

# STRATEGIES FOR REDUCING ENTERIC METHANE EMISSIONS IN FORAGE-BASED BEEF PRODUCTION SYSTEMS

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## 1. Introduction

The Canadian agricultural landscape includes some 4,804,496 hectares of tame or seeded pasture and 15,391,072 ha of natural land for pasture [1]. A significant portion of this forage is used by the Canadian beef cattle industry as a source of feed for cows, bulls and growing/young stock. Microbial breakdown of forage and other feedstuffs in the rumen, also known as enteric fermentation, results in the production of methane. Approximately, 87% of enteric methane originates in the reticulo-rumen while the remainder is produced in the hindgut. A significant portion of the latter, approximately 89%, is absorbed and expired through the lungs, with the remainder being excreted through the anus [2, 3]. Losses in gross energy intake associated with methane production range from 2-3% of gross energy intake (GEI) when animals are fed high grain diets [4] to 11.3% of GEI when consuming low quality forage [5].

In Canada, enteric fermentation (as calculated using Intergovernmental Panel on Climate Change (IPCC) Tier 1 values) contributes approximately 19,000 Kt CO<sub>2</sub> equivalents year<sup>-1</sup> – approximately 32 % of total agricultural emissions [6]. An understanding of the microbial processes responsible for the production of enteric methane production, coupled with the identification of management strategies leading to reduced methane emissions and improved animal performance will help facilitate the efforts of the Canadian Government to achieve a 6% reduction in greenhouse gas emissions by 2008-2012, as outlined in the Kyoto Protocol [7]. Several comprehensive reviews have examined enteric methane production by methanogenic bacteria [8, 9]. As a consequence, this chapter will not examine this area in detail but instead will summarize the applied research which has been conducted in Canada, in an attempt to identify potential mitigation strategies for forage-based, beef cattle production systems.

## **2. Enteric Fermentation**

Methane production in the rumen occurs as a consequence of the presence of a group of microorganisms called methanogens that reside in the reticulo-rumen and large intestine of ruminant livestock. These organisms play an important role in converting organic matter to methane. As described in a detailed review by McAllister et al. [8], proteins, starch and plant cell-wall polymers consumed by the animal are hydrolyzed to amino acids and simple sugars by the bacteria, protozoa and fungi which reside in the rumen. Primary and secondary digestive microorganisms further ferment the amino acids and sugars into volatile fatty acids, hydrogen, carbon dioxide and other end products. Methanogens then reduce carbon dioxide to methane, preventing the accumulation of hydrogen. Excessive quantities of hydrogen ions or protons, when allowed to accumulate in the rumen environment, result in a decline in pH, and subsequent inhibition of many organisms that are essential for fibre digestion.

## **3. Mechanisms by which methane production may be reduced**

Several mechanisms influence the availability of hydrogen in the rumen and subsequent production of enteric methane emissions by cattle. Processes that yield propionate act as net proton-using reactions while those that yield acetate result in a net increase in protons [10]. That is, the proportion of volatile fatty acids, specifically acetate:propionate, produced as a consequence of microbial fermentation in the rumen has a significant influence on methane production. This ratio may, for example, be influenced by the type of carbohydrate consumed by

the animal. Cereal-based diets that are high in starch favor propionate production and consequently tend to produce less methane per unit of feed consumed than forage-based diets [8].

In addition to the type of carbohydrate in the diet, other dietary factors influence the acetate:propionate profile in the rumen, including residence time in the rumen. Okine et al. [11] have demonstrated a 29% reduction in methane production when weights were added to the rumen to stimulate contraction of the rumen wall in order to decrease residence time of the feed in the digestive tract.

Digestibility of dietary energy may also influence enteric methane production. Boadi and Wittenberg [12] have demonstrated that a reduction in forage in vitro organic matter digestibility (IVOMD) from 61.5% to 38.5% tended ( $P = 0.14$ ) to lead to an increase in GEI lost as methane from  $6.0 \pm 0.38$  to  $6.9 \pm 0.98\%$  when animals were fed ad libitum. When intake was restricted to 2% of body weight, an increase in methane production, expressed as a percent of GEI, was no longer evident. As changes in diet digestibility and residence time in the rumen are associated with intake, it is not unexpected that level of intake also influences enteric methane emissions. Johnson and Johnson [4] concluded that feeding highly available carbohydrates at limited intakes, results in high fractional methane losses while feeding highly available carbohydrates at high intakes leads to low fractional methane losses. Further, Blaxter [13] has described an increase in total production of methane with increases in intake, from maintenance to twice maintenance. However, when expressed as amount of energy lost per unit of feed, a reduction is realized.

Another mechanism by which methane production may be reduced during the rumen fermentation process is through the provision of alternative hydrogen acceptors or sinks.

Compounds such as unsaturated fatty acids provide alternative hydrogen acceptors, consuming hydrogen in limited quantities, during biohydrogenation [14]. Dicarboxylic acids (such as fumaric and malic acids), which are intermediates in the propionic acid pathway, may also serve as alternative electron sinks for  $H_2$ , as described in a recent review by Boadi et al. [15]. Bayaru et al. [16] observed a 23% reduction in methane production, and increased propionic acid formation with no effect on DM digestibility when fumaric acid was added to whole crop sorghum silage fed to Holstein steers.

#### **4. Management Strategies Leading to a Reduction in Enteric Methane Emissions**

There are several management strategies that may be employed in the Canadian beef cattle industry to reduce enteric methane emissions via the mechanisms described above. These management strategies may be categorized as follows: forage utilization, feed additives, and improved production efficiencies. Each will be addressed in the subsequent section.

##### **4.1 Forage utilization**

###### **4.1.1 Quality**

Boadi and Wittenberg [12] have demonstrated that forage quality has a significant impact on enteric methane emissions. Cattle given hay of high (61.5 % IVOMD), medium (50.7% IVOMD) and low (38.5% IVOMD) quality differed ( $P < 0.01$ ) in dry matter intake, as animals consumed  $9.7 \pm 0.23$ ,  $8.9 \pm 0.23$  and  $6.3 \pm 0.23$  kg  $d^{-1}$ , respectively. Further, differences existed in enteric methane emissions ( $P < 0.01$ ), as  $47.8 \pm 4.02$ ,  $63.7 \pm 4.02$  and  $83.2 \pm 4.02$   $CH_4$  L  $kg^{-1}$

digestible organic matter intake was produced from cattle consuming the high, medium and low quality forages, respectively.

These same authors subsequently demonstrated this same phenomenon on pasture [17]. Steers grazing during the early period of the grazing season had 44% and 29% less energy lost as methane ( $P < 0.01$ ) than steers grazing during the mid and late grazing periods respectively. Further, steers experienced a 54% reduction ( $P < 0.01$ ) in enteric emissions upon entry vs. exit of a paddock. Efficiency of forage fermentation was linked to biomass availability and quality of pasture.

The impact of pasture forage quality and availability on enteric methane emissions from cattle in grass-based production systems has been studied by Ominski et al. [5]. Enteric methane emissions measured early and late in the grazing season were influenced by pasture type and season of grazing. Further, it appeared that emissions were influenced by pasture dry matter availability and quality, in that emissions were highest (11% of GEI) when pasture quality and availability were low. Emissions were lower when pasture quality was high and availability was low (6.9% of GEI) or when quality was low and availability was high (7.1-9.4% of GEI). Unfortunately, neither pasture ever attained a status of high forage quality and high pasture availability. It can be concluded that enteric emissions are highest when the animal is presented with poor quality forage and has limited opportunity to select higher quality forage as a consequence of reduced dry matter availability.

The impact of pasture quality on enteric emissions has recently been examined by Pinares-Patiño et al. [18]. In this study, beef cows were grazed on a mono-specific pasture of timothy at four stages of maturity: early vegetative, heading, flowering and senescence. Although the crude

protein and NDF values were 31.4 and 52.6; 13.2 and 59.8; 7.8 and 68.4; and 4.4 and 75.4 at vegetative, heading, flowering and senescent stages, respectively, organic matter intake (kg) and methane emissions ( $\text{g d}^{-1}$ ) were lower only at heading ( $11.3 \pm 1.4$ ;  $273.3 \pm 28.7$ ) but not at vegetative ( $9.1 \pm 0.7$ ;  $204.4 \pm 28.1$ ), flowering ( $10.1 \pm 1.5$ ;  $232.2 \pm 25.4$ ) or senescent ( $10.1 \pm 1.3$ ;  $228.4 \pm 32.9$ ) stages. Further, methane emissions when expressed as a percent of gross energy intake did not differ among treatments. Although the trial was designed to decrease species selection, it did not limit selection of plant parts. Therefore, the lack of response associated with maturity that was observed by the authors may be attributed to animal selection during grazing. Although the area of pasture allocated daily was calculated using required herbage area (set as twice intake capacity), herbage mass and the number of cows, post-grazing sward surface height ranged from  $11.3 \pm 1.4$  to  $51.2 \pm 5.0$  cm. Further, as the animals were strip grazed, they had access to the pasture grazed in the previous 12 hours. Under these conditions, animals could have selected the more vegetative plants or more digestible plant parts. Thus, it is paramount that potential mitigation strategies be assessed under conditions that parallel those observed in the Canadian production environment.

#### **4.1.2 Species**

McCaughey et al. [19] have demonstrated that the species present in a pasture may significantly influence enteric methane emissions. Pasture types examined were alfalfa-grass mix (78% alfalfa and 22% meadow bromegrass) or 100% meadow bromegrass. Although, cows grazing the alfalfa-grass pastures had significantly greater dry matter intake ( $11.4 \pm 0.4$  vs.  $9.7 \pm 0.4$  kg DM  $\text{d}^{-1}$ ), lower methane production was observed ( $373.8 \pm 10.1$  vs.  $411.0 \pm 10.1$  L  $\text{CH}_4$   $\text{d}^{-1}$ ) compared to their counterparts grazing grass-only pastures. As a consequence, cows grazing the

alfalfa-grass pastures lost less energy ( $P = 0.001$ ) through eructation of  $\text{CH}_4$  ( $7.1 \pm 0.4\%$  vs.  $9.5 \pm 0.4\%$  of GEI). This reduction in  $\text{CH}_4$  emissions may be attributed to a reduction in the proportion of structural carbohydrates. The NDF of the alfalfa-based pasture ( $58.4 \pm 0.8\%$ ) was lower than the NDF of the grass-based pasture ( $73.1 \pm 0.8\%$ ). Inclusion of legume-based forages in the diet is associated with higher digestibility and faster rate of passage [20] resulting in a shift toward high propionate in the rumen and reduced methane production. The improved feed utilization observed in the cow as a consequence of the reduced enteric emission proved to be beneficial to the calves in this study as calf growth rate was 11% higher on the alfalfa-grass pasture compared to the grass only pasture.

The need to examine animal performance concomitant with enteric emissions has been illustrated by Olson [21] who examined methane production of animals grazing native pasture compared to those grazing several alternative forage species (“Nordan” crested wheatgrass, “Hycrest” crested wheatgrass, “Vinall” Russian wildrye and “Syn-A” Russian wildrye) during a 30-day grazing season in the fall and spring. Enteric emissions from cattle grazing these species in the fall were the same for all pasture species even though intake was greater ( $P = 0.01$ ) and body weight loss was less ( $P = 0.05$ ) for the wildrye varieties compared to the wheatgrass varieties [22]. This same author observed that daily enteric methane emissions increased by approximately 70% ( $P < 0.01$ ) for lactating cows grazing the same pastures in the spring because animal intake, expressed as % BW, was significantly higher. Although pasture species did not effect grazing cow methane emissions, body weight gains of animals consuming crested wheatgrass varieties were higher than those of animals consuming Russian wildrye varieties. This work clearly demonstrates that the opportunity to use management strategies that match pasture forage with animal requirements as a means of optimizing performance with no increase in enteric emissions.

Although studies examining the mitigation potential of other species in Canada have not been published to date, such studies have been conducted in New Zealand using ram lambs [23]. Forages examined included fresh ryegrass/white clover pasture, lucerne, sulla, chicory, red clover, and lotus, as well as sulla/lucerne, chicory/sulla, and chicory/red clover mixes. All forages, which were cut on a daily basis, were of good quality with crude protein concentrations ranging from 12.3% (chicory) to 26.4% (lotus), fibre ranging from 12.7% (chicory) to 44.4% (pasture), and DM digestibility in excess of 65%. A two-fold range in methane emissions was observed from 11.5 g kg<sup>-1</sup> DMI with lotus to 25.7 g kg<sup>-1</sup> DMI with rye grass/white clover pasture. These studies not only demonstrated that species selection may play an important role in reducing enteric methane emissions, but more specifically that condensed tannins present in several forage species are associated with reduced methanogenesis and thus may be an effective technique to lower methane production. Other benefits associated with feeding condensed tannins in ruminant diets include reduced incidence of bloat and intestinal worm populations [24]. Further, as described by Jones et al. [25], ingestion of tannin-containing forages leads to the formation of insoluble tannin-protein complexes as a consequence of the ability of tannins to bind to plant complexes at pH ranges of 3.5 – 7.0. As these plant complexes dissociate at pH's below 3.0, as is characteristic of the postruminal environment, they serve to protect protein from microbial degradation in the rumen, thereby increasing the proportion of plant amino acids absorbed postuminally. To date, no data have been published to establish the mitigation potential of tannin-containing legumes such as sainfoin or birdsfoot trefoil in the Canadian production environment.

#### **4.1.3 Pasture management**

Several studies have been conducted in Canada that examine the impact of pasture management on enteric methane emissions [26, 17]. McCaughey et al. [26] examined the impact of two grazing systems (continuous vs. rotational) and two stocking densities (low, 1.1 steer ha<sup>-1</sup> or high, 2.2 steers ha<sup>-1</sup>) on animal intake and methane production. In this alfalfa-grass-based production system, neither intake nor methane production (expressed as emissions per unit gain or as a percent of gross energy intake) were affected by the management strategies described above.

Boadi et al. [17] examined the use of supplemental grain as a means of reducing enteric methane emissions in an alfalfa-grass pasture environment. Steers were fed 2, 4 and 4 kg of rolled barley on a daily basis during the early, mid and late periods respectively of the grazing season.

Although supplementation reduced forage dry matter intake by an average of 11% ( $P < 0.03$ ) and increased total organic matter intake by 14% ( $P < 0.001$ ), daily enteric emissions (L d<sup>-1</sup>) were similar in the supplemented and control steers. Further, there was no significant difference between the two treatments in terms of energy lost as methane (6.4% and 6.7% of GEI for supplemented and control steers, respectively). These data suggest that the benefits of grain supplementation in terms of mitigation potential on good quality pasture are limited, as pasture quality had a greater impact on methane production than did grain supplementation.

#### **4.1.4 Forage preservation and processing**

To the authors' knowledge no work has been conducted in Canada to date to establish the impact of ensiling on enteric methane emissions. A decrease in methane production as a consequence of ensiling has been reported [9]. This finding has not been reported elsewhere. In fact, Woodward et al. [27] in New Zealand, observed some of the highest methane losses reported in the literature

associated with feeding ryegrass silage (10.8% of gross energy) and lotus silage (8.6% of gross energy). Thus, additional research is needed to assess the methane mitigating potential of silages, as well as processing or chemical treatment of forages in the Canadian production environment.

## 4.2 Feed additives

Ionophores are frequently utilized in beef cattle production systems to improve animal performance, as well as to reduce the incidence of bloat and prevent outbreaks of coccidiosis . Improvements in feed efficiency of 5-6% have been attributed to a shift in the fermentation pathway from acetate to propionate [28]. Although ionophore supplementation may reduce methane emissions by 20-25%, work conducted at the University of Colorado has demonstrated that an adaptive response occurs in both forage and grain diets, resulting in a return to baseline methane levels in approximately two weeks [29].

The use of ionophores to reduce enteric methane emissions on pasture has been examined by McCaughey et al. [26]. As described above, steers in this trial were grazed under two management regimens – continuous or rotational. Half of the animals on each pasture were given a monensin controlled-release capsule (CRC) delivering 270 mg d<sup>-1</sup>. Neither voluntary intake nor methane production was affected by the presence of monensin.

The mitigation potential of other feed additives, including the addition of salts to alter the dietary cation-anion balance has been explored [30]. In this trial, salts were added to the rumen (via cannula) to achieve a dietary cation-anion balance of 10, 30, 50, and 70 meq 100g<sup>-1</sup> DM.

Methane emissions, expressed as g hd<sup>-1</sup> d<sup>-1</sup> (P < 0.009) and as a percent of gross energy intake (P < 0.02), were lower for cows receiving the diet containing 70 meq 100g<sup>-1</sup> DM compared to those

receiving the 10 and 30 meq 100g<sup>-1</sup> DM diet. Diet dry matter intake and rumen fermentation characteristics were not affected by the change in dietary cation-anion balance. Research conducted by Müller-Özkan [31] has demonstrated that the addition of calcium ions in vitro had a tendency to reduce activity of methane-producing bacteria, as evidenced by a decrease in methane production.

The addition of fat supplementation in high-energy finishing diets has been examined in several commercial production systems in Canada. Mathison [32] demonstrated that daily enteric methane emissions could be reduced by 33% when canola oil was added to an 85% concentrate feedlot diet. Further, a Manitoba study [33] demonstrated a 30% reduction in daily enteric methane emissions when comparing a typical feedlot diet (88.5% concentrate) with a ration of equal energy density containing a 44:42:14 ratio of concentrate, silage and whole sunflower seed. These studies demonstrate that fat supplementation may effectively reduce enteric emissions for finishing cattle. To the authors' knowledge, the mitigation potential of supplemental fat in low quality forage diets has not been addressed. Although this strategy of reducing enteric methane emissions may not seem viable from an economic perspective at the present time, future trading of carbon offsets may prove otherwise. In addition to economic viability, other factors that require exploration include practical application techniques in forage-based production systems and appropriate levels of supplementation to ensure that fibre degradation is not compromised.

### **4.3 Improved production efficiencies**

A summary of enteric methane emissions from numerous classes of cattle in the United States led Johnson and Johnson [4] to conclude that methane losses (% GEI) in commercial situations

do not deviate considerably from 6%. As a consequence, these authors have suggested that the best strategy for mitigation is to decrease methane loss per unit of product. Using this approach, strategies to decrease methane emissions in the cattle industry should include effective management of feed resources other than forage, such as water quality, mineral supplementation and ration balancing.

The impact of water quality on cattle performance has been demonstrated in a series of trials conducted by Willms et al. [34]. Calves from cows having access to water from a natural water source delivered to a trough (clean water) gained 9% more than calves from cows that had direct access to a pond. Yearling heifers having access to clean water gained 23% and 20% more weight than their counterparts drinking directly from a pond, or from a pond pumped to a trough, respectively. Thus, adopting management strategies that serve to improve water quality and subsequent animal performance should serve to reduce methane emissions per unit of product. Adequate mineral supplementation is another avenue by which the cattle industry may realize a net reduction in enteric methane emissions. Minerals, which serve numerous functions in the body – structural, physiological, catalytic and regulatory – are necessary if optimal growth, health and productivity of the animal are to be achieved [35]. An extensive study of pasture quality in the Eastern Interlake Region of Manitoba from 1996-1998 [36] provided evidence that many of the surveyed pastures were deficient in several trace minerals including copper, manganese and zinc. It is anticipated that lack of mineral supplementation or inadequate intake of supplemental mineral on these pastures would result in less than optimal performance and thus increased emissions per unit of product.

Other than effective management of feeding programs, there are several other management strategies that would serve to improve animal productivity. These include animal selection for

improved production, management for improved reproduction, and use of growth promoting agents.

Genetic selection of animals that consume less feed or produce less methane per unit of feed is another management strategy that may be employed to reduce enteric methane emissions. Trials conducted at the University of Manitoba have shown that as much as 27% of the variation in methane production from cattle on all-forage diets was associated with animal-to-animal variation [12]. Considerable variation among grazing animals has also been reported by Pinares-Patiño et al. [18], Lassey et al., [37] and Ulyatt et al., [38] where animal-to-animal variation accounted for 70% and 85% of the variation in daily methane production. Two traits that are actively being investigated as a means of identifying genetically superior animals are net feed efficiency and mean retention time of digesta in the rumen Hegarty [39].

## **5. A systems-based approach to management**

In addition to the above management strategies related to management of the forage and livestock components of beef production systems in Canada, it is important to consider opportunities for greenhouse gas mitigation as they relate to other facets of forage-based beef production including the potential for carbon sequestration associated with perennial cropping systems, wetland and shelterbelts. A recent agreement among Agrosuper, the world's eighth-largest pork producer, Japan's Tokyo Electric Power Company and Canada's TransAlta Corp [40] is a good example of the partnerships that are being formed between large corporations and the livestock sector in an attempt to meet the targeted reductions set out in the Kyoto protocol.

As a consequence of such agreements, a paradigm shift may be required in forage-based beef production. In the future, revenue from cow-calf operations may include traditional commodities such as forage and weaned/backgrounded calves, but may also include revenue generated from carbon offsets. Accordingly, management decisions should be made on the basis of net return to all facets of the production system.

A systems-based approach to greenhouse gas mitigation is currently being explored in Western Canada through several multidisciplinary research projects [41, 42]. The objective of these projects is to bring together scientists from a variety of disciplines, as well as leading conservation and producer groups, such that net greenhouse gas production may be assessed in a production system, and further that mitigation strategies which are economically and environmentally sustainable may be identified and disseminated to interested parties (producers, government officials etc).

This strategy is currently being employed by a team of animal, plant, soil and food scientists from the University of Manitoba who have teamed up with several livestock commodity groups, as well as members of the provincial and federal governments, to explore the net greenhouse gas emissions, as well as nutrient and pathogen movement associated with the application of liquid hog manure in grassland pasture systems.

## **6. Summary and Conclusions**

Research conducted to date has demonstrated that a reduction in enteric methane emissions from cattle in forage-based production systems is possible in commercial production systems. These strategies include feeding management strategies such as inclusion of legumes in forage mixes

and feeding highly digestible forages. Adoption of strategies that serve to improve production efficiency including feed analyses and ration balancing, pregnancy testing and provision of good quality water, will not only serve to reduce enteric methane emissions but will also prove to be economically beneficial. The mitigation potential of several commercially accepted practices, including the use of ionophores, probiotics, and silage-based feeding systems requires further evaluation, as does the use of novel production practices such as the inclusion of fat in forage-based diets. In addition, long-term research support is required to examine the potential for selection of low-methane emitting animals in forage-based production environments.

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