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Review

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 2003, largely driven by increase in livestock numbers. This paper therefore reviews certain areas of CH_4 emissions from ruminants, highlights on how some novel feed additives can decrease CH_4 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 CH_4 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, CH_4 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 stand-point 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 carbondioxide, methane and nitrous oxide. Methane has a positive radiative force on the climate; the global warming potential of methane is 21-times that of CO_2 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 CH_4 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 CH_4 emissions from ruminants and how some plants secondary metabolites can act as a selective inhibitor of methanogens.

METHANOGENIC ARCHAEA

The methanogenic archaea constitute a large and diverse group of Archaea (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 Archaea 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 (Kirchgessner et al., 1995). Sheep and cattle fed diets rich in concentrates contained 10^7-10^8 and 10^8-10^9 cfu ruminal methanogens/g, respectively (Morvan et al., 1996; Leedle and Greening, 1988). The methanogens classified as archaea 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 archaea (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 CH_4 emitted per animal may result, this is often secondary to the primary objecttive of improved productive efficiency (Ulyatt and Lassey 2000; GIA 2008). More intensive feeding regimes can have a marked impact on CH_4 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 CH_4 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-mangosteen 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.

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 (1957), G. N. Jarvis and K. N. Joblin unpublished data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bryantii	Gram variable	Bovine	P. Evans and K. N. Joblin, unpublished data
Methanobrevibacter	Coccobacilli	Bovine, ovine,	Smith and Hungate (1958), G.N. Jarvis and K.N. Joblin, unpublished data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smithii	Gram +ve	Ovine	K. N. Joblin and D. M. Pacheco, unpublished data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

+ve, positive; -ve, negative.

Formation of Methane by Microbes in the rumen

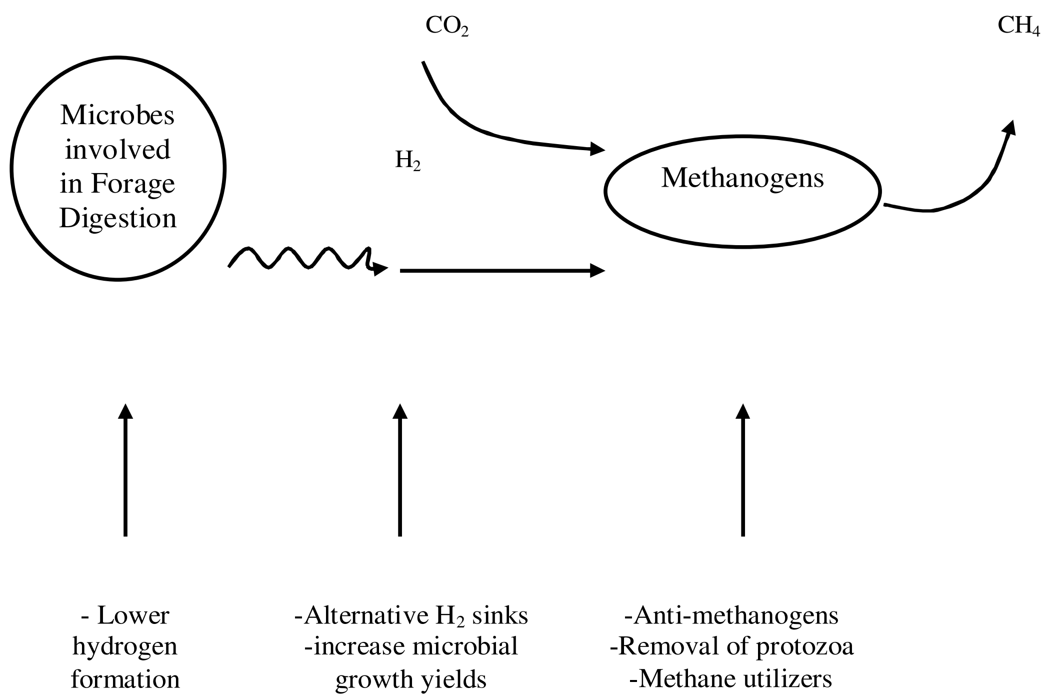

Figure 1. Schematic outline of steps involved in methane formation in the rumen and potential intervention sites for lowering methane emissions (Joblin, 1999).

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, methane oxidizers, halogenated methane analogues, defaunating agents, and probiotics as feed additives (Moss et al., 2000; Mc Allister and Newbold, 2008), although concerns 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 suppressed 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 specifically 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 efficiency, 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 environment. 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 increasing 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 emissions by sequestering hydrogen making it unavailable for methanogens.

Improvement in production efficiency: Any practice that increases productivity per animal reduces methane emissions. Animal technologies that increase productivity include genetic improvement of animal performance, genetic improvement of pasture and other feedstuffs potential, improved animal feed-handling practices, improved 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 compete 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 livestock 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 physiology, nutrition and subsequently, production. It is important to reduce the enteric methane emissions from ruminants, because methanogenesis corresponds to dietary energy loss as well as contributes to global warming. Therefore, in considering ethical animal production practices, special consideration needs to be given to the impacts of the system on the environment.

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