Enteric Methane Emission and Reduction Strategies in Sheep

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Abstract

Climate change is associated with the anthropogenic emissions of greenhouse gases (GHGs) like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) is widely evident throughout the world. CH_4 is considered one of the major GHGs, 20 times more potent than CO_2, contributing to 15–20% of total global GHG emission. Sheep and goat produce enteric CH_4 through the microbial degradation of feed. Globally, livestock sector produces approximately 80 Tg CH_4 per year through enteric fermentation. Of the total CH_4 production, 11 Tg is from Indian subcontinent, which corresponds to 14% of total global CH_4 production. Indian goat and sheep breeds produce 10.1 and 11.6 g/head/d CH_4 respectively. In the era of changing climate, it is very essential to have strategies that can reduce the CH_4 emission and improve the animal production. Among the various CH_4 mitigation strategies, dietary or nutritional interventions are most suitable and adoptable with no detrimental impacts on animal health. Other CH_4 mitigation strategies like biotechnological intervention and feed additives may fail due to the diversity in rumen micro fauna. A global vision of production systems should be taken into consideration while implementing the strategies to reduce the impact of CH_4 on global warming. All GHG emissions from the animal up to the farm scale as well as grassland use must be considered, and this is very essential to find a global solution.

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Global warming • Ionophores • Methane • Probiotics • Saponin • Sheep • Tannin

Contents

13.1 Introduction

Climate change associated with the anthropogenic emissions of greenhouse gases (GHGs) like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) is widely evident throughout the world. The GHG layer in the atmosphere is more or less transparent to incoming short-wave radiation, but it is opaque to the outgoing long-wave radiation and reflects back to the earth surface, resulting in abnormal warming of the earth surface called greenhouse effect (IPCC 2001). CH_4 is one of the major GHGs contributing to around 15–20% of total global GHG emission, and its global warming potential (GWP) is 20 times more than CO_2. Sheep and goat produce enteric methane through the microbial degradation of feed. Bacteria, protozoa and fungi (primary digestive microorganisms) together hydrolyze starch, proteins and plant cell wall polymers into simple amino acids and sugars. Further, these amino acids and sugars are fermented to volatile fatty acids (VFA; acetate, propionate and butyrate), hydrogen (H_2) and CO_2. Hydrogen, the gas responsible for CH_4 production, is produced by microorganisms which produce acetic acid during the fermentation. Butyrate is the other VFA responsible for CH_4 production, whereas production of propionate consumes H_2, making H_2 unavailable for CH_4 production, which causes dietary energy loss. Table 13.1 describes the enteric CH_4 emission in sheep and goat.

Globally, livestock sector produces approximately 80 Tg CH_4 per year through enteric fermentation (Cynoweth 1996). Of the total CH_4 production, 11 Tg is from Indian subcontinent, which corresponds to 14% of total global CH_4 production. CH_4 is responsible for 18% of the global atmosphere warming (Fig. 13.1). According to Singh (1997), Indian goat and sheep breeds produce 10.1 and 11.6 g/head/d CH_4 respectively. Globally, 700 g/kg of CH_4 is released into the atmosphere through anthropogenic activities, of which agriculture sector accounts for about two-third, with enteric methane fermentation contributing one-third of CH_4 from agriculture

Table 13.1 Estimates of methane emissions from sheep and goat

Animal type and region ($\times 10^{-6}$)	World Pop.	CH_4 Prod. (kg/hd/year)	Total CH_4 Prod.[b]
Sheep			
Developed countries[a]	400	8	3.2
Goats	476	5	2.4

Adapted from Crutzen et al. (1986)

[a] Includes Brazil and Argentina

[b] Total estimate for emissions from domestic animals has an uncertainty factor of ±15%

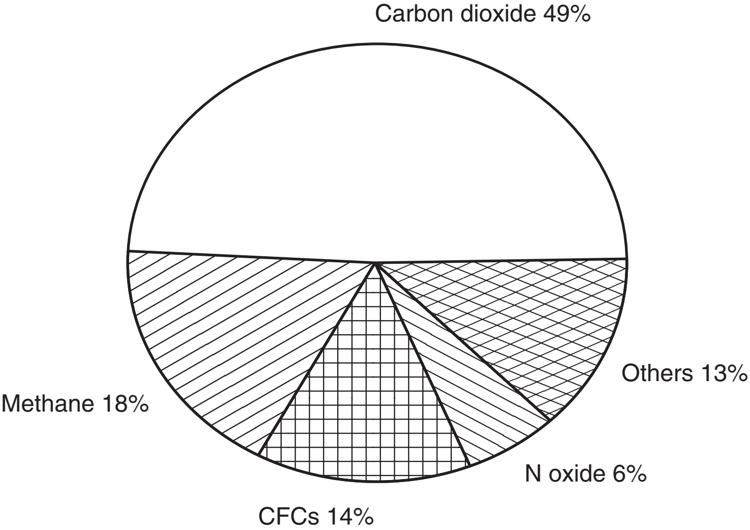

Fig. 13.1 Relative contribution (%) of greenhouse gases to atmospheric warming (Source: World Resources Institute)

sector (Moss et al. 2000). According to the reports of 1996, world population of the sheep and goat are estimated to be around 1057 million and 677 million respectively (Morand-Fehr and Boyazoglu 1999) and annually one sheep releases 9 kg CH_4 (Mbanzamihigo et al. 2002). Further, sheep and goat together emit 200 g/kg of CH_4 through enteric methane fermentation. In addition to the GHG emission and global warming issues, release of CH_4 through enteric CH_4 fermentation indirectly causes loss of dietary energy (20–150 kJ/MJ) (Johnson and Johnson 1995). This chapter is an attempt to discuss in detail the various enteric CH_4 reduction strategies in sheep. Efforts have been made to address the role of sheep in contributing to global warming and the various options that are available within the rumen to target for reducing the enteric CH_4 emission in sheep. In addition, emphasis has been given for identifying different strategies and these strategies are explained in detail with appropriate examples which might help sheep industries in reducing CH_4 emission and for optimizing their productivity by preventing the dietary energy loss.

13.2 Consequences of Global Warming

Figure 13.2 depicts the trend in atmospheric CH_4 accumulation. Even with the current global warming rate of 0.8 °C, deleterious impacts are already evident on both global economy and ecology. Arctic Ocean ice masses are already shrunken to half from 1970s level (Stroeve et al. 2007). Simultaneously, volume of ice is also decreasing with thinning of ice sheets (Kwok et al. 2009). An increase in the temperature by 4 °C or more can change the earth system and its natural resources and ecological services. Increase in the frequency of extreme events, rise in sea level and loss of biodiversity are some of the other consequences of global warming. Thermal expansion of ocean and glacier melt water influx are the two largest contributors to the rise in sea level (Rahmstorf et al. 2007). Global sea level is rising very rapidly and has risen by about 20 cm. Scientists also projected a rise of 50–150 cm by the end of 2100 (Rahmstorf et al. 2007). In addition to this, IPCC projected an increase in the frequency of weather events like drought, heat waves, intensified rainfall events, floods and hurricanes (IPCC 2007). Loss of species and genetic diversity is also expected with 2 °C rise in temperature. Adaptive and regenerative capacity of the nature will be destabilized with 20–30% loss of genetic diversity as per IPCC prediction. Further, Mangroves and coral reefs will face detrimental impacts. In addition, the climate change impacts will also be evident on all natural resources such as drinking water and animal genetic resources.

Any perturbations in the normal functioning of the climate system can lead to huge ecological calamities like unexpected cessations of ocean currents, sudden shifts in the monsoonal circulation and destabilization of large glacier masses (Lenton et al. 2008). Even 1.9 °C increase in the temperature can lead to the entire Greenland ice sheet melting and it can further contribute to 7 m rise in sea level (IPCC 2007).

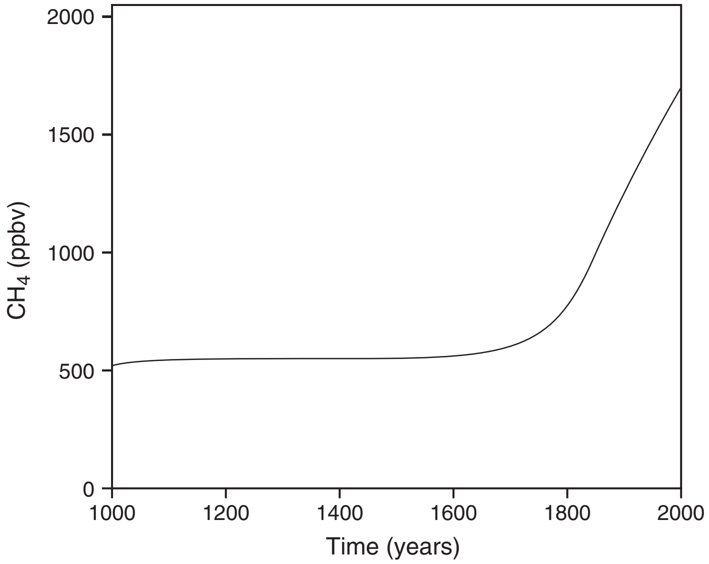

Fig. 13.2 Trends in atmospheric methane accumulation (Khalil and Rasmussen 1986)

13.3 Effect of Climate Change on Livestock

Climate change can have severe impacts on livestock which can be categorized into direct and indirect effects. By far the production losses are primarily incurred through indirect impact. The compromised quantity as well as the quality of feed during summer season might affect the livestock production systems. Climate change can have significant effect on the trade of finished lambs both by altering the lambing time of ewes and by affecting the forage growth pattern during spring season (Rowlinson 2008). Table 13.2 describes the impact of climate change on livestock and its production system.

Table 13.2 Impacts of climate change on livestock and livestock systems

Factor	Impacts
Feeds	*Land use and system change*
	As climate changes and becomes more variable, species niches also change. May modify animal diets and compromise the ability of stallholders to manage feed deficits
	Changes in the primary productivity of crops, forages and rangeland
	Effects depend significantly on location, system and species. But in C4 species, temperature increase up to 30–35 °C may increase productivity of crops, fodders and pastures
	For food-feed crops, harvest indexes will change and so will the quantity of stover and availability of metabolizable energy for dry season feeding
	In the semi-arid rangelands where contractions in the growing season are likely, rangeland productivity will decrease
	Quality of plant material
	Increased temperatures increase lignifications of plant tissues and thus reduce the digestibility and the rates of degradation of plant species. The resultant reduction in livestock production may have an impact on food security and incomes of smallholders
	Interactions between primary productivity and quality of grasslands will demand modifications in grazing systems management to attain production objectives
Biodiversity	In places, warming accelerates the loss of genetic and cultural diversity in agriculture already occurring as a result of globalization, in crops and domestic animals.
	A 2.5 °C increase in global temperature above pre-industrial levels will see major losses; 20–30% of all plant and animal species assessed could be at high risk of extinction (IPCC 2007)
	Ecosystems and species show a wide range of vulnerabilities to climate change
Livestock	Major impacts on vector-borne diseases: expansion of vector populations into cooler areas or into more temperate zones.
	Increases the heat-related mortality and morbidity in livestock

Thornton et al. (2009, 2008)

13.3.1 Direct Effects

Direct effects of climate change on livestock production are caused by alterations in the climatic variables such as temperature, humidity, precipitation and wind speed. Different animals (ruminants and non-ruminants) respond to variations in the ambient temperature differently based on their range of comfort zone. Ruminant animals are blessed with wide range of comfort zone and higher level of temperature tolerance, so narrow fluctuations in the ambient temperature do not have any significant effects in their performance. As per IPCC projections, areas that are currently wet will become wetter and dry regions will become drier in future. So the areas with low temperature and high precipitation will become more suitable for the sheep production because of the higher rate of their survival. At the same time, production performance of dairy cows and buffaloes in the tropical dry regions can be hampered due to increase in ambient temperature. To counter the detrimental effects of elevated ambient temperature, animals should be provided with adequate amount of water and shade. However, unlike the ruminants, non-ruminants possess a very narrow range of comfort zone. This is one of the main reasons for keeping pig and poultry under an intensive system of rearing so that the farmers can effectively manage these animals. During winter season, these houses may serve as source of cold protection to the animals. However, existing housing systems may not be sufficient to counter the detrimental effects of heat stress. Air conditioning/cooler systems should be established in order to cool the animals during summer. In addition, there were issues associated with the transport of live animals during summer season when the environmental temperature is at the peak. Although experts feel that the direct effects of climate change on the animal are likely to be small, still they feel efforts are needed to breed for thermo-tolerance by effectively utilizing the indigenous germplasm (Rowlinson 2008).

13.3.2 Indirect Effects

13.3.2.1 Nutrition and Feeding

Climate change is widely believed to have multiple impacts on the pasture and grazing systems available for the animals (Hopkins and Del Prado 2007); these include:

- The change in CO_2 concentration drastically affecting the herbage growth
- The composition of pastures as well as the ration of grasses and legumes availability are altered
- The alteration in the concentration of water-soluble carbohydrates and N might alter the herbage quality and total dry matter (DM) yields
- The drought condition during summer season might again affect the DM yields
- Increased N leaching as a result of greater intensity of rainfall

It is very unlikely that climate change would bring in any changes in the composition of feed that is offered to sheep. The least cost ration formulation tool offers huge scope for changing the ingredients without altering the specifications of the nutrients that are needed for a particular species. Practices do exists pertaining to including imported ingredients and high quality by-products in the ration formulation. The forage component is a major component of diet in ruminants, and this differs with the rearing system, with the forage making up the entire diet in extensive system of rearing as compared to intensive system where concentrate supplementation forms an equal part of the diet along with forages. Climate change is expected to have negative impact on the source of forages that are available to feed ruminant species, and it was projected that both quality and quantity of forages were found to be compromised. This may play a role in impacting the available forage resources and a lot of changes are expected on the forage species which are yet to be explored. The dry matter production is compromised particularly in the winter season. Therefore, the expected increase in temperature is believed to have benefits for early seasonal growth in mixed pasture. Further, the increased rainfall in certain areas can increase the soil moisture deficits, which may again affect the dry matter yield, and this warrants additional irrigation to restore the appropriate growth of pasture. The altered climate may affect the stage of maturity of crop before harvesting, and this can affect both the quality and the quantity of existing species. Again, improving the microclimate might help to reverse this condition. However, in hilly areas which are characterized by low temperature, climate change is expected to increase the pasture production and this might have a positive impact on animal production.

In a few regions, climate change may lead to shifting in the forage species by increasing the hectare of grown crop, which might help to meet the requirement in other regions during scarcity period. However, in arid and semi-arid regions in certain instances the palatable species might be replaced by non-palatable species, resulting in lower edible biomass for the animals.

13.4 Methane Mitigation in Sheep

Enteric CH_4 mitigation from sheep could have double benefit of preventing the global warming as well as preventing the dietary energy loss. There are various approaches by which reduction in enteric CH_4 emission is targeted: inducing changes in metabolic pathways, altering the rumen microbial population and improving the diet digestibility potential.

During the digestion process in the anaerobic condition in rumen, hydrogen is released in the process of generation of energy in the form of ATP. Free hydrogen that is liberated during the process of digestion must therefore be removed; otherwise, it inhibits dehydrogenases and affects fermentation process. The type of diet and the type of rumen microbes decide the amount of hydrogen produced in the rumen. The type of VFAs that are produced in the rumen determines the quantum of free hydrogen remaining in the rumen. For example, production of propionate consumes hydrogen molecule, while production of acetate and butyrate releases hydrogen molecules. Therefore, targeting propionate to be the end product of digestion could serve as alternate hydrogen sink in the rumen. Further, the process of

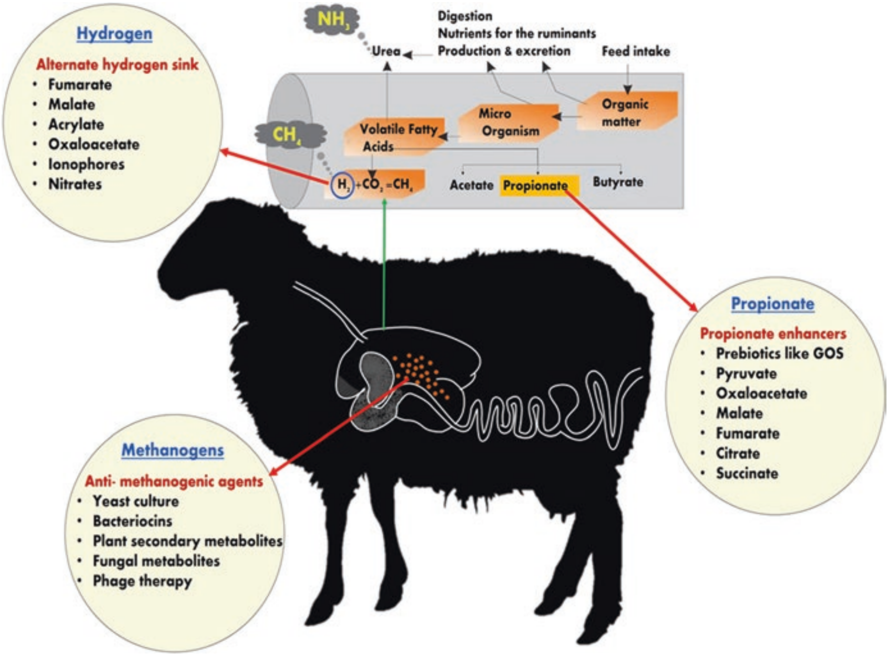

Fig. 13.3 Different mechanisms of enteric methane reduction in sheep

methanogenesis also utilizes hydrogen to form CH_4. The formation of CH_4 from hydrogen and CO_2 is brought about by methanogenic archaea. Figure 13.3 describes the different mechanisms by which enteric CH_4 can be reduced in sheep.

There are three pathways by which enteric CH_4 reduction could be achieved: (1) provision of hydrogen sink; (2) supplementing with anti-methanogenic agents and (3) supplementing with propionate enhancers. Care should be taken that reduction of hydrogen production should be achieved without affecting the fermentation process. Therefore, reducing methanogenic population should be targeted with concomitant stimulation of pathways that consume hydrogen to prevent the negative effects associated with increased partial pressure of this gas. Figure 13.4 describes the different CH_4 mitigation strategies in sheep.

13.4.1 Mitigation Through Feeding

13.4.1.1 Increased Proportion of Concentrates in the Diet of the Animal

Alteration of ruminal pH with intent to modify ruminal microbial population has been widely practised to reduce enteric CH_4 emission. One such attempt is to replace plant fibre with starch, thereby decreasing the ruminal pH to alter the microbial population. The protozoa and cellulolytic bacteria do not tolerate low pH, thereby

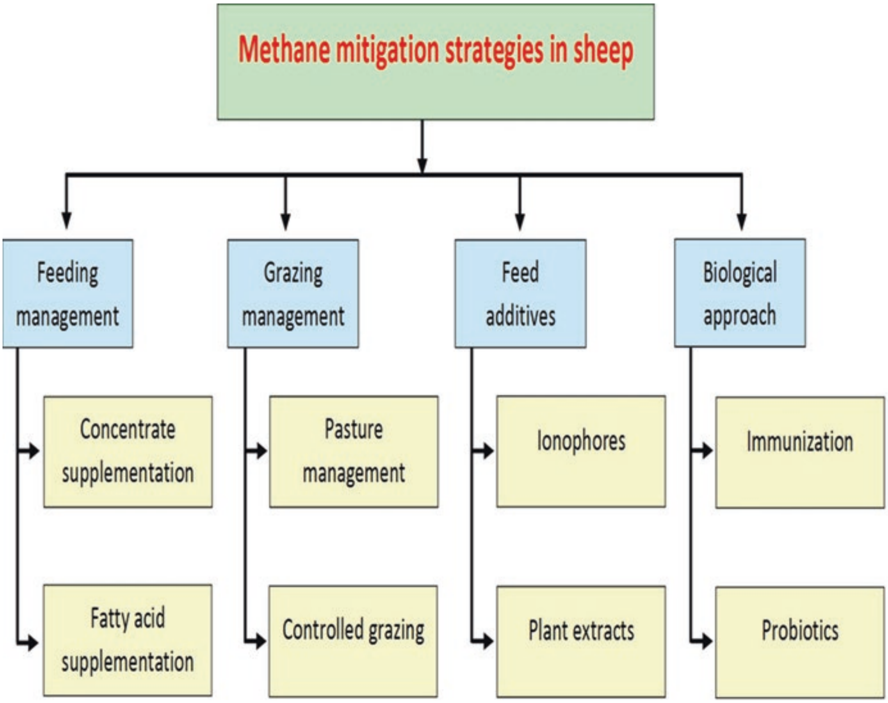

Fig. 13.4 Different methane mitigation strategies in sheep

leading to lower production of H_2. With the exception of buffalo, a strong positive correlation has been established in different animal species between ruminal pH and mocrobial population (Morvan et al. 1996). This particular exemption in buffalo could be attributed to the presence of non-H_2-producing cellulolytic bacteria *F. succinogenes*. Generally a curvilinear relationship has been established between the levels of concentrate in the diet. The concentrate supplementation brings about CH_4 reduction by altering the VFA production (Bhatta et al. 2005). It has been established that increased concentrate supplementation leads to more propionate production, thereby reducing the enteric CH_4 emission as propionate acts as alternate H_2 sink (Sauvant and Giger-Reverdin 2007). Further, the level of dietary starch is also correlated with CH_4 production during concentrate supplementation. Generally the diet containing starch content of 40% and above decreases CH_4 production by over 56% (Martin et al. 2007). However, the level of concentrate should be balanced as over-supplementation leads to acidosis in the rumen. This drawback of acidosis could be reversed through dietary fat supplementation to depress ruminal methanogenesis without reducing the ruminal pH. Generally, medium-chained fatty acids were found to be more effective in altering the methanogen population as compared to long-chain fatty acids (Machmuller et al. 2003). Poly unsaturated fatty acids (PUFA) can also depress CH_4 production by eliciting toxic effect to the cellulolytic bacteria and protozoa (Nagaraja et al. 1997; Doreau and Ferlay 1995). This toxic effect of PUFA could be attributed to its action on the cell membrane of gram-positive bacteria. Further, it has been established that linolenic acid has toxic effect on the bacteria. All these changes in the microbial population shift the ruminal fermentation towards propionate production, thereby leading to more utilization of H_2. The limitation of fat supplementation is that the microbial population may tend to adapt to fat supplementation in a long run. This warrants future research efforts in exploring fatty-acid-supplementation-oriented enteric CH_4 reduction without allowing microbes to adapt for such supplementation (Grainger et al. 2008).

13.4.2 Grazing Management Practices

13.4.2.1 Pasture Management

Improved pasture management is often considered as a reliable option for reducing enteric CH_4 emission. Quality pasture can reduce emission either through improving the animal productivity or by reducing the proportion of energy lost. There is evidence showing reduced CH_4 emission per unit of quality pasture consumed in temperate region as compared to tropical region (Molano and Clark 2008). However, there are also reports suggesting no impact of pasture quality on CH_4 reduction potent. These results suggest that well-managed pastures do not invariably lead to CH_4 reduction but it could curb lifetime CH_4 emission or emission per kilogram of product. Increased stocking densities as a result of improved pastures could increase emission rate per hectare. In a study conducted on an Australian sheep farm, Alcock and Hegarty (2006) reported a very low level of CH_4 reduction on body weight basis. The reason for the less reduction of CH_4 in their study could be attributed to the high productivity of sheep on individual basis in their farm. However, Lovett et al. (2006a, b) reported the influence of soil types, with higher milk yield and lower GHG emission per kilogram of milk produced when dairy cows grazed in the drier soils.

13.4.2.2 Controlled Grazing

Implementing controlled grazing system is considered as one of the best ways to improve the sheep productivity. This approach could yield higher proportion of quality forage as compared to conventional grazing practices. The latest developments pertaining to new fencing and watering technologies offer huge scopes for the farmers and entrepreneurs to develop their grazing systems. The uninterrupted use of grazing land by sheep throughout the grazing season can be achieved through management practices of continuous stocking. Such system most often fails to maximize the productive potential of the land, leading to forage wastage, less pasture productivity and lower weight gain per unit of land. Rather, controlled grazing is considered to be a better management strategy to produce a more productive grazing system. In this grazing system the grazing land is subdivided into individual grazing units called paddocks, which are alternatively grazed and rested throughout the grazing system. Pasture productivity, stocking density and the desired residency period of the sheep are the factors which will determine the size and number of paddocks. Therefore the controlled grazing system is better placed than the conventional grazing system to maintain an effective balance between forage demand and supply. As a result, controlled grazing system has several advantages such as promoting higher forage yield, uniform level of forage quality and improved harvest efficiencies. These advantages make controlled grazing system more effective in producing more productive sheep with greater body weight gain per acre, thereby improving the economy of sheep farms while reducing the rate of CH_4 emission per kilogram body weight gain. Further, controlled grazing system has another notable advantage of acting as a natural sink for CO_2. The improved pasture quality in the controlled grazing can build up the carbon in the soil and plant biomass, leading to reduced CO_2 emission to the atmosphere. However, in semi-arid region where the growing of the vegetation takes place from July–September and withers off in October–November, this practice has no relevance. Similarly, when the majority of the sheep are reared under an extensive system of rearing and there is migration during acute summer, this option is not feasible.

13.4.3 Mitigation Through Feed Additives

13.4.3.1 Ionophores and Organic Acids

Monensin, the common ionophore antibiotics used to improve the animal production efficiency, is considered as one of the best feed additives which has the properties to reduce enteric CH_4 emission (Beauchemin et al. 2008). This reduction in CH_4 emission by monensin is brought about by shifting the fermentation pattern towards propionogenesis. Further, organic acids such as malate and fumarate are other feed additives that could help to reduce enteric CH_4 emission in sheep. Wallace et al. (2006) reported an exceptional CH_4 reduction percentage of around 75 on supplementing 10% encapsulated fumeric acid in sheep diet. Further, Martin et al. (1999) reported that malate content of fresh forages such as lucerne can lead to enteric CH_4 reduction by changing the rumen fermentation pattern. Similar results were also reported by Bhatta et al. (2008) in sheep.

13.4.3.2 Plant Extracts

The use of plant secondary metabolites such as tannins, saponins and essential oils to reduce enteric CH_4 emission is gaining importance in recent years as these metabolites are of natural origin as compared to chemical additives (Bhatta et al. 2002, 2006). The mechanism of CH_4 reduction using tannin supplementation is brought about by two pathways recently: direct anti-methanogenic effect and indirect pathway of less hydrogen production through reduced feed degradation. Bhatta et al. (2009a) observed direct reduction in methanogenesis by tannin supplementation by two ways: directly by reducing the number of archaea and indirectly by reducing the number of protozoa. The source containing both condensed and hydrolysable tannins is more effective in suppressing CH_4 emission as compared to those containing only hydrolysable tannins. This was further confirmed by feeding trials in goats kept in an open circuit respiration chamber. It was observed that at lower level of tannin (2.5%), CH_4 suppression was primarily due to the reduction in the number of archaea/protozoa, whereas at higher levels of tannin (5.0%), increased CH_4 suppression was due to the combined effect of reduced archaea coupled with reduction in digestibility of nutrients (Bhatta et al. 2009a, b). The inhibitory effect of saponins on CH_4 reduction could be attributed to its anti-protozoal effect (Newbold et al. 1987). However, further research efforts are needed to identify the exact dose of plant extract supplementation which could prevent rumen microbial adaptation to avoid the presence of residues of such additives in animal products and to nullify anti-nutritional side effects of such supplementation.

13.4.4 Mitigation Through Biotechnologies

13.4.4.1 Immunization and Biological Control

The latest biotechnological tools are currently being explored for finding solution through sheep-mediated climate change. However, substantial progress has not been made in this aspect primarily due to multiple factors influencing enteric CH_4 production. In a study carried out in Australian sheep, a vaccine against three methanogens was developed, through which a decrease in CH_4 production by 8% was reported. However, such a vaccine was found to be ineffective against other methanogens (Wright et al. 2004). Further, the diversified microbial population depending on the feeding conditions may also contribute for this vaccine failure. There are also reports which identified the role of bacteriocins for enteric CH_4 reduction. Nisin is one such bacteriocin which was predicted to have CH_4 reduction potential in animals by mimicking the role of ionophore monensin (Callaway et al. 1997). However, there are no published reports on the effects of nisin for enteric CH_4 reduction under in vivo condition. Bovicin HC5 is a type of bacteriocin produced from rumen bacteria and is used for reducing the CH_4 production up to 50% under in vitro condition preventing adaptation of methanogens.

13.4.4.2 Probiotics

Another interesting approach for reducing enteric CH_4 emission is achieved through probiotics supplementation. There are also efforts to deviate H_2 from methanogenesis to acetogenesis pathway since the final end product acetate of this pathway can act as additional source of energy for the animals. However, acetogens were found to be less efficient than methanogens in the competition for reducing equivalents in the rumen further, and several attempts to boost their activity were found to be unsuccessful. There are also attempts to isolate new H_2-utilizing species which may be considered as a better alternative than already tested acetogens (Klieve and Joblin 2007).

13.5 Can Genetic Improvement of Sheep Reduce Methane Emission?

Increasing the level of production in the sheep through the identification and enhanced modification of heritable traits could help to decrease the overall CH_4 emission. Improving the feed conversion efficiency could help to reduce enteric CH_4 emission by increasing the animal productivity and this is the typical example of how a heritable trait could be used to minimize CH_4 emission in sheep. There are also strategies combining improved genetics with good management practices to increase the reproductive efficiency. Increased lambing rates and weaning weights through such attempts could curb CH_4 emission per unit of product. This is because the increased reproductive efficiency reduces the size of the flock to produce the desired number of lambs as the consumer demand can be met through fewer but efficient sheep. More emphasis should be given to conduct research pertaining to genetic improvement in an attempt to increase the overall productivity of sheep and at the same time reduce the enteric CH_4 emission.

13.6 Is There Any Animal Variation in Methane Production?

There are ongoing debates around the world pertaining to decreasing emission through low-CH_4-producing animals. Very high variability for CH_4 production have been established within the animal and ranking of animals based on CH_4 production potential may differ with diet composition and physiological status of the animals or between two successive measurements of same diet and feed intake (Pinares-Patino et al. 2007a; Munger and Kreuzer 2008). These authors have established repeatability between 47 and 73% based on the type of diet used for the animals, and this repeatability could be attributed either to the animal differences in microbial ecosystems or to intrinsic animal characteristics suc as retention time in the rumen. This is because animals with low retention time might produce less CH_4 in the rumen (Pinares-Patino et al. 2007a, b). However, there are no much research reports available to assess the heritability of CH_4 production and to apply such trait for genetic selection. In a study, Hegarty et al. (2007) established that selection of animals based on feed conversion efficiency residual feed intake could reduce CH_4 production.

13.7 Conclusion

There are several strategies available for enteric CH_4 mitigation. Currently, feeding management strategies are widely used to reduce CH_4 emission in sheep. There are also promising advanced biotechnological strategies available in sheep but their applications in the field condition are limited because of the wide variation in the diet composition and wider diversity in rumen microbial population. Strategies pertaining to improving the production efficiency of sheep might yield better results in terms of reducing the enteric CH_4 emission in sheep.

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