REMOVING METHANE EMISSIONS FROM DAIRY COWS

Karen A. Beauchemin\textsuperscript{1}, Sean M. McGinn\textsuperscript{1} and Chris Grainger\textsuperscript{2}

\textsuperscript{1}Agriculture and Agri-Food Canada, \textsuperscript{2}Department of Primary Industries, Ellinbank

INTRODUCTION

Methane is produced in the rumen (called enteric methane, CH\textsubscript{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\textsubscript{4} and released via the breath. Thus, methane losses can be considered an inefficiency in converting feed energy to milk. In addition, CH\textsubscript{4} is a potent greenhouse gas (GHG) that contributes to global warming. Reducing CH\textsubscript{4} losses is an environmentally sound practice that can improve production efficiency. Our review presents some nutritional approaches that can reduce enteric CH\textsubscript{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 (Fig. 1).

\textbf{Figure 1.} Production of methane in the rumen.

\begin{center}
\begin{minipage}{0.65\textwidth}
\begin{itemize}
  \item \textbf{Step 1. Digestion}\\
  \hspace{1em} carbohydrates $\rightarrow$ \textit{monosaccharides} (glucose)
  \\
  \item \textbf{Step 2. Production of volatile fatty acids by bacteria}\\
  \hspace{1em} glucose + 2 water $\rightarrow$ 2 \textit{acetate} + 2 carbon dioxide + 4 hydrogen \\
  \hspace{1em} glucose $\rightarrow$ 2 \textit{butyrate} + 2 carbon dioxide + 2 hydrogen \\
  \hspace{1em} glucose + 2 hydrogen $\rightarrow$ 2 \textit{propionate} + 2 water
  \\
  \item \textbf{Step 3. Production of CH\textsubscript{4} by methanogenic bacteria}\\
  \hspace{1em} carbon dioxide + 4 hydrogen $\rightarrow$ \textit{methane} + 2 water
\end{itemize}
\end{minipage}
\end{center}
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 CO2 into CH4 and water. Thus, diets that favor lower acetate to propionate ratio usually decrease CH4 production. Diets that restrict the hydrogen available in the rumen for methanogenic bacteria generate less enteric CH4. Diet composition and the amount of feed consumed are the primary drivers of enteric CH4 production (Fig 2).

Most of the enteric methane produced by cattle originates in the rumen. However, fermentation also occurs post-ruminally. About 13% of CH4 is produced in the hind gut, with about 89% of it absorbed across the intestinal mucosa into the blood stream. Likewise, about 95% of CH4 generated in the rumen is transferred to the lungs where the animal breathes it out. As a result, 99% of CH4 emission is lost via the nostrils and mouth and only 1% of the total CH4 emission is lost through the rectum (Murray 1976).

**THE US CONTRIBUTION TO METHANE AND GREENHOUSE GAS EMISSIONS**

The United Nations Framework Convention on Climate Change (UNFCCC) emissions inventory for 2005 identifies the US as a major source of GHG. The US is estimated

**Figure 2.** Relationship between methane (CH4) 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).
to generate almost 40% if the global emissions, compared to about 23% for the European Community (EC; an aggregate of 15 countries within the European Union) and 4% for Canada (Table 1). In the US, agriculture accounts for 7.4% of its GHG, which is similar to Canada (7.6%) but lower than for the EC (9.2%).

In the US, the contribution of CH4 accounts for 30% of all agricultural emissions, while the remaining 70% is attributed to nitrous oxide (N2O). The division of CH4 to N2O in Canada is closer to 50:50, while in the EC it is 44:56.

The percentage of CH4 generated by enteric fermentation, compared to all CH4 sources, is similar between Canada and the US (22.5 and 21.2%), while the EC value is larger at 46.7%. On a global basis, enteric CH4 production accounts for roughly 28% of all CH4 emissions. Methane losses resulting from livestock manure are a much smaller than that from enteric loses, e.g., 7.8% for the US. Agriculture soils are the main source of N2O loses in agriculture (Table 1).

In the US, beef cattle are responsible for 70.7% of the enteric CH4 emission while dairy accounts for 24.7% of this emission (US EPA 2007). For CH4 losses from livestock manure, beef cattle emissions are relatively lower (5.6%) than the emissions attributed to dairy cows (43.3%) due to the anaerobic state of dairy manure.

**STRATEGIES FOR REDUCING METHANE EMISSIONS FROM DAIRY COWS**

In the US, the Environmental Protection Agency calculates the enteric CH4 emissions produced by the dairy sector as part of the national greenhouse gas inventory (US EPA

---

**Table 1.** A comparison of the percentage of methane (CH4) and nitrous oxide (N2O) emitted as determined from the 2005 emissions data reported by the United Nations Framework Convention on Climate Change (www.unfccc.int/2860.php) — data are for the exclusion of Land Use, Land Use Change and Forestry (LULUCF).

<table>
<thead>
<tr>
<th>Region</th>
<th>% of Global Emission</th>
<th>% of all CH4 Emission</th>
<th>% of all N2O Emission</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Enteric</td>
<td>Manure</td>
</tr>
<tr>
<td>Canada</td>
<td>4.1</td>
<td>22.5</td>
<td>2.9</td>
</tr>
<tr>
<td>EC5</td>
<td>23.1</td>
<td>46.7</td>
<td>16.6</td>
</tr>
<tr>
<td>USA</td>
<td>39.8</td>
<td>21.2</td>
<td>7.8</td>
</tr>
<tr>
<td>Global</td>
<td>7.9</td>
<td>27.7</td>
<td>6.7</td>
</tr>
</tbody>
</table>

1 Percentage contribution by the region to all global GHG emissions.
2 Percentage contribution of the regions agriculture relative to the whole region’s GHG emission.
3 Percentage of the region’s CH4 emissions attributed to enteric production and manure management.
4 Percentage of the region’s N2O emissions attributed to manure management and agriculture soils: European Community.
The calculation estimates gross energy intake of individual animals, applies a CH4 conversion rate (fraction of gross energy intake converted to CH4), and then sums the daily emissions by animal category (lactating cows, replacement heifers, calves). For lactating dairy cows, the conversion rates used range from 4.8% in California to 5.8% for many states. These values are lower than the conversion rates adopted by the International Panel on Climate Change (6.5%) and most other countries (IPCC 2006).

Using this method of calculation, CH4 reduction can be achieved either by reducing the number of cows or by reducing the conversion rate. For example, the Canadian dairy industry has decreased its CH4 emissions by about 20% in the past two decades because cow numbers have declined as a result of increased milk production per cow. The Supply Management System in Canada imposes quotas on production, thus increases in cow productivity have been accompanied by a decrease in cow numbers. Increasing animal productivity usually increases emissions per cow (due to higher feed intake), thus reductions are only achieved if product output is capped.

In the US, reductions in CH4 emissions from dairy cows will likely only occur by reducing the 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 (Beauchemin et al. 2008). Other non-dietary approaches being examined include 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 (McAllister and Newbold 2008). While a number of strategies to reduce CH4 have been proposed, the mitigant must meet the following criteria before it will be adopted on-farm: 1) documented effectiveness in reducing emissions, 2) profitable (or at least revenue neutral), and 3) feasible to implement on-farm.

**ECONOMIC IMPLICATIONS OF REDUCING METHANE EMISSIONS**

Enteric CH4 formation in the rumen represents inefficiency in terms of converting feed energy to milk. For a high producing dairy cow, a 20% reduction in CH4 emissions represents the same amount of energy needed to synthesize 0.6 kg/d of milk. In theory, implementing a dietary change to reduce CH4 emissions could increase milk production simply by sparing energy. Revenue generated from increased milk yield could partially offset the cost of the dietary mitigant.

There may also be an opportunity in the future for dairy producers to benefit financially from carbon off-set programs. At the present time, the Agricultural Methane Emissions Offset Program under the Chicago Carbon Exchange does not recognize reductions in enteric CH4 emissions. However, this will likely change in the near future as the technology for monitoring emissions on-farm becomes more readily available. Based on the current trading value of CH4 on the Chicago Carbon Exchange ($2.05/100 metric tonnes CO2 equivalent), a 20% reduction in CH4 from a dairy cow would generate a revenue of
$0.03/cow/d (350 g CH4 /cow/d × 0.20 = 0.07 tonnes CH4 × 21 CO2/CH4 = 1.47 tonnes CO2 equivalent × 0.0205 = $0.03/cow/d). Assuming a milk price of $0.30/kg, the breakeven cost of feeding a cow to reduce CH4 emissions by 20% is $0.21/d (0.6 kg milk × 0.30 = $0.18 + $0.03 = $0.21/d). These calculations are theoretical at best as very few studies have been conducted to look at the long-term effects of reducing CH4 on the lactational performance of dairy cows.

NUTRITIONAL STRATEGIES THAT REDUCE ENTERIC CH4 PRODUCTION

Some dietary strategies that reduce enteric CH4 production are listed in Table 2. Diet modifications reduce CH4 emissions by decreasing the fermentation of feed in the rumen, shifting the site of digestion from the rumen to the intestines, diverting H2 away from CH4 production during ruminal fermentation, or by inhibiting the formation of CH4 by rumen bacteria.

Table 2. Dietary strategies that reduce enteric CH4 production.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Percentage Reduction in CH₄</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strategies with higher certainty of reducing CH4 production</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fats and oilseeds</td>
<td>5–25</td>
<td>Level dependant</td>
</tr>
<tr>
<td>Ionophores</td>
<td>0–10</td>
<td>Dose dependant, response may decline after several months</td>
</tr>
<tr>
<td>Higher grain diets</td>
<td>5–20</td>
<td>Level dependant, increases the risk of acidosis</td>
</tr>
<tr>
<td>Replacing barley with corn</td>
<td>0–7</td>
<td>Depends on grain processing</td>
</tr>
<tr>
<td>Use of cereal silage and corn silage</td>
<td>5–10</td>
<td>Depends on grain content of silage</td>
</tr>
<tr>
<td>Use of legumes</td>
<td>5–10</td>
<td>Response often confounded with stage of maturity</td>
</tr>
<tr>
<td>Tannin-containing forages</td>
<td>10–20</td>
<td>High potential, but production often limited by agronomics</td>
</tr>
<tr>
<td>Strategies that are experimental</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condensed tannin extracts</td>
<td>0–15</td>
<td>Depends on source, high levels may decrease milk production</td>
</tr>
<tr>
<td>Saponins</td>
<td>0–10</td>
<td>Depends on source</td>
</tr>
<tr>
<td>Yeast</td>
<td>0–5</td>
<td>Depends on strain, commercial strains have not been tested for their effectiveness</td>
</tr>
<tr>
<td>Essential oils</td>
<td>0–20</td>
<td>Promising results with garlic, but further testing needed</td>
</tr>
<tr>
<td>Fiber-degrading enzymes</td>
<td>0–10</td>
<td>Commercial products have not been tested for their effectiveness</td>
</tr>
</tbody>
</table>

1 Estimated by the authors based on a review of the literature.
The strategies in Table 2 have varying degrees of uncertainty associated with their estimated reduction in CH4. A brief discussion of these strategies follows, but a more complete review of the impact of diet on CH4 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 CH4 emissions based on diet composition (e.g. Blaxter and Clapperton 1969, Moe and Tyrrell 1979, Pelchen and Peters 1998).

**Feeding Fats and Oilseeds**

Adding fats to the diet reduces CH4 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 CH4 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 CH4 emissions (g/kg DMI) for a range of fat sources and diets (Beauchemin et al. 2008). Over a broad range of conditions, CH4 (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 CH4 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 CH4 suppressants include animal fats, oilseeds, and refined oils (Table 3). Pure oils are more effective against CH4 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 substantially damaged during mastication. Byproducts from the ethanol and food processing industries can be less expensive sources of fat. In addition to reducing enteric CH4, these fat sources also reduce net GHG emissions (net GHG emissions includes the GHG associated with crop growth, processing, transportation, etc.).

Fats increase the energy density of the diet, which can improve cow productivity
Figure 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; \(Y = 5.562 \text{ (SE = 0.590)} \times \text{percentage added fat;} r^2 = 0.67; P = 0.004\). Further details on the studies used in this analysis are given in Beauchemin et al. (2008).

Table 3. Supplemental sources of fats for use in dairy diets.

<table>
<thead>
<tr>
<th>Item</th>
<th>% Fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cottonseed (with lint)</td>
<td>23</td>
</tr>
<tr>
<td>Whole soybeans</td>
<td>19</td>
</tr>
<tr>
<td>Sunflower seeds</td>
<td>44</td>
</tr>
<tr>
<td>Crushed canola seeds</td>
<td>40</td>
</tr>
<tr>
<td>Cooked potato chips</td>
<td>18</td>
</tr>
<tr>
<td>Corn distillers dried grains</td>
<td>15</td>
</tr>
<tr>
<td>Brewers grains</td>
<td>10</td>
</tr>
<tr>
<td>Bakery waste (dried)</td>
<td>13</td>
</tr>
<tr>
<td>Citrus pulp (wet)</td>
<td>10</td>
</tr>
<tr>
<td>Naked oats</td>
<td>15</td>
</tr>
<tr>
<td>Tallow and animal fats</td>
<td>100</td>
</tr>
</tbody>
</table>
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 CH4 output. At times, monensin may also lower rumen protozoal numbers. This is important, as a direct relationship exists between rumen protozoal numbers and CH4 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 CH4 emissions from ruminants.

The effect of monensin on lowering CH4 production appears to be dose-dependent. In recent studies, providing a dose of 10-15 ppm had no effect on CH4 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 CH4 production or reduced total CH4 but not CH4 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 CH4 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 CH4 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 methanogenesis may not persist over time (Johnson and Johnson 1995). Guan et al. (2006) recently reported that monensin (33 mg/kg) lowered CH4 emissions in beef cattle by up to 30%, but levels were restored within 2 months. In that study, the effect of ionophores on CH4 production was related to protozoal populations, which adapted to ionophores over time. In contrast, Odongo et al. (2007) provides evidence that adaptation to ionophores may not always occur; in their study monensin lowered CH4 production in dairy cows over a 6-month period. It is evident that the long-term effects of monensin on CH4 emissions require further study.

**Feeding Higher Concentrate Diets**

Increasing the grain content of the TMR lowers the proportion of feed energy converted to CH4 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 CH4 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, CH4 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 CH4 emissions have been identified, but the CH4 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 CH4 emissions because grain silages favor the production of propionate rather than acetate in the rumen. Improved forage quality typically results in greater CH4 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 CH4 production per day. However, the amount of CH4 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 CH4, but this relationship is also influenced by the maturity of the forage at the time of consumption. Legumes produce less CH4 because they have lower NDF content and pass more quickly through the rumen. Tannin-rich forages (e.g., sanfoin, birsd’s foot trefoil, big trefoil) can reduce emissions, but many of these forages are not agronomically suited to the geographical locations in the US.

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 CH4 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. Averaged over the 5-week experiment, the low and
high tannin levels reduced CH4 emissions by 16 and 28%. However, the reduction in CH4 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 CH4 or digestibility of the dietary DM (Beauchemin et al. 2007).

These studies show that tannins hold some promise in terms of CH4 abatement, but the source and optimum level of tannin need considerable refinement to ensure CH4 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 CH4. 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 CH4 (McGinn et al. 2004). One product caused a 3% decrease in CH4 production (g/g DMI) while the other product increased CH4 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 CH4. Because yeast products are generally modestly priced and already widely used in ruminant production, acceptance of a CH4-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 CH4 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 CH4 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 CH4 produced per unit of fiber degraded (Beauchemin et al, unpublished). Furthermore, feeding dairy cows a diet containing corn silage with added enzyme reduced CH4 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 CH4 production. The potential of enzyme additives for CH4 abatement warrants further research, because enzymes are likely to have positive effects both on milk production and CH4 abatement.

CONCLUSIONS

There is an increasing body of research that demonstrates the potential of reducing CH4 through diet manipulation. However, many of these approaches require further research to fully document long-term impact on CH4 emissions, milk production, and profitability. While feeding diets that lower CH4 emissions from the dairy industry is environmentally responsible, dairy producers are unlikely to adopt these measures unless there are also positive economic impacts.

REFERENCES


