Research is required to establish if concentrates can be formulated to bring about significant reductions in methane production.

Effect of Forage Quality

When viewed in isolation, increasing forage digestibility increases daily methane emissions because of increased intake. However at high intake levels, the proportion of energy lost as methane decreases as the digestibility of the diet increases (Johnson and Johnson, 1995). In addition, improving forage digestibility will improve productivity because DM and energy intake are increased. Therefore the gains outlined above due to increased productivity should materialise. Indeed increasing the digestibility of pasture for grazing ruminants has been proposed as the most practical means of reducing their methane emissions (Hegarty, 1999a). However, he later points out that if animal numbers do not decrease in response to the improved productivity, then emissions from the sector will increase rather than decrease (Hegarty, 2002).

Effect of Forage Type

Legumes generally have higher intakes and digestibility than grass swards and thus give rise to higher productivity. This should reduce methane emissions as discussed above. However, it has also been reported that legumes give rise to reduced methane emissions when fed at comparable intake levels (Beever et al., 1985). McCaughey *et al.* (1999) speculated that the reduced emissions could result from a modified ruminal fermentation pattern combined with higher passage rates as reported by Minson and Wilson (1994).

There are substantial differences in the carbohydrate fractions of forages such as grass silage, maize silage or whole crop wheat silage, which will affect their methanogenic potential. In addition, these forages can give rise to differences in productivity: e.g. maize silage supports higher intake and performance than grass silage.

Within a forage species, there may be potential to select cultivars that result in reduced methane production. Recent *in vitro* work at our institute (Lovett et al., 2003a) has demonstrated differences between cultivars of perennial ryegrass in their methanogenic potential (Figure 5). The differences were significantly related to chemical composition of the cultivars, but differences between cultivars could also be due to differences in contents of organic acids, as outlined below.

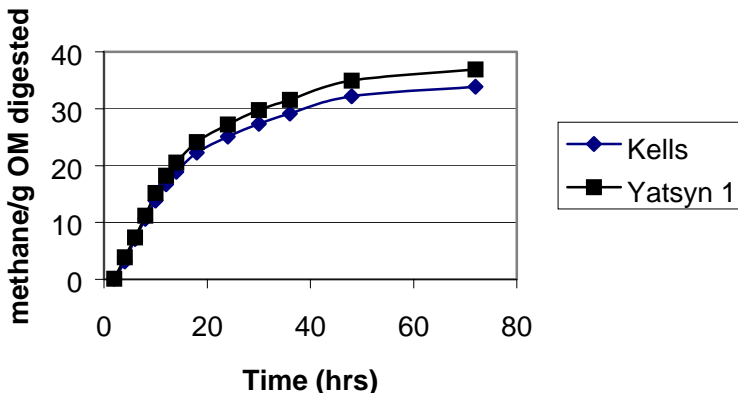


Figure 5. Differences in ryegrass cultivars in methane emissions per g of organic matter digested during in vitro incubation (Lovett *et al.*, 2003a)

In summary, there are several promising strategies to reduce methane emissions through forage selection, but these need further investigation, particularly at a whole farm level.

Use of Ionophores

Ionophores (e.g. monensin) are antibiotics produced by bacteria (*Streptomyces* spp.). Several ionophores have been licensed for use in beef cattle in many countries, and dairy cows in some countries (e.g. Australia, Mexico and Brazil). The review of NRC (2001) outlined increases in milk production, better feed conversion efficiency, reduced acidosis, ketosis and bloat resulting from the feeding of ionophores. In the rumen, they increase the proportion of gram positive bacteria, resulting in a shift in fermentation acids from acetate and butyrate to propionate, consequently methane production is reduced (NRC, 2001). Intake is also reduced in many experiments, with O'Kelly and Speirs (1992) calculating that this is responsible for 0.55 of the decline in methane emissions following monensin application. However, several researchers have reported that the effects on methane production are transient (Rumpler *et al.*, 1986; Abo-Omar, 1989; Carmean, 1991; Johnson *et al.*, 1991; Saa *et al.*, 1993) indicating that microbial adaptation occurs.

Effect of Dietary Oil Supplementation

As outlined above, defaunation or removal of protozoa from the rumen is one method which could reduce methane emissions. One method by which defaunation can be brought about is the addition of certain oils/fats (Machmüller *et al.*, 1998). In the absence of protozoa, rumen CH₄ output is reduced by 0.13 on average, although this varies with diet (Hegarty, 1999b). The magnitude of

reduction in CH₄ output following dietary supplementation of fats/oils is source dependent, with coconut oil identified as being very effective (Dong *et al.*, 1997; Machmüller *et al.*, 1998). Recent studies at our institute with beef cattle have shown it to be effective in reducing methane emissions at 0.045 of DM intake (Lovett *et al.*, 2003b), and also that the response is linear from low to moderate levels (Figure 6; Jordan *et al.*, 2004). There are reductions in intake and diet digestibility, but in two growth studies (Lovett *et al.*, 2003b; unpublished data), these were compensated for by the increased dietary energy density, and the reduced energy loss as methane. However, we have not measured the effect in dairy cows. In particular the impact on milk fatty acid composition would need to be determined.

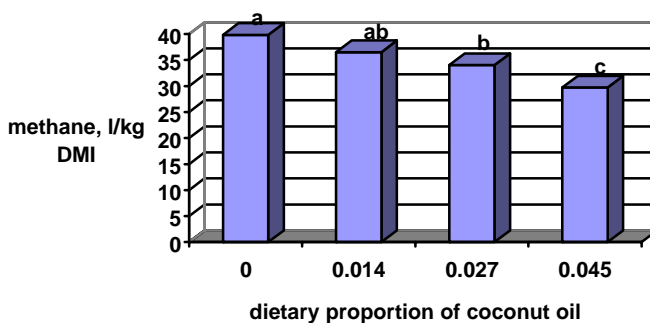


Figure 6. Effect of level of coconut oil supplementation to finishing beef heifers on emissions of methane per kg of dry matter intake (DMI) (Jordan *et al.*, 2004)

Propionate Enhancers

Methane is formed as a result of the need to remove hydrogen from the rumen. Propionate formation also utilizes hydrogen. Therefore if precursors of propionate are added to the diet, they should reduce methane production by removing some of the hydrogen produced during ruminal fermentation. The organic acids such as malate, fumarate, citrate, succinate, etc are propionate precursors, and it has been demonstrated both *in vitro* (Martin and Streeter, 1995; Asanuma *et al.*, 1999; Carro *et al.*, 1999; Newbold *et al.*, 2002) and *in vivo* (Newbold *et al.*, 2002) that their addition to the diet reduces methane production, with the response being dose dependent (Martin and Streeter, 1995). They appear to either have no effect or to enhance animal performance or intake (Martin *et al.*, 1999; Newbold *et al.*, 2002). Their use as dietary supplements is likely to be limited by their costs, but they are found in significant quantities in forages (Muck *et al.*, 1991; Callaway *et al.*, 1997) where they are intermediates in the citric acid cycle. Differences between forage species have been reported. For instance, Callaway *et al.* (1997) reported

much higher malate concentrations in alfalfa (2.9 – 7.5% of DM) than Muck et al. (1991) reported for permanent pasture grass (less than 0.6% of DM), although extraction method, which can have an effect, differed between the studies. There is less information on concentrations among different varieties/cultivars of the same plant, although some differences have been reported for alfalfa (Callaway et al., 1997) and tall fescue (Maryland et al., 2000). If these differences are at least partly under genetic control (i.e., are not influenced totally by environmental factors), then there may be scope to breed cultivars with high contents of organic acids which would reduce methane production. This would be extremely valuable in regions where production systems have a substantial grazing component, which often does not lend itself to other mitigation strategies (that involve delivering some product/supplement to the animal in the diet) because concentrates are often not fed in these situations.

Other strategies

Several other strategies under investigation have not been considered here. These include, amongst others,

- investigation of the use of a vaccine against rumen methanogens by CSIRO Livestock Industries in Australia,
- halogenated methane analogues (e.g. bromochloromethane) and related compounds such as amichloral, chloroform, and chloral hydrate,
- acetogens (bacteria that utilize hydrogen to form acetate instead of methane; they dominant over methanogens in termites and the hind-gut of pigs, but in the rumen, they are out-competed by methanogens), as reviewed by Fievez et al. (1999)
- saponins (act as a defaunating agent)

■ Conclusions

There are many strategies that could be considered for the purpose of reducing methane emissions from enteric fermentation in dairy cattle. Many of these are things that producers generally seek to optimise in any case, such as maximising productivity, reducing culling rates, and maximising forage quality. Increasing the proportion of concentrate in the diet is also strongly associated with reduced methane emissions from enteric fermentation, but in many North American herds, this is close to the maximum possible that is consistent with good cow health and digestion. Other strategies need further investigation to fully evaluate their effects. For instance, selecting between forages and between concentrate ingredients should in theory reduce emissions, but there is a need for research to evaluate these strategies. Dietary supplementation

with oil has been shown to be effective, but research is needed in dairy cows. Ionophores as dietary supplements reduce methane emissions, but the effect may be transient, and in any case, they are not universally licensed for use in dairy cows. Several other strategies are at various stages of investigation, such as the use of malate or other propionate precursors. Thus there are grounds for optimism that in the medium term, new effective strategies will become available to supplement those already in existence. Finally, more consideration should be given to total farm GHG emissions, not just methane emissions from enteric fermentation when investigating this issue.

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