Livestock-environment interactions: Methane emissions from ruminants

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Livestock producers face a number of challenges including pressure from the public to be good environmental stewards and adopt welfare-friendly practices. However, environmental stewardship and animal welfare may have excitingly conflicting objectives. Examples include pasture-based dairy and beef cattle production where high-fiber diets increase methane emissions compared with grain feeding practices in confinement. Livestock account for 35-40% of global anthropogenic emissions of methane, via enteric fermentation and manure, which together account for about 80% of the agricultural emissions. Recent estimates indicate that the methane emissions from African cattle, goats, and sheep are likely to increase from their current level of about 7.8 million tons of methane per year in 2000 to 11.1 million tons per year by 2030, largely driven by increase in livestock numbers. This paper therefore reviews certain areas of CH₄ emissions from ruminants, highlights on how some novel feed additives can decrease CH₄ emissions from ruminants; and how some plants secondary metabolites might act as a selective inhibitor of methanogens. An enteric methane emission (which is one of the greenhouse gases) represents an economic loss to the farmer where feed is converted to CH₄ rather than to product output. As developing countries are now responsible for almost three-quarters of such emissions, this has important implications in terms of mitigation strategies, because these countries are presently outside the remit of the Kyoto Protocol.

Key words: Environment, CH₄ emissions, feed additives, mitigation, ruminants.

INTRODUCTION

Livestock producers face a number of challenges including pressure from the public to be good environmental stewards and adopt welfare-friendly practices. They often implement practices beyond those required from a regulatory standpoint to meet the demands of consumers. Ruminant livestock has been recognized as a major contributor to greenhouse gases (Steinfeld et al., 2006). Livestock account for mainly 80% of all emissions from the agricultural sector. Emissions into the air by any animal production system can be problematic in terms of pollutants and toxicity and in terms of odour and the perception of air quality by human neighbours. The three major greenhouse gases are carbon dioxide, methane and nitrous oxide. Methane has a positive radiative force on the climate; the global warming potential of methane is 21-times that of CO₂ over 100 years (UNFCCC, 2007), albeit it is much shorter-lived in the atmosphere. It also has serious impact on high atmosphere ozone formation. It is important to reduce methane production from the rumen, because methanogenesis corresponds to 2-12% of dietary energy loss (Czerkawski, 1969) as well as contributing to global warming. Enteric methane emissions represent an economic loss to the farmer where feed is converted to CH₄ rather than to product output (CCTP, 2005). Livestock accounts for 35-40% of the global anthropogenic emissions of methane, via enteric fermentation and manure (Steinfeld et al., 2006). Recent estimates by Herrero et al. (2008) indicate that methane emissions from African cattle, goats and sheep are likely to increase from their current level of about 7.8 million tons of methane per year in 2000 to 11.1 million tons per year by 2030; largely driven by increase in livestock

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numbers. Again, there are considerable differences in methane emission per tropical livestock unit (TLU, 250 kg body weight), depending on the production system and diet, from 21 (less productive systems) to 40 (more productive systems) kg per TLU per year. Developing countries are responsible for almost three-quarters of the enteric methane emissions. Developing countries are now responsible for almost three-quarters of the enteric methane emissions which have important implications in terms of mitigation strategies.

This paper therefore, reviews certain aspects of enteric methane emissions from ruminants, how some novel feed additives can decrease CH₄ emissions from ruminants and how some plants secondary metabolites can act as a selective inhibitor of methanogens.

METHANOGENIC ARCHAEA

The methanogenic archaebacteria constitute a large and diverse group of Archaebacteria (Boone et al., 1993). Methanogenic species were cultured from the rumen for enumeration and isolation of methanogens (Table 1). They have unique features that separate them from bacteria and the eukaryotes (Balch et al., 1979; Woese et al., 1990). The methanogens are the only recognized ruminal microbes belonging to the Archaebacteria and are an integral part of the rumen microbial ecosystem (Hungate, 1966; Miller, 1995; Wolin, 1979). By scavenging hydrogen gas, methanogens play a key ecological role in keeping the partial pressure of hydrogen low so that fermentation can proceed efficiently (Wolin, 1982; Wolin et al., 1997). Although about 70 methanogenic species belonging to 21 genera have been identified from anaerobic environments, and a range of different methanogens co-exist in the rumen (Jarvis et al., 2000; Sharp et al., 1998; Tajima et al., 2001; Whitford et al., 2001), to date only seven ruminal species have been isolated and purified. The population densities of methanogens in the rumen appear to be influenced by diet and in particular by the fibre content of the diet (Kirchhessner et al., 1995). Sheep and cattle fed diets rich in concentrates contained 10⁷-10⁸ and 10⁵-10⁶ cfu ruminal methanogens/g, respectively (Morvan et al., 1996; Leedle and Greening, 1988). The methanogens classified as archaebacteria have a distinctly different cell wall structure from true rumen bacteria (Woese et al.1990).

METHANE MITIGATION STRATEGIES

Enteric methane emissions by ruminants are more amenable to mitigation. Enteric methane emissions is a major source of greenhouse gas in agriculture, and is formed in the rumen through a process called enteric fermentation. During this normal digestive process, hydrogen is released by other microbes during fermentation of forage and is used by methanogenic archaebacteria (that is methanogens) to convert carbon dioxide to methane. The majorities (80%) of all emissions come from ruminants; because this methane comes from point sources and is related to poor nutrition and livestock numbers, a range of mitigation options are available (Joblin, 1996). Methane emitted from grazing animals can now be accurately measured (Lassey et al., 1997), so mitigation strategies can be tested and monitored in the field.

Although a number of enteric methane mitigation strategies exist, following Clemens and Ahlgrimm (2001), such strategies can be broadly divided into ‘preventive’ and ‘end of pipe’ options. Preventive measures tend to reduce carbon/nitrogen inputs into the system of animal husbandry, generally through dietary manipulation, and while a reduction in the volume of CH₄ emitted per animal may result, this is often secondary to the primary objective of improved productive efficiency (Ulyatt and Lassey 2000; GIA 2008). More intensive feeding regimes can have a marked impact on CH₄ emissions (Lerner and Matthews, 1988), while carefully tailored feed and forage management practices can equally result in substantive cuts in enteric methane production. Van Caeseele (2002), for example, cites research suggesting that high quality forage can reduce per capita emissions by up to 50%; cattle grazing on mixed alfalfa-grass pasture produce lower emissions per head than those grazing on grass-only pasture and rotational grazing are superior to continuous grazing vis-à-vis methane production.

Moss (1992) found that augmenting the volume of starches (rumen resistant) in the diet curtailed CH₄ discharges, while Grainger et al. (2008) suggested that whole cottonseed appears to be a promising dietary supplement in methane emission mitigation. Equally, improving metabolic efficiency through the enforced ingestion of growth promoting hormones produces comparable reductions in methane releases (Bauman et al., 1985), although the effect may only be temporary as there is evidence to suggest that the rumen ecosystem adapts to new feed environment. Onanong et al. (2009) established that the roughage-to-concentrate ratios, as well as the supplementation of soapberry fruit-mango-steen peel pellets containing condensed tannins and saponins, caused changes in ruminal microorganisms and their fermentation end-products. This led to the decrease in methane production.

Microbial-intervention strategies have the advantage over improved nutrition strategies in that they do not require a reduction in animal numbers to achieve a reduction in methane emissions. Also, they can be used in conjunction with improved-nutrition strategies. Potential intervention sites for methane mitigation have been identified (Joblin 1996), and outlined in Figure 1. Apart from being effective, methane mitigation strategies must be suitable for on-farm application. The strategies should be safe, practicable, leave no residues in meat and milk, be cost effective and be applicable to grazing animals.
Table 1. Methanogenic species cultured from the rumen.

<table>
<thead>
<tr>
<th>Genus and species</th>
<th>Morphology</th>
<th>Host</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanobacterium</td>
<td>Long rods, filaments</td>
<td>Bovine, ovine</td>
<td>Jarvis et al. (2000), Oppermann et al. (1957), G. N. Jarvis and K. N. Joblin unpublished data</td>
</tr>
<tr>
<td>formicicum</td>
<td>Gram variable</td>
<td>Bovine</td>
<td>P. Evans and K. N. Joblin, unpublished data</td>
</tr>
<tr>
<td>bryantii</td>
<td>Gram variable</td>
<td>Bovine, ovine,</td>
<td>Smith and Hungate (1958), G.N. Jarvis and K.N. Joblin, unpublished data</td>
</tr>
<tr>
<td>Methanobrevibacter</td>
<td>Coccobacilli</td>
<td>Bovine, ovine,</td>
<td>Smith and Hungate (1958), G.N. Jarvis and K.N. Joblin, unpublished data</td>
</tr>
<tr>
<td>ruminantium</td>
<td>Gram +ve</td>
<td>Corvine</td>
<td>K. N. Joblin and D. M. Pacheco, unpublished data</td>
</tr>
<tr>
<td>smithii</td>
<td>Gram +ve</td>
<td>Ovine</td>
<td>K. N. Joblin and D. M. Pacheco, unpublished data</td>
</tr>
<tr>
<td>Methanomicrobium</td>
<td>Motile curved rods</td>
<td>Bovine</td>
<td>Jarvis et al. (2000), Paynter and Hungate (1968)</td>
</tr>
<tr>
<td>mobile</td>
<td>Gram –ve</td>
<td>Caprine, bovine</td>
<td>Beijer (1952), Patterson and Hespell (1979)</td>
</tr>
<tr>
<td>Methanosarcina</td>
<td>Pseudosarcina</td>
<td>Bovine</td>
<td>Jarvis et al. (2000)</td>
</tr>
<tr>
<td>barkeri</td>
<td></td>
<td>Caprine, bovine</td>
<td>G. N. Jarvis, L. C. Skillman and K. N. Joblin, unpublished data</td>
</tr>
<tr>
<td>Methanoculleus</td>
<td>Irregular cocci</td>
<td>Cervine</td>
<td>G. N. Jarvis, L. C. Skillman and K. N. Joblin, unpublished data</td>
</tr>
<tr>
<td>olentangyi</td>
<td>Gram –ve</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

+ve, positive; -ve, negative.

Formation of Methane by Microbes in the rumen

![Figure 1](image-url)

**Figure 1.** Schematic outline of steps involved in methane formation in the rumen and potential intervention sites for lowering methane emissions (Joblin, 1999).

Potential intervention sites for methane mitigation have been identified (Joblin, 1996) and these include interventions to decrease the hydrogen upon which methanogens feed, the development of alternative hydrogen sinks (Joblin, 1999), the administration of anti-methanogens, and the removal of protozoa. The 'end of pipe' options which is equally called the 'novel feed additives' option is used to reduce or inhibit the production of methane.
(methanogenesis) from ruminants. Such options include
the application of ionophores, propionate enhancers, me-
thane oxidizers, halogenated methane analogues, defau-
nating agents, and probiotics as feed additives (Moss et
al., 2000; McAllister and Newbold, 2008), although con-
cerns have been expressed that the volumes required to
effectively curb emission levels are likely to prove toxic to
the animal, interfere materially with digestive processes
and/or be uneconomic to apply (Ulyatt and Lassey,
2000). A different strategy, highlighted by Shu et al.
(1999) and Baker (cited by Moss et al., 2000), involves
immunizing livestock using anti-methanogenic vaccines,
although such research is currently in its infancy. Kamra
et al. (2008) reported in vitro studies of plant extracts
having anti-methanogenic or anti-protozoal activities.
Also, Wood et al. (2009) reported in vitro studies of using
encapsulated fumaric acid in ruminal fluid of sheep to
suppress methane formation by 19%, and 76% decrease in trial with growing lambs. Plant extracts rich in
saponins and tannins have been established to have anti-
methanogenic activity.

**RECOMMENDATIONS**

There has been minimal adaptation of practices to speci-
fically reduce methane emissions from livestock and to
safeguard the environment. The following recommendations
will go a long way to drastically reduce enteric methane emissions from ruminants:

High-grain diets: Feeding of high-grain diets to reduce
methane emissions and increase animal production effi-
ciency, without contributing to the animal health problems
that are typically associated with high-grain diets is
recommended.

Ruminal fermentation time: Methane is released from
the rumen where feed is fermented in an anaerobic envi-
ronment. The shorter the period of time feed remains in
the rumen, the less carbon is converted to methane.
Residence time in the rumen can be shortened by in-
creasing the digestibility of feed grains or forages and
by feeding on concentrated supplements.

Alternate hydrogen acceptors: Addition of unsaturated
edible oils in feed may be used to reduce methane emis-
sions by sequestering hydrogen making it unavailable for
methanogens.

Improvement in production efficiency: Any practice that
increases productivity per animal reduces methane emis-
sions. Animal technologies that increase productivity
include genetic improvement of animal performance,
genetic improvement of pasture and other feedstuffs
potential, improved animal feed-handling practices, im-
poved pasture nutritional and water management, and
early marketing of animals.

Modification of bacteria in the rumen: Alteration of
ruminal microbes may lead to significant reduction in
methane emissions; however, considerable research is
needed to genetically produce microbes that can com-
pete with natural microbes for sustained time periods.

Plant extracts (saponins and tannins) used as novel
feed additives are able to decrease the number of hydrogen producers such as protozoa in the rumen. This
is a promising way for the future.

Fumarate and malate (dicarboxylic acids) stimulate
hydrogen use for propionate synthesis at the expense of
methane in the rumen. These products naturally found in
plants open promising perspective. Dietary encapsulated
fumaric acid decrease methane formation by 76% in the
trial with growing lambs. This is also are very promising
findings that should be explored by feed manufacturers
and livestock farmers.

**CONCLUSION**

Essentially, we must be aware of the fact that any lives-
tock production system that meets the goals of social
responsibility in terms of animal welfare or other societal
concerns may also have some negative impacts on the
environment that must be recognized in order to be
addressed. The manipulation of the ruminal fermentation
has tremendous potential for improving animal physi-
ology, nutrition and subsequently, production. It is im-
portant to reduce the enteric methane emissions from rumi-
nants, because methanogenesis corresponds to dietary
energy loss as well as contributes to global warming.
Therefore, in considering ethical animal production prac-
tices, special consideration needs to be given to the
impacts of the system on the environment.

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