Reducing Methane Emissions from Dairy Cows

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Take Home Messages

- About 6 to 10% of the total energy consumed by the dairy cow is converted to methane in the rumen and released to the environment.
- Reducing methane losses is an environmentally sound practice that can also increase milk production and improve production efficiency.
- A number of dietary approaches to reducing methane emissions from dairy cows have been identified. Of these, feeding lipids has the greatest certainty in reducing methane emissions. Adding 2 to 4% fat to the diet can reduce methane emissions by 10 to 20%.

Introduction

Methane is produced in the rumen (called enteric methane, CH_4) as part of the normal process of feed digestion. Typically, about 6 to 10% of the total gross energy consumed by the dairy cow is converted to CH_4 and released via the breath. In addition, CH_4 is a potent greenhouse gas that contributes to global warming. Reducing CH_4 losses is an environmentally sound practice that can improve production efficiency. Our review presents some nutritional approaches that can be implemented to reduce enteric CH_4 emissions from dairy cows.

Enteric Methane Production

Carbohydrates are converted in the rumen to volatile fatty acids (VFA) during the fermentation of feed. The most abundant VFA are acetate, propionate and butyrate. Hydrogen is also generated during this process (Figure 1).

Step 1. Digestion

carbohydrates → monosaccharides (glucose)

Step 2. Production of volatile fatty acids by bacteria

glucose + 2 water → 2 **acetate** + 2 carbon dioxide + 4 hydrogen

glucose → 2 **butyrate** + 2 carbon dioxide + 2 hydrogen

glucose + 2 hydrogen → 2 **propionate** + 2 water

Step 3. Production of CH_4 by methanogenic bacteria

carbon dioxide + 4 hydrogen → <u>methane</u> + 2 water

Figure. 1. Production of methane in the rumen.

The formation of acetate generates twice the amount of hydrogen as does the formation of butyrate, whereas the formation of propionate actually *uses* hydrogen. Methane producing bacteria (known as methanogens) convert hydrogen and carbon dioxide into CH_4 and water. Thus, diets that favour lower acetate to propionate ratio usually decrease CH_4 production. Diets that restrict the hydrogen available in the rumen for methanogenic bacteria generate less enteric CH_4. Diet composition and dry matter intake (DMI) are the primary drivers of enteric CH_4 production (Figure 2).

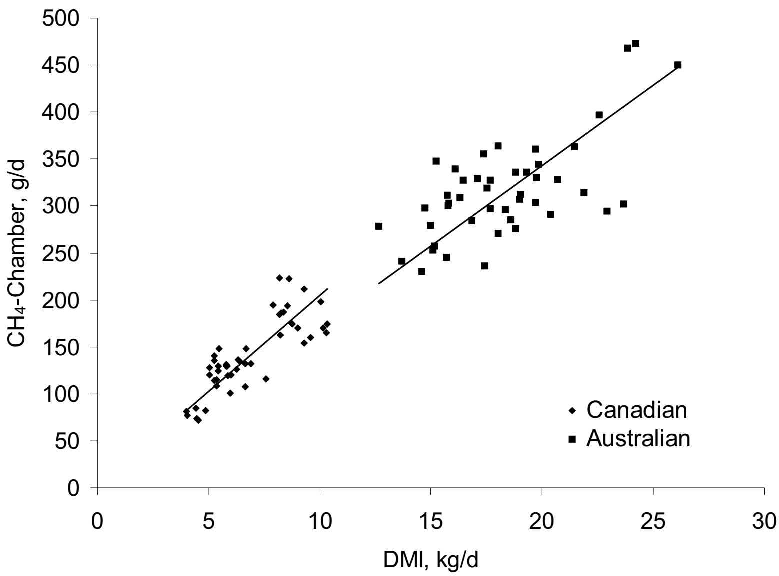

Figure 2. Relationship between methane (CH_4) emission determined in chambers and dry matter intake (DMI) for dairy cows (Australian study; Grainger et al. 2007) and beef cattle (Canadian study; McGinn et al. 2006). Lines are through the origin and have slope estimates of 17.06 for the Australian data and 20.79 for the Canadian data ($P < 0.001$; SED = 0.928). Graph is from Grainger et al. (2007).

Most of the enteric methane produced by cattle originates in the rumen, although some fermentation also occurs post-ruminally. About 13% of CH_4 is produced in the hind gut, with about 89% of it absorbed across the intestinal mucosa into the blood stream. Likewise, about 95% of CH_4 generated in the rumen is transferred to the lungs where the animal breathes it out. As a result, 99% of the CH_4 emission is lost via the nostrils and mouth and only 1% of the total CH_4 emission is lost through the rectum (Murray 1976). Therefore, almost all CH_4 is emitted from dairy cows via the mouth with very little released via flatulation.

▪ Methane Emissions from the Canadian Dairy Industry

The total greenhouse gases from Canadian agriculture contribute 7.6% of all greenhouse gases produced within Canada. On a global basis, Canada emits only 2% of the total global emissions. Despite the relatively small role played by Canadian agriculture globally, it is desirable for all sectors in the global economy to improve their efficient use of resources. Improving the efficiency by which cattle convert feed to meat or milk will ultimately reduce CH_4 emissions and the cost per kilogram of milk or meat produced.

In 2005, enteric CH_4 production by livestock was responsible for generating 25,000 kt of CO_2-equivalent emission or 44% of the annual 57,000 kt of total greenhouse gas emissions from Canadian agriculture (EC 2008). Methane generated from livestock manure accounted for another 6% of agriculture's greenhouse gas emissions. The emission of nitrous oxide from agriculture soils (related to the use of N fertilizers), and that from livestock manure, contributed 40% and 10% of the total from this sector, respectively.

The enteric CH_4 produced from the Canadian dairy industry is approximately 25% of all the enteric CH_4 associated with Canadian cattle (AAFC 1999). Most of the remaining 75% is produced by beef cattle, which comprise 84% of all the cattle in Canada. Lactating cows generate 66% of the enteric CH_4 produced by the dairy industry; the rest is produced by dry cows and replacement heifers. Across Canada, the range in greenhouse emissions (kg CO_2-equivalent) per kg milk is 0.97 to 1.13, with an average of 1.02 (Vergé et al. 2007). Each cow generates approximately 4.55 Mg CO_2-equivalent annually. By comparison, the typical passenger vehicle generates 5.48 Mg CO_2-equivalent annually (EPA 2007).

It is estimated that since 1990, CH_4 emissions from the dairy industry have decreased by about 24%, simply due to improved efficiency of milk production and a concomitant decrease in cow numbers (EC 2002). However, in the non-dairy sectors, livestock numbers have increased over that time and so have the total greenhouse gas emissions, i.e., beef, swine and poultry have increased by 21, 19 and 27%, respectively.

▪ Strategies for Reducing Methane Emissions from Dairy Cows

The enteric CH_4 emissions produced by the dairy sector are calculated annually by Environment Canada as part of the national greenhouse gas inventory (EC 2008). The calculation estimates gross energy intake of individual animals, applies a 6.5% CH_4 conversion rate (fraction of gross energy intake converted to CH_4), and then sums the daily emissions by animal category (lactating cows, replacement heifers, calves).

Using this method of calculation, CH_4 reduction can be achieved either by reducing cow numbers or by reducing the conversion of feed to CH_4 in the rumen. As mentioned previously, the Canadian dairy industry has decreased its CH_4 emissions by about 24% since 1990 because cow numbers have declined as a result of increased milk production per cow. Because the Supply Management System in Canada imposes quotas on production, increases in cow productivity have been accompanied by a decrease in cow numbers. Increasing animal productivity only reduces emissions if product output is capped (e.g. through Supply Management) because increased productivity increases CH_4 emissions per cow (due to increased feed intake).

Further reductions in CH_4 emissions from dairy cows can also occur by reducing the conversion of feed to CH_4 in the rumen (i.e., CH_4 conversion rate). Various research groups around the world are exploring the potential of strategically using feed ingredients and supplemental feed additives as a means of reducing conversion rates (as reviewed by Beauchemin et al. 2008). In addition, non-dietary approaches are being examined including vaccination, biological controls (bacteriophage, bacteriocins), chemical inhibitors that directly target methanogens, and promotion of acetogenic populations in the rumen to lower the supply of metabolic hydrogen to methanogens (as reviewed by McAllister and Newbold 2008).

While a number of ways of reducing CH_4 have been proposed, they must meet the following criteria before being adopted on-farm: 1) documented effectiveness in reducing emissions, 2) profitable (or at least revenue neutral), and 3) feasible to implement on-farm. In most cases, there is a lack of information for dairy producers to properly evaluate profitability of the mitigation strategies proposed.

▪ Economic Implications of Reducing Methane Emissions

Enteric CH_4 formation in the rumen represents inefficiency in terms of converting feed energy to milk. For a high producing dairy cow, a 20% reduction in CH_4 emissions represents the same amount of energy needed to synthesize 0.6 kg/d of milk. Implementing a dietary change to reduce CH_4 emissions can increase milk production by sparing energy, which is redirected to milk production. Revenue generated from increased milk yield can partially offset the cost of the dietary mitigant. In the future, dairy producers may also be able to generate revenue via carbon exchange programs.

A number of carbon exchange programs are currently operational, including the Chicago Climate Exchange, the Montreal Climate Exchange and the European Climate Exchange, which are used mainly by large greenhouse gas emitting industries, such as the oil and gas industry, to purchase carbon credits that offset their emissions. These exchanges do not presently recognize reductions in enteric CH_4 emissions. However, this will likely change in the near future as the technology for monitoring emissions on-farm becomes more readily available. For example, Alberta Environment recently introduced the Alberta Offset Program that allows emissions trading. In this system, it is recognized that feeding of 4 to 6% lipids to beef cattle reduces CH_4 by 20%.

Based on the current trading value of CH_4 on the Chicago Climate Exchange ($2.05/metric tonne of CO_2 equivalent), a 20% reduction in CH_4 from a dairy cow would generate a revenue of less than $0.01/cow/d (0.350 kg CH_4 /cow/d × 0.20 = 0.00007 tonnes CH_4 × 21 CO_2/CH_4 = 0.00147 tonnes CO_2 equivalent × 2.05 = $0.003/cow/d). However, the price of carbon is likely to increase in the future. Carbon credits are trading on the European Climate Exchange for around $37/tonne, while UN certified credits have been trading at around $21/tonne in 2007. Thus, the value of methane reduction presently is as high as about $0.05/cow/d. Assuming a milk price of $0.60/kg, the breakeven cost of feeding a cow to reduce CH_4 emissions by 20% is $0.36/d (0.6 kg milk × 0.60 = $0.36) with up to another $0.05 from revenue from carbon reduction. It must be emphasized that this calculation assumes that CH_4 reduction spares energy for milk synthesis. These calculations are theoretical at best as very few studies have been conducted to look at the long-term effects of reducing CH_4 on the lactational performance of dairy cows. In addition, carbon exchange programs are currently geared to large emitters (energy sector) and it is difficult for livestock producers to participate in these programs.

▪ Nutritional Strategies that Reduce Enteric CH_4 Production

Some dietary strategies that reduce enteric CH_4 production are listed in Table 1. Diet modifications reduce CH_4 emissions by decreasing the fermentation of feed in the rumen, shifting the site of digestion from the rumen to the intestines, diverting hydrogen away from CH_4 production during ruminal fermentation, or by inhibiting the formation of CH_4 by rumen bacteria.

The strategies in Table 1 have varying degrees of uncertainty associated with their estimated reduction in CH_4. A brief discussion of these strategies follows, but a more complete review of the impact of diet on CH_4 production can be found elsewhere (Johnson and Johnson 1995, Boadi et al. 2004, Monteny and Chadwick 2006, Beauchemin et al. 2008, McAllister and Newbold 2008). In addition, various models have been developed to predict CH_4 emissions based on diet composition (e.g. Blaxter and Clapperton 1969, Moe and Tyrrell 1979, Pelchen and Peters 1998).

Table 1. Dietary strategies that reduce enteric CH_4 production.

Strategy	% reduction in CH_4 [1]	Comment
Strategies with higher certainty of reducing CH_4 production		
Fats and oilseeds	5–25	Level dependent
Ionophores	0–10	Dose dependent, response may decline after several months
Higher grain diets	5–20	Level dependent, increases the risk of acidosis
Replacing barley with corn	0–7	Depends on grain processing
Use of cereal silage and corn silage	5–10	Depends on grain content of silage
Use of legumes	5–10	Response often confounded with stage of maturity
Tannin-containing forages	10–20	High potential, but production often limited by agronomics
Strategies that are experimental		
Condensed tannin extracts	0–15	Depends on source, high levels may decrease milk production
Saponins	0–10	Depends on source
Yeast	0–5	Depends on strain, commercial strains have not been tested for their effectiveness
Essential oils	0–20	Promising results with garlic, but further testing needed
Fiber-degrading enzymes	0–10	Commercial products have not been tested for their effectiveness

[1] Estimated by the authors based on a review of the literature.

Feeding Fats and Oilseeds

Adding fats to the diet reduces CH_4 emissions by decreasing organic matter fermentation in the rumen, reducing the activity of methanogens and protozoal numbers, and for lipids rich in unsaturated fatty acids, through hydrogenation of fatty acids (Johnson and Johnson 1995). The effectiveness of adding lipids to the diet to reduce CH_4 emissions depends on many factors including level of supplementation, fat source, fatty acid profile, form in which the fat is administered (i.e., either as refined oil or as full-fat oilseeds) and the type of diet. However, level of added fat is by far the most important factor. Figure 3 shows the relationship between level of added fat (% of DMI) and the reduction in CH_4 emissions (g/kg DMI) for a range of fat sources and diets (Beauchemin et al. 2008). Over a broad range of conditions, CH_4 (g/kg DMI) was reduced by 5.6% with each 1% addition of supplemental fat. In most cases, 2 to 3% fat can be added to dairy cow diets without negative effects. The total amount of fat in the diet (added fat plus fat in the basal diet) should not exceed 6 to 7% of the diet otherwise a depression in DMI may occur, negating the advantages of increased energy density of the diet.

There is considerable variation in the CH_4 reductions observed among fat sources. Higher reductions can be achieved with fats that contain medium chain fatty acids (i.e., C12:0 and C14:0). Examples of these types of oils are: coconut oil, myristic acid, palm kernel oil, high-laurate canola oil, and some genetically modified canola oils. However, refined oils containing medium chain fatty acids are unlikely to be used in North America because of their cost.

Sources of long-chain fatty acids that can be effective CH_4 suppressants include animal fats, oilseeds, and refined oils (Table 2). Pure oils are more effective against CH_4 than the same amount of lipid supplied via crushed oilseeds, but oilseeds are preferred because they have less adverse side-effects on feed intake and fiber digestibility. Oilseeds such as sunflower seed and cottonseed can be fed unprocessed, but others such as canola seed and flaxseed need to be processed before feeding because they are not broken down during mastication. Byproducts from the ethanol and food processing industries can be less expensive sources of fat. In addition to reducing enteric CH_4, these fat sources also reduce net greenhouse gas emissions (which includes the greenhouse gases associated with crop growth, processing, transportation, etc.).

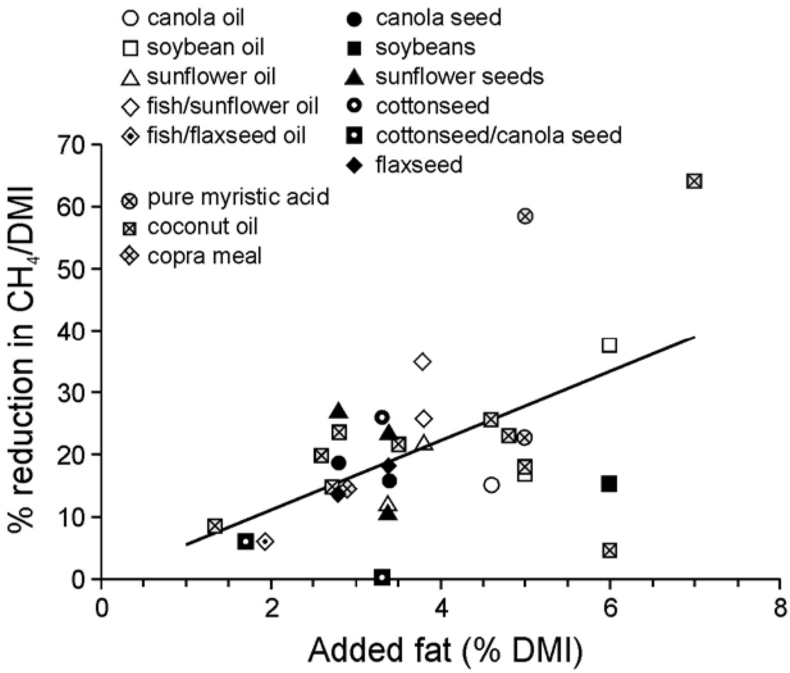

Fig. 3 Summary of literature results for 33 treatment means showing the effect of added fat from various sources on the percentage reduction in methane (g/kg dry matter intake) relative to the control diet (added inert fat or no added fat). The solid line represents the regression accounting for the effect of study; Y = 5.562 (SE = 0.590) × percentage added fat; r^2 = 0.67; *P* = 0.004. Further details on the studies used in this analysis are given in Beauchemin et al. (2008).

Table 2. Supplemental sources of fats for use in dairy diets.

Item	% fat
Cottonseed (with lint)	23
Whole soybeans	19
Sunflower seeds	44
Crushed canola seeds	40
Cooked potato chips	18
Corn distillers dried grains	15
Brewers grains	10
Bakery waste (dried)	13
Citrus pulp (wet)	10
Naked oats	15
Tallow and animal fats	100

Fats increase the energy density of the diet, which can improve cow productivity in some situations. However, high levels of added fat can reduce feed intake, fibre digestibility, and milk fat percentage, so care must be taken in choosing the appropriate level of supplementation.

Use of Ionophores

Ionophores such as monensin are antimicrobials typically used in dairy cattle diets to improve feed efficiency. Monensin decreases the proportion of acetate and increases the proportion of propionate in the rumen — an effect that decreases CH_4 output. At times, monensin may also lower rumen protozoal numbers. This is important, as a direct relationship exists between rumen protozoal numbers and CH_4 formation in the rumen. Rumen protozoa are estimated to provide a habitat for up to 20% of ruminal methanogens while methanogens living on and within protozoa are thought to be responsible for about a third of the CH_4 emissions from ruminants.

The effect of monensin on lowering CH_4 production appears to be dose-dependent. In recent studies, providing a dose of 10-15 ppm had no effect on CH_4 production (g/d or g/kg DMI) in dairy cows (Grainger et al. 2008; Waghorn et al. 2008) while a dose of 15-20 ppm either had no effect on CH_4 production or reduced total CH_4 but not CH_4 per kilogram of DMI in dairy cows (VanVugt et al. 2005). Higher doses (24 to 35 ppm), which are typically fed to dairy cows in North America, reduced CH_4 production (g/d by 4 to 13% and g/kg DMI by 0 to 10%) in beef cattle and dairy cows (Sauer et al. 1998, McGinn et al. 2004, VanVugt et al. 2005, Odongo et al. 2007), with short-term decreases in CH_4 of up to 30% being reported in beef cattle when 33 ppm of monensin was included in high or low forage diets (Guan et al. 2006).

Unfortunately, the inhibitory effects of ionophores on CH_4 production may not persist over time (Johnson and Johnson 1995). Guan et al. (2006) recently reported that monensin (33 mg/kg) lowered CH_4 emissions in beef cattle by up to 30%, but levels were restored within 2 months. In that study, the effect of ionophores on CH_4 production was related to protozoal populations, which adapted to ionophores over time. In contrast, Odongo et al. (2007) provide evidence that adaptation to ionophores may not always occur; in their study monensin lowered CH_4 production in dairy cows over a 6-month period. It is evident that the long-term effects of monensin on CH_4 emissions require further study.

Feeding Higher Concentrate Diets

Increasing the grain content of total mixed rations (TMR) lowers the proportion of feed energy converted to CH_4 by decreasing the acetate:propionate ratio in the rumen fluid. Furthermore, methanogens are susceptible to the low pH conditions in the rumen that result from feeding high grain diets. However, the potential of using concentrates to lower CH_4 emissions from the dairy sector is limited because the increased incidence of rumen acidosis jeopardizes cow health and reduces milk fat content.

Replacing Barley Grain with Corn Grain

In addition to feeding more grain, CH_4 emissions are also lowered by feeding corn rather than barley grain. This difference is due to a partial shift in the site of digestion from the rumen to the intestines, as corn is typically less extensively digested in the rumen than is barley. Of course, the method used to process the grain is also an important consideration; high moisture grains, steam flaking of corn, and fine grinding increase ruminal digestion compared with dry rolling, steam rolling and coarse grinding.

Forage-Related Strategies

Several forage-related strategies that reduce CH_4 emissions have been identified, but the CH_4 response to implementing these strategies can be variable as many interacting factors can arise. In general, replacing grass and legume forages with corn silage and whole crop small grain silages reduces CH_4 emissions because grain silages favor the production of propionate rather than acetate in the rumen. Improved forage quality typically results in greater CH_4 output per day because high-quality forages have a faster passage rate from the rumen, which leads to greater feed intake and more fermentable substrate in the rumen. The result is greater daily enteric CH_4 production per day. However, the amount of CH_4 produced per unit of energy consumed or per kilogram of milk typically decreases as the quality of forages increases. Feeding legumes compared to grasses tends to reduce CH_4, but this relationship is also influenced by the maturity of the forage at the time of consumption. Legumes produce less CH_4 because they have lower NDF content and pass more quickly through the rumen. Tannin-rich forages (e.g., sanfoin, bird's foot trefoil, big trefoil) can reduce emissions, but many of these forages are not agronomically suited to the geographical locations in Canada.

Feed Additives

Condensed tannin extracts

Condensed tannins are phenolic compounds extracted from the bark of black wattle trees (*Acacia mearnsi*; grown in South Africa) and Quebracho-Colorado trees (grown in South America). Adding *Acacia* tannin extract powder to the diet of sheep at a rate of 2.5% of DMI decreased enteric CH_4 by about 12% with only a marginal decrease in fibre digestion (Carulla et al. 2005). However, Australian researchers used this same source of tannin extract in a dairy cow study and observed negative effects on milk production (Grainger et al., unpublished). In that study, the extract was mixed with water and provided to the cows twice daily as a drench at 1.5 and 3.0% of DMI. Within a few days, cows receiving the high dose dropped sharply in milk production (4 kg/d) and showed signs of ill health. Consequently, the high rate was reduced to 2.25% of DMI for the remainder of the study. Averaged over the 5-week experiment, the low and high tannin levels reduced CH_4 emissions by 16 and 28%. However, the reduction in CH_4 was accompanied by a drop in the digestibility of the feed and a negative effect on milk yield (4.9 and 9.7% reduction in milk yield for the low and high tannin levels, respectively) and fat and protein yield (8 and 11% reductions in milk solids for the low and high tannin levels). At the Lethbridge Research Centre, we supplemented the diet of growing beef cattle with up to 1.8% condensed tannin extracted from Quebracho-Colorado trees and observed no effects on enteric CH_4 or digestibility of the dietary DM (Beauchemin et al. 2007).

These studies show that tannins hold some promise in terms of CH_4 abatement, but the source and optimum level of tannin need considerable refinement to ensure CH_4 is lowered without negatively affecting milk production. Tannins have an additional advantage in that they are also highly reactive with protein and can affect the partitioning of nitrogen within the cow shifting the route of excretion away from urine towards feces. Reduced urinary nitrogen excretion would result in reduced environmental losses through nitrate leaching, ammonia volatilisation and nitrous oxide emissions.

Yeast

Yeast cultures of *Saccharomyces cerevisiae* are widely used in ruminant diets to improve rumen function and milk production. Commercial products vary in the strain of yeast used and the number and viability of yeast cells present. Laboratory studies suggest that some live yeast strains can stimulate the use of hydrogen by acetogenic strains of ruminal bacteria, thereby enhancing the formation of acetate and decreasing the formation of CH_4 in the rumen. However, we conducted a study with growing beef cattle to evaluate two commercial yeast products, as commercial strains have not been selected for their effects on CH_4 (McGinn et al. 2004). One product caused a 3% decrease in CH_4 production (g/g DMI) while the other product increased CH_4 production (g/g DMI) by 8%. These results indicate that while it may be possible to select strains of yeast based on their anti-methanogenic effects, the commercially available strains of yeast likely have only minor, if any, effects on CH_4. Because yeast products are generally modestly priced and already widely used in ruminant production, acceptance of a CH_4-reducing yeast product would likely be high. However, considerable research and development would be needed to deliver such a product to the marketplace. To date, commercial manufacturers have been reluctant to invest in such products because animal performance, rather than CH_4 abatement, is the primary driver for product development.

Enzymes

Enzyme additives are concentrated fermentation products that contain fiber-digesting enzymes (e.g., cellulases, hemicellulases). The focus to date has been on developing enzyme additives that improve fiber digestion (Beauchemin et al. 2003), but it may also be possible to develop enzyme additives that reduce CH_4 emissions. In a recent *in vitro* study in our lab, one particular enzyme candidate increased fiber degradation of corn silage by 58%, with 28% less CH_4 produced per unit of fiber degraded (Beauchemin et al. unpublished). Furthermore, feeding dairy cows a diet containing corn silage with added enzyme reduced CH_4 production (g/g DMI) by 9% (Beauchemin et al. unpublished). Enzymes that improve fiber degradation typically decrease the acetate:propionate ratio in rumen fluid (Eun and Beauchemin 2007), which is thought to be the primary mechanism whereby enzymes decrease CH_4 production. The potential of enzyme additives for CH_4 abatement warrants further research, because enzymes are likely to have positive effects both on milk production and CH_4 abatement.

■ Conclusions

There is an increasing body of research that demonstrates the potential of reducing CH_4 through diet manipulation. However, many of these approaches require further research to fully document their long-term impact on CH_4 emissions, milk production, and profitability. While feeding diets that lower CH_4 emissions from the dairy industry is environmentally responsible, dairy producers are unlikely to adopt these measures unless there are also positive economic impacts.

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