Research Paper

A review on reduction of greenhouse gas emission from ruminants through nutritional strategies

Accepted 11th October, 2013

ABSTRACT

Greenhouse gas mitigation has become a major topic of discussion at international, national and local levels, with strategies being developed to reduce emissions. The possibility of man-made releases of GHG’s possibly contributing to climate change has been the key driver in the push to reduce greenhouse gas emissions, with many people, including prominent scientists and world leaders concerned about the potential changes to the environment. This concern about greenhouse gases has resulted in a variety of research targeted towards mitigating emissions from all sectors. Current research in some areas indicates that improving the production process by making it more efficient not only reduces greenhouse gas emissions but improves the economics because there is less waste products. The emission of greenhouse gases, notably of methane, by domestic animals and possible ways of reduction has been the subject of many international studies in recent years. Methane mitigation in ruminants is possible through various strategies. Today, the feeding management approach is the most developed. The sustainability of methane suppressing strategies is an important issue. This review has identified a number of feeding strategies that will result in reduced methane emissions from ruminants such as the feeding of highly digestible forages, concentrates, diet manipulation to provide alternate hydrogen acceptors, inclusion of legumes in forage mixtures, inclusion of supplemental fats in diets and diet manipulation to shift the fermentation pathway. From the review, we can conclude that it is important to adopt those strategies based on their potential on methane reduction as well as, environmentally friendly. The choice of application primarily depends on the cost associated with it.

Key words: Methane, ruminant, greenhouse gas, climate change, enteric fermentation.

INTRODUCTION

Climate change is the biggest global health threat of the 21st century. A systematic appraisal of available evidence showed that the risks from changing patterns of disease, food insecurity, unsafe water and sanitation, damage to human settlements, extreme events, and population growth and migration were far more severe for human health than most observers had understood.

The message added an important new dimension to the political debate about how to respond to climate change. The threat was not only environmental and economic; it was directed at life itself. Global demand for livestock products is expected to double during the first half of this century, as a result of the growing human population, and its growing affluence. Climate change is one of the most serious long-term challenges facing farmers and livestock owners around the globe today. These climate changes will greatly impact arable agriculture, especially forage and grazing livestock production, which are directly dependent...
upon weather and climate (Alan, 2008).

The greenhouse effect is a natural phenomenon necessary for life on earth. Greenhouse gases are atmospheric gases that absorb and re-emit long-wave radiation released by the earth back to the surface and as a consequence average global temperatures are predicted to rise (0.5 to 2.5°C by 2030) (IPCC, 2001). After carbon dioxide, the most important greenhouse gas is methane which traps over 21 times more heat per molecule as compared to carbon dioxide CO₂ (EPA, 2003). One of the largest biogenic (that is, produced by a living organism) source of CH₄ is digestive fermentation from ruminant animals (Alan, 2008).

Microbial enteric fermentation in the gastrointestinal tract of livestock can produce CH₄ gas as a by-product. On average, about 4 to 12% of Gross Energy Intake (GEI) is converted to CH₄ gas. Ruminants with their large forestomach contribute the most per head per day (Karín, 2001). Several techniques to measure CH₄ losses from farm animals exist. They were recently reviewed by Kebreab et al. (2006b); most widely used among them are respiration calorimetric chambers and sulphur hexafluoride (SF₆) as a tracer gas. Also, there are several ways to express CH₄ losses; as % of GEI and liter per kg of dry matter intake (Giger-Reverdin et al., 2003).

According to EPA (2003), reducing methane emissions is one of the most cost-effective ways to realize immediate environmental benefits because of methane’s potency as a greenhouse gas. Since methane represents a loss of carbon from the rumen and therefore an unproductive use of dietary energy, scientists have been looking for ways to suppress its production. A quarter of the greenhouse gases come from animals themselves, mainly from cows, sheep and goats, because of the bacteria in their stomach.

Therefore, feeding and grazing strategies to mitigate CH₄ emissions can contribute to reducing overall GHG emissions, as well as, improve cattle performance (Alan, 2008). The emission of greenhouse gases (GHG), notably of methane (CH₄), by domestic animals and possible ways of reduction has been the subject of many international studies in recent years (Moss et al., 2000; Boadi et al., 2004; Kebreab et al., 2006a) because mitigating methane losses from cattle has economic as well as environmental benefits. Therefore, the aim of this paper is to review the potential nutritional mitigation strategies to reduce methane production from ruminants.

PRINCIPLES AND BACKGROUND OF METHANE PRODUCTION

Sources of greenhouse gases from ruminant animals

There are three main sources of greenhouse gas emissions in agriculture: enteric fermentation, agricultural soils and manure management. Animal agriculture contributes to accumulation of methane gas directly through production of methane in fermentative digestion in the rumen.

Enteric fermentation (fermentation in the digestive tract) is a natural part of the digestion process which results from the activity of microorganisms in the digestive tract. Digestion in ruminants (for example, cattle and sheep) differs from that in monogastrics (for example, pigs and poultry) in that substantial fermentation occurs in their large stomach called the rumen, resulting in large quantities of CH₄ being produced which are voided through belching (Frank et al., 2000).

Methane production

Methane originates from anaerobic microbial fermentation processes in the gastro-intestinal tract of ruminant animals. This fermentation occurs particularly in the reticulorumen, rumen in short. In an adult cow, the rumen occupies a volume of over 100 L of which usually 85 to 90% is fluid (Moss et al., 2000). The high moisture content and a temperature that is kept rather constant at around 37°C makes this an eminently suited environment for microbes to survive and grow, provided the microbes are regularly supplied with a suitable substrate. Substrates needed by the microbes are provided through the ingestion of feed by the host animal. The feed ingested by a ruminant is attacked by the microbes and degraded in a wide range of end products.

The anaerobic condition in the rumen and hindgut limit the oxidation of organic substrate into carbon dioxide and water, but an internal rearrangement of the carbon, hydrogen and oxygen present in the feed between microbial biomass and the end products, keeps the system going. During this process, reducing equivalents (H₂) are generated.

To prevent the accumulation of H₂, which by itself is poisonous to the microbes, a H₂ sink is needed. Various H₂ sinks are present in the rumen of which the conversion of H₂ and CO₂ into CH₄ is by far the most important. An accumulation of CH₄ is prevented by eructation and respiration, and the CH₄ is emitted to the environment.

Other important end products of fermentation are microbial mass and volatile fatty acids. Methanogens coexist with the substrate degrading micro-organisms and produce CH₄ from CO₂ and H₂. By far, the major part of the H₂ formed in the rumen is converted into CH₄ (Mills et al., 2001). Besides methanogenesis, H₂ and CO₂ can be converted to acetate by acetogens, which are also present in the rumen environment (Moss et al., 2000).

In addition to that in the rumen, fermentation also in the hindgut contributes to enteric CH₄ production. This contribution appears generally to be less than 10% and slightly lower than the contribution of the hindgut to the digestion of organic matter (Kebreab et al., 2006b). In Canada, CH₄ emissions from enteric fermentation are...
estimated by multiplying the population of various animal types by average emission rates as presented in Table 1 (Environment Canada, 2002).

**Factors influencing methane yield**

Factors that can be identified as influencing CH₄ yield include dietary characteristics as well as, the fermentation conditions in the rumen. Important dietary characteristics are daily feed intake and the resulting rumen fill the proportion of concentrates in dietary dry matter, the composition, rate and extent of degradation of individual feed fractions (the types of carbohydrate and protein) in dietary dry matter.

Among important fermentation conditions are acidity of rumen fluid, the presence of unsaturated long chain fatty acids, composition of the microbial population within the rumen, dynamics of the passage of particles, fluid and the microbial population, inflow of saliva and the absorption capacity of the rumen wall. The combined effect of both types of factors is represented in conditions that characterize the ruminant, such as production level, stage of lactation and management related interventions like grazing regime, feeding regime, housing and milking (Smink et al., 2003).

Because of the multiple factors that may have changed simultaneously and have affected rumen fermentation and hence, CH₄ yield, the effect of nutritional measures on VFA and CH₄ production may be difficult to predict and interpret. The observed effect of a nutritional intervention on CH₄ yield is therefore strongly confounded with the concomitant changes brought about in these factors. Some of the principal factors affecting rumen function and CH₄ production are subsequently discussed.

**Feed intake**

Changes in dry matter intake not only affect the amount of substrate available for microbial degradation, but it also changes fermentation conditions and the size of the microbial population. For example, the fate of ingested starch changes with changes in the amount of dry matter ingested, as increased intake levels will lead to a proportionally higher amount of starch digested in the small intestine rather than being fermented in the rumen. Almost all models that predict CH₄ production by ruminants require daily feed intake or a closely related variable as an input.

**Intrinsic degradation characteristics**

Microbial degradation of substrates in the rumen depends primarily on intrinsic characteristics that determine the susceptibility of the substrate to be attacked, degraded and utilized by micro-organisms. Obviously, intrinsic characteristics are important determinants of substrate degradation and utilization by micro-organisms, VFA production and the concomitant CH₄ yield. A higher passage rate due to a higher feed intake level as well as, a less degradable substrate may both increase the escape of substrate and lead to a decrease in CH₄ yield.

**Type of substrate fermented and type of diet**

Different types of fermented carbohydrate give different profiles of VFA production and hence, CH₄ yield (Bannink et al., 2005a). Independent of the effect of fluid acidity, an analysis of VFA profiles showed about 25 and 15% lower CH₄ yields for fermented sugars and starch, respectively, on concentrate-rich diets as compared to forage-rich diets (Bannink and Dijkstra, 2005b).

**Fermentation rate and fluid acidity**

The acidity of rumen fluid influences rumen fermentation. As the pH values lower than 6.2 appear to reduce the activity of fibrolytic micro-organisms degrading cell walls, hence, pH determines cell wall degradability and its contribution to microbial growth, and VFA and CH₄ yields. An increased rate of substrate fermentation as a result of an increased feed intake or due to large concentrate meals, leads to increased rates of VFA production, higher VFA concentrations and a more acidic rumen fluid. As a result, the profile of VFA shifts towards a propionate lower CH₄ yield. In an analysis of in vivo data on rumen fermentation, a decrease of the pH of the rumen fluid from 6.5 to 5.5 was estimated to lead to about 15% less CH₄ produced from both fermented sugars and starch (Bannink et al., 2005a, b).

**Nutritional strategies to reduce methane emission**

In general, methane production by livestock represents inefficiency because the feed energy converted to methane is not used by the animal for maintenance, growth, production and reproduction. While efforts to improve efficiency by reducing methane formation in the rumen directly have been of limited success, it is recognized that improvements in overall production efficiency will reduce methane emissions per unit of product produced. 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.

A number of experiments were carried out to investigate possible mitigation practices. Changes in feeding strategy
Table 1. Methane emission factors for domesticated livestock.

<table>
<thead>
<tr>
<th>Animal types</th>
<th>Enteric fermentation (kg CH$_4$/head/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulls</td>
<td>75</td>
</tr>
<tr>
<td>Dairy cows</td>
<td>118</td>
</tr>
<tr>
<td>Beef cows</td>
<td>72</td>
</tr>
<tr>
<td>Dairy heifers</td>
<td>56</td>
</tr>
<tr>
<td>Beef heifers</td>
<td>56</td>
</tr>
<tr>
<td>Heifers for slaughter</td>
<td>47</td>
</tr>
<tr>
<td>Steers</td>
<td>47</td>
</tr>
<tr>
<td>Calves</td>
<td>47</td>
</tr>
<tr>
<td>Sheep</td>
<td>80</td>
</tr>
<tr>
<td>Goats</td>
<td>80</td>
</tr>
<tr>
<td>Horses</td>
<td>13</td>
</tr>
</tbody>
</table>

Source: Environment Canada (2002).

have a large impact on GHG production by farm animals.

It is widely recognized that alterations in the diet strongly affect rumen functioning and the performance of ruminants (for example, roughage: concentrate ratio, or the fiber, starch, sugars and protein content of the feed). Similarly, dietary composition may strongly affect the supply and subsequent fermentation of substrate in the large intestine of pigs as well as, ruminants (quantity of and type of starch, fibre and protein inflow to large intestine). These feeding strategies are subsequently discussed.

Forage utilization

Forage/pasture quality

Methane production in ruminants tends to decrease with the quality of the forage fed. A Manitoba study showed that CH$_4$ emissions of grazing steers that had access to high quality pastures declined by 50% as compared to emissions from matured pastures (Karin, 2001). Boadi and Wittenberg (2002) have demonstrated that forage quality has a significant impact on enteric methane emissions. Efficiency of forage fermentation was linked to biomass availability and quality of pasture. 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. According to Ominski and Wittenberg (2006), steers grazing during the early period of the grazing season had 44 and 29% less energy lost as methane compared to steers grazing during the mid and late grazing periods, respectively. Further, steers experienced a 54% decline in enteric emissions upon entry versus exit of the grazing paddock.

This study has concluded that enteric CH$_4$ emissions are highest when the animal is presented with poor-quality forage and has limited ability to select higher quality forage components as a consequence of reduced dry matter availability.

Boadi and Wittenberg (2002) reported that forage quality has a significant impact on enteric CH$_4$ emissions. Cattle given hay of high (61.5% in vitro organic matter digestibility [IVOMD]), medium (50.7% IVOMD) and low (38.5% IVOMD) qualities had significantly higher dry matter intake and lower enteric CH$_4$ emissions as forage quality increased.

In another study, the authors observed the same phenomenon on pasture (Boadi and Wittenberg, 2002). It can be concluded that enteric CH$_4$ emissions are highest when the animal is presented with poor-quality forage and has limited ability to select higher quality forage components as a consequence of reduced dry matter availability (Ominski and Wittenberg, 2006). In cattle on poor quality forage, a number of essential microbial nutrients may be deficient and microbial growth efficiency in the rumen is low. In these conditions, methane produced may represent 15 to 18% of the digestible energy (Leng, 2009).

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.

Forage species (legume versus grass)

McCaughey et al. (1999) 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 brome grass; cows grazing the alfalfa-grass pastures had significantly greater dry matter intake; lower methane production was observed as compared to their counterparts grazing grass-only pastures. Inclusion of legume-based forages in the diet is
associated with higher digestibility and faster rate of passage resulting in a shift toward high propionate in the rumen and reduced methane production.

Use of legumes in grazing rotations as observed by McCaughey et al. (1999) lower CH\textsubscript{4} emissions (7.1% of GEI) from alfalfa-grass pasture than grass only pastures (9.5% of GEI). Methane yield from the ruminal fermentation of legume and legume-grass forages are also generally lower than the yield from grass forages (Moss et al., 2000). Explanation for the reduced CH\textsubscript{4} emissions can be attributed to the lower proportion of structural carbohydrates in legumes and faster rate of passage which shift the fermentation pattern towards higher propionate production (Alan, 2008). Research from New Zealand (Ramirez-Restropoa and Barry, 2005) suggests that feeding forage legumes like lucerne or red clover also tends to decrease CH\textsubscript{4} losses as compared to grass.

**Pasture/grazing management**

Several Canadian research studies have examined the impact that pasture and grazing management has on enteric CH\textsubscript{4} emissions. A study by McCaughey et al. (1997) reported that CH\textsubscript{4} production was greatest for steers continuously grazing at low stocking rates (1.1 steer per hectare with 307 L per day) and least for steers grazing continuously at high stocking rates (2.2 steers per hectare with 242 L per day).

A possible explanation for these observed results for the higher stocking rate may be due to lower forage availability and intake for the grazing animal. When pastures were rotationally grazed, stocking rates had no effect on CH\textsubscript{4} production. At low stocking rates, CH\textsubscript{4} production was 9% lower on rotational grazing than continuous grazing. Pasture quality is the critical factor in ensuring lower CH\textsubscript{4} emissions from grazing animals in any particular grazing system (Alan, 2008).

**Forage preservation and processing**

**Forage preservation method (hay versus silage)**

Shingfield et al. (2002) reported that the intensity of ruminal fermentation was quantitatively influenced by the method of preservation of alfalfa; total and individual VFA productions were lower with alfalfa silage compared to alfalfa hay. Total methane production was depressed (33%) by the utilization of alfalfa silage instead of alfalfa hay. Fractions of GE intake and DE lost as methane were also lower (32 and 28%, respectively) with alfalfa silage than with alfalfa hay.

The same author explains that the highest CH\textsubscript{4} losses reported in the literature is associated with feeding ryegrass silage and lotus silage. This would not be unexpected since digestion is reduced in the rumen with ensiled forages due to the extensive fermentation that occurs during silage making. Often, silage additives such as bacterial inoculants and organic acids are added to the ensiling process to enhance the quality and palatability. These ensiling additives can lower acetic acid and increase propionate production and thereby reducing enteric CH\textsubscript{4} emissions.

**Processing of forage**

The physical form of feed (particularly roughages) is another factor which influences the extent of methanogenesis: a whole pelleted diet tends to reduce CH\textsubscript{4} production. Grinding of forages to improve the utilization by ruminants has been shown to decrease CH\textsubscript{4} losses per unit of feed intake by 20 to 40% when fed at high intakes (Johnson et al., 1996).

The explanation for the decline in CH\textsubscript{4} production is due to the lower fibre digestibility, decreased ruminally available organic matter and faster rate of passage associated with ground or pelleted forages (LeLiboux and Peyraud, 1999). The main limitation to the potential use of more processed forage feed to reduce CH\textsubscript{4} emission is the economical cost to cattle producers.

Formation of end-products of fermentation in the rumen was also affected by processing of hay: pelleting alfalfa hay decreased VFA production. Methane production was reduced (20%) by the physical treatment of hay. Similarly, methane losses reported as 21 and 13% respectively of GE intake and DE were depressed by processing of alfalfa hay (Alan, 2008).

**Forage maturity**

It is recognized that CH\textsubscript{4} production in ruminants generally increases with forage maturity (Moss et al., 2000). In contrast, a study by Pinares-Patino et al. (2003) evaluated beef cows grazing on a non-specific pasture of timothy at four stages of maturity: early vegetative, heading, flowering and senescence observed organic matter intake and CH\textsubscript{4} emissions lower only at heading.

The effect of forage maturity on methane production was evaluated using a diet based on 100% alfalfa hay harvested at two different stages of maturity: vegetative and mid-bloom. The replacement of the mid-bloom alfalfa hay with the vegetative hay had a small effect (4%) on methane production. Boadi et al. (2002) observed early grazing of alfalfa-grass pastures reduced CH\textsubscript{4} production by 29 to 45% in steers as compared to grazing at mid and late seasons.

**Concentrates**

Compared to forages, concentrates are usually lower in cell wall components. Due to the presence of non-structural carbohydrates (starch and sugars), concentrates normally
ferment faster than forages, giving rise to elevated levels of propionic acid. Veen (2000) suggest that CH₄ production can be lowered by almost 40% (from 272 to 170 g/day) when a forage rich diet is replaced by a concentrate rich diet. Increasing the dietary proportion of concentrates usually reduces CH₄ losses. The CH₄ reduction observed by Bannink et al. (1997) showed that concentrate rich diets have lower and higher coefficients of conversion of substrate into acetate and propionate respectively.

Concentrates and concentrate ingredients are quite variable with regard to their content of structural (cellulose, hemicelluloses) and non-structural (starch, sugars) carbohydrates. The degradative behaviour of both groups of carbohydrates also varies widely, notably the rate of degradation of starch. Consequently, VFA profile and CH₄ loss vary accordingly. All carbohydrate fractions yielded CH₄, but the highest contribution to CH₄ losses came from sugars. The low proportion of GEI lost as CH₄ was probably caused by a propionate type of rumen fermentation, the very low figure for the corn based diet must have resulted from a larger proportion of starch in corn escaping digestion in the rumen. Feeding more concentrates per animal, especially those with a higher amount of (rumen resistant) starch and less sugars has a very positive effect on the reduction of CH₄ losses (Tamminga et al., 2007).

Addition of fats and oil to ruminant diets

There are a number of mechanisms that can affect the rumen fermentation process within the animal that subsequently will reduce enteric CH₄ emissions. A number of recent reviews on this subject (Boadi et al., 2004; Omsinski and Wittenberg, 2006) are available that evaluate the pros and cons of the addition of fats to cattle diets, ionophores, defumation, bacteriocins, probiotics, and use of alternative hydrogen acceptors or sinks (that is, organic acids: malate and fumarate etc) to mitigate CH₄ emissions. It is known that there is a reduction in the amount of feed fermented with additions of fats. Methane emission was reduced by 33% when 4% canola oil was added to a diet containing 85% concentrate in a feedlot study (Karin, 2001). Adding oils to dairy diets has also been recommended as a way to reduce CH₄ losses.

According to Veen (2000), possibilities to include more fat in dairy diets is limited, because feeding fat of animal origin is forbidden and many vegetable fats often do stimulate milk production, but have a negative influence on fat and protein content of the milk. According to this author, attention should be paid to the use of fish oils, because there are indications that they might reduce CH₄ emission without showing a negative effect on cell wall digestibility in the rumen.

In beef cattle, the addition of sunflower oil (400 g per day) decreased CH₄ emissions by 22% with no negative effect on DM intake, but reductions in DM and NDF digestibility were 9 and 23% respectively (McGinn et al., 2004). Currently, oil prices are rising because of the increasing demands for oil by booming economies in Asia and political instability of oil producing regions. High oil prices reduce the chances of vegetable fats and oils as a cost-effective measure to reduce CH₄ losses.

Among the feeding factors able to reduce CH₄ emission by ruminants, particularly cattle, fat-rich feeds have a certain interest, presumably more for their high net energy content than for their ability to reduce methanogenesis. Results of adding fats to diets of cattle on CH₄ emission are variable and seem to be influenced by the type of FA (chain length, degree of unsaturation), the type of animal (beef versus dairy cattle), the type of diet (forage versus concentrate rich), and the length of the experimental period. Next to reduced CH₄ losses, reductions in DMI and cell wall digestibility have often been observed (Tamminga et al., 2007).

Feeding additives

Several bioactive compounds among which were essential oils, ionophores, saponin containing plant extracts, surfactants and tannins were investigated in vitro for their protozoa reducing activity (Hristov et al., 2003). Ionophores, notably monensin, have been suggested as depressing agents for CH₄ production in ruminants and were discussed by Moss et al. (2000).

Organic acids

A number of feed additives have shown potential as inhibitors of CH₄ in vitro experiments (Tamminga et al., 2007). A number of recent reviews on this subject (Boadi et al., 2004; Omsinski and Wittenberg, 2006) are available that evaluate the addition of organic acids (malate and fumarate etc) to cattle diets and use of alternative hydrogen acceptors or sinks to mitigate CH₄ emissions.

Organic acids (malate, fumarate) have been assayed as diet additives. In vivo results are inconsistent. An exceptional decrease in methane production by 75% has been shown by Wallace et al. (2006) with 10% encapsulated fumaric acid in the diet of sheep, but the hydrogen used to produce propionate from fumarate is not enough to explain such a drop in methane. Further research is needed with such a product (Martin et al., 2009).

It has also been suggested that the addition of organic acids and the intermediates of carbohydrate degradation in the rumen would stimulate the production of propionic acid in the rumen and could reduce CH₄ losses (Castillo et al., 2004), by acting as a H₂ sink. Newbold et al. (2005) tested 15 potential precursors of propionate, including pyruvate, lactate, fumarate, acrylate, malate and citrate in short-term batch cultures.
Sodium acrylate and sodium fumarate produced the most consistent effect decreasing CH$_4$ production by between 8 and 17%. Free acids rather than salts were more effective in reducing CH$_4$, but also decreased pH with possible negative effects on fibre degradation. In longer term (21 days) in vitro incubations and fumarate addition decreased CH$_4$ production by 28% whilst maintaining DM degradation, whereas malate was not effective.

**Ionophores**

Some feed additives, such as the ionophores, reduce CH$_4$ production after their inclusion in the diet. 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. Although, ionophore supplementation may reduce methane emissions by 20 to 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 (Johnson et al., 1996).

**Plant secondary metabolites**

To protect themselves against microbial and insect attack, plants produce a variety of secondary compounds. Some of them are also toxic to animals, but others are not. Research on the effect of plant secondary metabolites, notably condensed tannins (Ramirez-Restropo and Barry, 2005), essential oils and saponins (Wallace, 2004), is receiving much attention these days, primarily with the aim that secondary plant metabolites can possibly replace antimicrobials.

As a side effect, in some instances inhibiting effects on CH$_4$ have been observed, most likely mediated through an effect on rumen protozoa. In recent years, there is growing interest in the use of plant secondary compounds (tannins and saponins) as a CH$_4$ mitigation strategy because of their natural origin in opposition to chemical additives. Most trials with plant extracts have been done in vitro and the response of these molecules on methanogenesis is highly variable.

**Condensed tannins**

A number of plant secondary metabolites have shown some potential as inhibitors of CH$_4$ in vitro experiments. This seems notably the case with condensed tannins that reduced CH$_4$ losses both in vitro and in vivo experiments (Tamminga et al., 2007). In New Zealand sheep, housed indoors and fed with different forages (lucerne, sulla, red clover, cichory and lotus), CH$_4$ losses were reduced by between 20 and 55% as compared to animals pastured on ryegrass/white clover mixtures (Ramirez-Restropo and Barry, 2005). In goats fed with the condensed tannin containing forage sericea lespedeza, Puchala et al. (2005) observed in Oklahoma (USA) a reduction in CH$_4$ loss of over 30%.

**Saponins**

Saponins are naturally occurring surface-active glycosides, occurring in many plant species, wild plants as well as, cultivated crops. They usually consist of a sugar moiety linked to a hydrophobic compound, either triterpenoid or steroid in nature (Francis et al., 2002). Saponin containing plants and their extracts has been shown to suppress the bacteriolytic activity of rumen ciliate protozoa (Moss et al., 2000). Saponins are considered to have detrimental effects on protozoa through their binding with sterols present on the protozoal surface (Francis et al., 2002). Because of their anti protozoal activity, saponins might have the potential to reduce CH$_4$.

**Supplementation of molasses block**

Research in the past 20 years has clearly illustrated that supplementation of cattle on low quality forage based diets increases productivity through increasing efficiency of feed utilization (Leng, 1990). A mixture of nutrients as can be supplied for instance in molasses urea multi-nutrient block lick ensures an efficient microbial digestion in the rumen. A small amount of protein meal that is directly available to the animal (that is, by-pass protein) stimulates both productivity and efficiency of feed utilization (the evidence and theory is discussed.

Provision of molasses urea blocks to draught oxen which in general receive only straw in most developing countries will have a major effect on methane production, reducing it to perhaps half the present production rate (Leng, 2009).
different nutritional strategies to reduce methane emissions from ruminant animals. These methods include: improving the quality of forage, improving grazing practices, use of rotational grazing instead of continuous grazing, inclusion of legumes in legume forage mixes, feeding highly digestible forages, processing and preservation of feeds and adding fat and oils. The choice of application of the potential mitigation strategies and adoption into the industry will primarily depend on the cost associated with it. Strategies that are cost effective and have no potential negative effects on livestock production hold a greater promise.

RECOMMENDATION

In order to reduce the methane emission those feeding strategies, land use change for grazing and land degradation (Alemayehu, 2008) should be getting focus through integrated research and extension approach.

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