



Mitigating Enteric Methane Emission from Livestock Through Farmer-Friendly Practices

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Abstract

Enteric methane emission in ruminants in addition to being an environmental pollutant causes a loss of 10–11% of the total gross energy intake of the animal. The various strategies available to mitigate enteric methane emission include management strategies, feeding strategies, rumen manipulation and advanced strategies. Feeding strategies are practical approaches to mitigate enteric methane emission and can be practiced with ease by farmers under field conditions. Various approaches that cause rumen manipulation and thereby reduce enteric methane emission are supplementation of bacteriocins, ionophores, fats, oils, organic acids, probiotics, prebiotics, sulphate, halogenated methane analogues, nitroxy compounds, fungal metabolite, secondary plant metabolites, microalgae and exogenous enzymes. In the Indian context, ruminant livestock are grazed in wastelands or fed with poor-quality agricultural waste, whose digestibility is low, and the nutritional requirement of the animals is not met resulting in poor productivity. Improving per animal productivity is a potent tool to reduce enteric methane emission per unit of product produced, and this can be achieved through ration balancing. As regards the greenhouse gas abatement opportunities, measures to reduce enteric methane production have immense economic and ecological benefits to the farmers.

Keywords

Ruminants · Enteric methane emission · Mitigation · Livestock management · Manure management · Pasture management · Feed management · Rumen manipulation · Secondary metabolites

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8.1 Introduction

The “agriculture, forestry and other land use (AFOLU)” sector releases 10–12 Gt CO₂e per annum. Greenhouse gas emissions from agricultural activities (Fig. 8.1) include “land use changes”; enteric methane emission from ruminants; lowland rice cultivation; N₂O emissions from nitrogenous fertilizer use; and crop residue burning (Lipper et al. 2014; Smith et al. 2014; Venkatramanan and Shah 2019). Methane is a very significant greenhouse gas in view of its global warming potential and atmospheric lifetime. The causes for “increases in CH₄ concentration include natural wetlands emissions (177–284 Tg CH₄ yr⁻¹), agriculture and waste (187–224 Tg CH₄ yr⁻¹), fossil fuel related emissions (85–105 Tg CH₄ yr⁻¹), other natural emissions (61–200 Tg CH₄ yr⁻¹), and biomass and biofuel burning (32–39 Tg CH₄ yr⁻¹)” (Venkatramanan and Shah 2019). Livestock are one of the largest single sources of anthropogenic methane emission in the world. Amongst livestock, ruminants (cattle, buffaloes, sheep and goats) are the principal sources of enteric methane emission.

About 30% of methane emissions at the global level are released from the ruminant activity. In other words, globally, 2.7 Gt of CO₂e of enteric CH₄ per annum are released from the ruminants. As regards the livestock methane emissions, 2.1 Gt (77%) of CO₂e is contributed by cattle, 0.37 Gt (14%) of CO₂e by buffaloes and 0.26 Gt CO₂e by small ruminants like sheep and goats (FAO 2017).

In India, 49.1% of enteric methane was contributed by cattle, 42.8% by buffaloes, 5.38% by goats and 2.59% by sheep. Importantly, during 1961–2010, the increase in methane emissions (70.6%) from livestock population of India is much

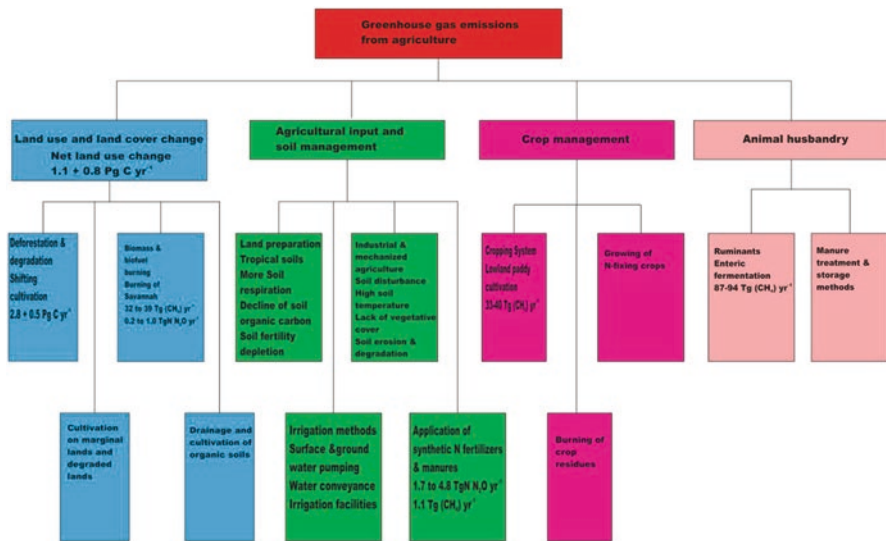


Fig. 8.1 Greenhouse gas emissions from agriculture. The GHG values mentioned represent the annual anthropogenic fluxes in Tg/year averaged over 2000–2009 time period. (Source: Venkatramanan and Shah 2019; GHG values from Ciais et al. 2013)

greater than the increase in methane emissions from livestock population worldwide (54.3%). It is reported that by 2050, about 15.7% of enteric CH₄ emission at the global level will be contributed by the Livestock population of India (Patra 2014). One of the reasons for high enteric methane emission in India is the larger bovine population which emits more methane than any other livestock species. On an average, cattle and buffaloes aggregately emit more than 90% of the total enteric methane emission of the country. The contribution from small ruminants is relatively small and constitutes only 7.7%. Rest of the methane emissions arise from the species such as yak and mithun, which are scattered to specific states only. Enteric methane emission from crossbred cattle is comparatively much more than the emissions from indigenous cattle (46 versus 25 kg/animal/year). Enteric methane emission from livestock is not uniform across the states and varies considerably according to the livestock numbers, species, type of feed and fodders, etc. (Malik et al. 2015).

The National Institute of Animal Nutrition and Physiology, India, has developed a statewise inventory for enteric methane emission from Indian livestock. Their estimates revealed that Uttar Pradesh was the largest enteric methane emitting state and other major methane emitting states were Rajasthan, Madhya Pradesh, Bihar, West Bengal, Maharashtra, Karnataka and Andhra Pradesh. These states altogether have 66% of the total livestock population and are responsible for 68% enteric methane emissions (Bhata et al. 2016).

Enteric methane emission in livestock is a consequence of ruminal/hindgut fermentation. In the reticulo rumen or hindgut of livestock, simple and complex carbohydrates are hydrolyzed to 5 or 6 carbon sugars by enzymes secreted by microbes. These sugars are then fermented to volatile fatty acids through metabolic pathways that produce metabolic hydrogen. The metabolic hydrogen is converted to hydrogen by hydrogenase expressing bacterial species (Methanogens), and the hydrogen is converted to methane by archaea. In fact, the dissolved hydrogen through a negative feedback restrains fermentation pathways occurring in the rumen. Incidentally, the non-removal of dissolved hydrogen can lessen the degradation of carbohydrate, growth rate of microbes, and also the production of microbial protein (Wolin 1974; McAllister and Newbold 2008). Methanogenesis can be regarded as an evolutionary adaptation that enables the rumen ecosystem to dispose of hydrogen, which may otherwise accumulate and inhibit fibre degradation.

Enteric methane emission in ruminants in addition to being an environmental pollutant causes a loss of 10–11% of the total gross energy intake of the animals. Methane mitigation options are therefore associated with improved efficiency of animal production. Thus enteric methane mitigation measures would be advantageous both environmentally and nutritionally.

8.2 Strategies to Mitigate Enteric Methane Emission

There are various strategies available to mitigate enteric methane emission. The strategies may be broadly grouped as management strategies, feeding strategies, rumen manipulation and advanced strategies.

8.2.1 Management Strategies

Management strategies that could be adopted to control enteric methane emission are reducing the ruminant livestock population, breeding management and manure management.

8.2.1.1 Reducing the Ruminant Livestock Population

In underdeveloped and developing nations, agriculture and livestock rearing is a way of life and indeed contributes greatly to the income of the farmers. Nevertheless, unable to maintain and rear high producing ruminants, the small-scale farmers primarily meet their demands by maintaining a large number of livestock which are low producing ruminants (Tarawali et al. 2011). This can increase the total enteric methane emission in a given area. Thus the most effective methane mitigating strategy will be to increase livestock productivity, which may permit reduction in livestock numbers to provide the same product output at a reduced enteric methane emission. Higher animal performance also reduces methane emission because this can lead to a reduction in the number of animals in the production system.

8.2.1.2 Breeding Management

Adopting a superior breeding program to enhance per animal productivity is one of the best options to reduce enteric methane emission as the production of enteric methane is greatly reduced on account of improvement in the productivity of livestock. It is thus important to consider the enteric methane production per unit of the livestock product produced (kg of milk, meat, or wool).

Another school of thought is that genetics influences enteric methane emission in ruminants (Robertson and Waghorn 2002; Pinares-Patino et al. 2007). Different amounts of methane emission per unit intake of the same quality ration at the same level of performance were recorded, and accordingly livestock were categorized as “high” and “low” methane emitters (Pinares-Patino et al. 2007). Genetic selection and breeding of such animals that consume less feed and produce less methane per unit of feed may be one of the management strategies for reduction in methanogenesis.

8.2.1.3 Manure Management

Animal manure from both ruminant and non-ruminant livestock contributes to methane emission. Stored manure is an important source of methane emission (Priano et al. 2014). Manures are organic compounds which on decomposition by anaerobic bacteria transform their carbon skeleton into methane. Production of methane from manure from dairy cattle, beef cattle and dairy ewe was reported to be 33.2, 2.0 and 0.3 kg/head/year, respectively (Merino et al. 2011).

Many factors indeed influence the emission of methane from manure. Physical properties of manure like density, humidity, amount of digestible material and temperature influence methane emission (Priano et al. 2014; Sagggar et al. 2004). The type of ration fed to the animal influences the manure quality and the quantity of methane emitted from it. Methane emissions from manure storage arise only when

animals are intensively reared. When animals are managed on grazing this scenario does not arise. Methane emitted from manures can be greatly reduced by minimizing the duration of storage of manure and giving lesser time for the “microbial fermentation” to take place. Anaerobic digesters are recommended as a mitigation strategy for methane, and are a source of renewable energy as well and provide sanitation opportunities for developing countries.

8.2.2 Feeding Strategies

Feeding strategies are practical approaches to mitigate enteric methane emission and can be practiced with ease by farmers under field conditions. These may include pasture improvement, feed processing, increasing concentrate in ration and strategic supplementation.

8.2.2.1 Pasture Improvement

Enteric methane emission is influenced by the type of forage the animal feeds upon. Animals grazing on mixed pastures, having leguminous forages, emit less methane than animals grazing on grass alone pastures. This effect can be explained by the presence of condensed tannins in legumes (Waghorn 2007).

There is also variation in enteric methane emission of ruminants grazing on tropical or temperate pastures. C_4 grasses in tropical pastures can produce more methane per kg of dry matter ingested than temperate grasses with C_3 photosynthesis. This is due to the poor digestibility of C_4 grasses compared to C_3 grasses (Archimède et al. 2011).

In temperate pastures itself, Boadi et al. (2002) reported less energy loss as methane in steers grazing on pastures during the early period of the grazing season than the mid- and late-grazing period. Pastures rich in grasses with high sugar content are suitable for animal grazing for a simple reason that high sugar-rich grasses promote the growth of rumen microbes resulting in the increased synthesis of microbial protein and decreasing the production of methane. Hence improving pasture quality is another important way by which enteric methane emission can be reduced.

8.2.2.2 Feed Processing

The processing of feeds especially roughages can improve the feeding value by increasing its digestibility and/or by increasing feed intake. Any attempt to increase feed digestibility/intake has potential to reduce enteric methane emission. Improving the nutritive value of low-quality forages/feeds that are fed to ruminants could increase their productivity and consequently reduce methane emissions.

Feed processing techniques may include chaffing and grinding of straws, alkali/ammonia treatment of straws and feed residues and urea-molasses blocks. These processing techniques are reported to check the methane emission from rumen by 10%. The reduction of forage particle size has significant benefits like increasing feed intake and digestibility, increasing microbial activity due to increase in the surface area of the substrate and consequent improvement in the productivity of

livestock (Gerber et al. 2013). Ammoniation or protein supplementation of low-quality forages or crop residues increased methane losses in proportion to digestibility; however methane production per unit of product produced was reduced (Johnson and Johnson 1995). Beauchemin et al. (2008), had stated that methanogenesis was lower on feeding silage compared to feeding hay and was also lower in finely ground feed or pellets compared to roughly processed feed.

8.2.2.3 Increasing Concentrate in Ration

Altering the roughage concentrate ratio of ruminant ration by increasing concentrates at the expense of roughage causes reduction in methane emission. Methane production can be reduced to 3% from 6.5% by feeding ruminants more concentrates (Beauchemin and McGinn 2005).

Higher concentrate feeding decreases fibre (cellulose and hemicellulose) and increases starch which results in significant modifications in both the physiochemical conditions in the rumen and microbial populations. Increase of amylolytic bacteria results in a change in short chain fatty acid production, promoting a proportional increase of propionate and a reduction of acetate which reduces the hydrogen availability in the rumen, causing reduced methane emission (Pereira et al. 2015). Beauchemin and McGinn (2005) reported that beef cattle, fed diets containing mainly corn grain produce about 30% less methane than when fed diets containing mainly barley grain. Methane emission can be reduced by enhancing the nutritive value and digestibility of feed by balancing the ration with addition of concentrate for grazing animals.

This strategy of increasing concentrate in ration to reduce methane emission has its own limitations. In high concentrate rations, increased production of lactic acid could trigger ruminal acidosis, reduce milk fat and shorten the productive life span of animals. Moreover, its economic viability is also questionable. Increasing the concentrate proportion will have negative impact on fibre digestibility which could cause potential loss in production and will also result in increased concentration of fermentable organic matter in manure and is likely to increase methane emissions from stored manure (Lee et al. 2012).

8.2.2.4 Strategic Supplementation

In tropical countries, where ruminant livestock are grazed in wastelands or on very poor-quality pastures or fed with poor-quality agricultural waste, the digestibility of the diet is low and the nutritional requirement of the animals is not met. In this context protein supplementation in the diets increases the nutrient digestibility and significantly decreases methane production in the rumen (Mehra et al. 2006). Balanced diet with inclusion of protein supplements when fed to the lactating cows and buffaloes caused a marked reduction in the methane emission and an observable increase in both the production of milk and fat content in milk (Kannan and Garg 2009). Similar findings were observed when lactating crossbred cows are fed with balanced diet with respect to calcium, phosphorus and protein (Kannan et al. 2011).

8.2.3 Rumen Manipulation

Enteric methane emission from ruminant livestock can be reduced by various approaches that cause rumen manipulation viz., supplementation of bacteriocins, ionophores, fats, oils (Beauchemin et al. 2008), organic acids (Newbold et al. 2005; Wallace et al. 2006), probiotics, prebiotics, sulphate, halogenated methane analogues, nitroxy compounds (Morgavi et al. 2010), fungal metabolites and secondary plant metabolites (Patra et al. 2006; Wallace et al. 2002; Calsamiglia et al. 2007), microalgae, exogenous enzymes, etc.

8.2.3.1 Bacteriocins

Bacteriocins are naturally occurring bacterial products with a bactericidal activity. They are effective as they directly inhibit methanogens and redirect hydrogen to other reductive rumen bacteria such as propionate producer or acetogens. Callaway et al. (1997) have shown that nisin, a food additive, reduces methanogenesis by 36%. However, the organisms developed resistance quickly. This problem can be overcome by the use of bacteriocin of rumen origin. Lee et al. (2002) found that semi-purified bacteriocin inhibits 50% of methane production *in vitro* and methanogens did not show any adaptation to these bacteriocins.

8.2.3.2 Ionophores

Ionophores are generally used as feed additives in order to improve the efficiency of digestion in ruminants. Ionophores include tetronasin, monensin, lasalocid, salinomycin, narasin, lysocellin, etc. These ionophore antibiotics are carboxylic polyether compounds produced by various strains of *Streptomyces*, e.g. monensin by *S. cinnamonensis* and lasalocid by *S. lasoliensis*. Monensin is moderately active against gram-positive bacteria, certain mycobacteria and coccidia, while lasalocid is specifically active against hydrogen producing bacteria and results in higher propionate production which in turn is related to low methane production (Kobayashi et al. 1992).

Ionophores increase the proportion of gram-positive bacteria in the rumen, resulting in a shift in fermentation acids from acetate and butyrate to propionate, and hence decrease the methane production. Several studies were conducted to know the efficacy of monensin in rumen modification. Few studies found the positive mitigating potential of monensin in enteric methane emission. Nevertheless, the ionophore effects on enteric methane emission are ephemeral as the microbes adapt themselves (Kataria 2015).

8.2.3.3 Fats/Oils

Adding fats to the diet can reduce methane emission by lowering ruminal fermentability and also through hydrogenation of unsaturated fats (Johnson and Johnson 1995). As methane is produced in the rumen to act as a hydrogen sink during the fermentation of carbohydrate, polyunsaturated fatty acids (PUFA) having double or triple bonds have potential to be used as hydrogen sinks, because these bonds will get saturated by hydrogen and less hydrogen will be available for methane

production. Adding 4.6% canola oil, a source of unsaturated fat, to a high-forage diet was an effective suppressant of methane, with daily methane emissions decreasing by 32% and methane emissions as a percentage of GE intake decreasing by 21% (Beauchemin and McGinn 2006).

Fat feeding has also been shown to reduce methane through a reduction in protozoal numbers. Methanogenic bacteria are metabolically associated with ciliate protozoa (Newbold et al. 1995), and feeding oil can cause substantial decreases in protozoan populations (Ivan et al. 2004). Rumen protozoans were found to be responsible for higher hydrogen production and also acting as a habitat for the methanogens present in the rumen (Newbold et al. 1995). In defaunated ruminants, the methanogenic bacteria do not get the symbiotic partner and methane synthesis is partially inhibited. On defaunation, the methane production is reduced by 20–50% (Van Nevel and Demeyer 1996) depending on the various factors in the diet of the animal.

8.2.3.4 Organic Acids

Within the rumen, methane represents a terminal hydrogen sink. Propionate production represents an alternative hydrogen sink in normal rumen fermentation, provided sufficient precursors are available. The precursors to propionate production are “pyruvate”, “oxaloacetate”, “malate”, “fumarate” and “succinate”. The propionate can also be produced from pyruvate through an important pathway called acrylate pathway. Organic acids mentioned above have potential to jettison reducing power and thereby methane production can be reduced. Dietary supplementation of dicarboxylic organic acids such as malate, fumarate, aspartate etc. reduces methane production (Martin 1998). These organic acids are converted to succinate or propionate by reduction process, and less hydrogen will be available for methane production.

Addition of fumaric acid decreased methane emissions *in vitro* (Asanuma et al. 1999) and *in vivo* (Bayaru et al. 2001) but not in all studies (McGinn et al. 2004), possibly because of the level of supplementation used. Malate, a potent methane inhibitor, is present in animal feeds like alfalfa (2.9–7.5% of DM) and Bermuda grass (1.9–4.5%), but its level varies with variety and stage of maturity. *In vitro*, continuous rumen culture experiments have shown that adding graded levels of fumarate to fermentations of rye grass pasture substrate linearly depressed methane production while linearly increased propionate production (Kolver et al. 2004). The long-term effects of organic acids on methane mitigation have not been demonstrated. Moreover, the high price of organic acids makes its use uneconomical.

8.2.3.5 Probiotics

Probiotics such as yeast cultures are used to stimulate bacterial activity in the rumen. The probiotics have been shown to stabilize the rumen pH, increase propionate levels and decrease the amount of acetate, methane and ammonia production. Probiotics cause the redirection of hydrogen ions away from methanogenesis and also decrease production of hydrogen during feed fermentation. Addition of *Saccharomyces cerevisiae* reduced methane production *in vitro* (Mutsvangwa et al.

1992). Lactic acid utilizing bacteria like *Megasphaera elsdenii* and *Propionibacterium* spp. and yeast like *S. cerevisiae* have major effects on methanogenesis by decreasing methane (Seo et al. 2010). Chaucheyras et al. (2012) suggested that live yeast cells can stimulate the use of hydrogen by acetogenic strains of ruminal bacteria thereby enhancing the formation of acetate and decreasing the formation of methane.

8.2.3.6 Prebiotics

Prebiotic compounds such as mannan-oligosaccharide (MOS), fructo-oligosaccharide (FOS), galacto-oligosaccharide (Mwenya et al. 2004) enhances propionate production by stimulating *Selenomonas*, *Succinomonas* and *Megasphaera* with inhibition of acetate producers such as *Ruminococcus* and *Butyrivibrio*. The administration of galacto-oligosaccharides has brought about reduction of methane production up to 11%.

8.2.3.7 Sulphate

Sulphate reducing bacteria have the highest affinity to utilize hydrogen in the rumen, even better than methanogens, but the availability of sulphate in the rumen appears to be a limitation. Hegarty (1999) showed that to reduce methane emissions by 50%, about 0.75 moles of sulphate ingestion per day is required. Kamra et al. (2004) observed that sulphate supplementation helps in increasing the production of fibre degrading enzymes and fibre degradation in the rumen. Therefore, for a high fibre ration, sulphate/sulphite supplementation improves fibre degradability and inhibits methanogenesis. However, a proper dose needs to be optimized, as toxic levels of sulphide can be generated on sulphate reduction.

8.2.3.8 Halogenated Methane Analogues

Various halogenated methane analogues have been tried as methane inhibitors. They include carbon tetrachloride, chloral hydrate, trichloroacetamide, DDT, trichloroacetaldehyde, bromochloromethane, chloroform, methylene chloride, methylene bromide, nitrapyrin, hemiacetal of chloral and starch (Haque 2001). Favourable effects on supplementation of these have been reported only in those animals fed on high roughage diets. Bromochloromethane inhibits methane production by reacting with reduced form of vitamin B₁₂ which inhibits methanogenesis.

8.2.3.9 Nitrooxy Compounds

The “3-nitrooxypropanol (NOP)” and “ethyl-3-NOP” were found to possess an important anti-methanogenic property which indeed aids in reducing methane production. In fact, “3-nitrooxypropanol (NOP)” through interference with a co-enzyme (methyl-coenzyme M reductase) of methanogens checks the methanogen growth and thereby reduces methane production. Also, 3-NOP has inhibitory effects against methanogenic archaea without inducing any effects on growth of non-methanogenic bacteria in the rumen (Duin et al. 2016).

8.2.3.10 Fungal Metabolites

Lovastatin which is a secondary fungal metabolite is found to limit the activity of “3-hydroxy-3-methyl glutaryl coenzyme A reductase”. HMG-CoA reductase is an important enzyme involved in the biosynthesis of cholesterol (Jahromi et al. 2013). Rice straw fermented with *Aspergillus terreus* was found to possess lovastatin which was observed to reduce the population of methanogens and production of methane. Saprophytic fungal strains *Mortierella wolfii* were found to be a suitable candidate for the inhibition of the methanogenesis process (Cosgrove et al. 2012). The fungal metabolites, viz. “pravastatin” and “mevastatin”, were observed for reducing the ratio of ruminal acetate to propionate and also reducing the methanogen population (Morgavi et al. 2013).

8.2.3.11 Secondary Plant Metabolites

Plants produce chemicals collectively called as secondary plant metabolites that help in the self-defence of the plant species concerned. Most of these secondary plant metabolites have anti-microbial and anti-methanogenic activity. There are numerous plant extracts each with varying effects on ruminal fermentation and feed digestion (Kamra et al. 2005).

Garlic oil extracted from *Allium sativum* is a complex mixture of many secondary plant products including allicin, diallyl sulfide, diallyl disulfide and allyl mercaptan and a decrease in methane production was observed on supplementing garlic oil (Busquet et al. 2005). Ethanol and water extracts of the bulb of *Allium sativum* (garlic) reduced methane production significantly in the rumen liquor of buffaloes (Patra et al. 2006).

Methanol extract of seed pulp of *Terminalia chebula* (kadukka) reduced methane production significantly in the rumen liquor of buffaloes (Patra et al. 2006). The presence of tannins in *Terminalia chebula* might be responsible for reduction in methane emission. Phenolic acids such as p-coumaric acids, ferulic acids, cinnamic acids and phloretic acids and some monomeric phenolics have been found to decrease methane, acetate and propionate production (Asiegbu et al. 1995). Tannin, an important secondary plant metabolite, was found to be toxic against rumen organisms like protozoans, methanogens and other microbes that degrade the fibrous material. There are reports indicating a decrease in methane emission with dietary addition of condensed tannins or inclusion of condensed tannin containing forage (Carulla et al. 2005). Negative effects on ruminal fibre digestion, which may relate to decreased number of cellulolytic bacteria, formation of condensed tannin complexes that are resistant to enzymatic digestion and impaired substrate adhesion by fibrinolytic microbes, would reduce hydrogen availability to lessen methanogenesis (Carulla et al. 2005). Patra et al. (2006) showed that adding water extracts of neem seeds decreased total rumen volatile fatty acid (VFA) digestibility and also reported antiprotozoal activity.

Essential oils beneficially affect ruminal fermentation, causing an increase in VFA (Castillejos et al. 2005) and decrease in the rate of amino acid deamination (McIntosh et al. 2003). The antimicrobial activity of essential oils and secondary plant metabolites is highly specific, which raises the possibility that these

compounds can be used to target methanogens. McIntosh et al. (2003) reported that growth of the methanogen *Methanobrevibacter smithii* was inhibited when the concentration of essential oil in supplemental product exceeded 1000 ppm.

Saponins have been found to have anti-protozoal and anti-methanogenic activities (Sliwinski et al. 2002). There are plants, which contain saponins such as *Alfalfa* (3–5%), *Sapindus rarak*, *Sapindus mokorossi*, *Yucca schidigera* (4%), *Quillaja saponaria* (10%), etc. that cause a decrease in methane production by 20–60%. Saponins reduce the protozoal population which reduces the inter species hydrogen transfer to the methanogenic bacteria attached to the protozoa, thereby decreases the hydrogen availability to the methanogens.

8.2.3.12 Microalgae

Asparagopsis, a genus of microalgae, even at 2% of total substrate organic matter, was reported to reduce methane production by 99% in, *in vitro* condition. Similarly, *Oedogonium*, a member of filamentous algae, was found to decrease methane production (Machado et al. 2014). Further, *Cystoseira trinodis* and *Dictyota bartayresii*, members of brown algae, are found under *in vitro* conditions to inhibit methane production (Dubois et al. 2013).

8.2.3.13 Exogenous Enzymes

The role of exogenous enzymes in mitigating enteric methane emission has been reviewed with contradictory results. Exogenous enzymes increase fibre digestibility, improves feed efficiency and decreases fermentable organic matter in manure, thus reducing overall methane emission from ruminant production system. However, Chung et al. (2012), reported increased enteric methane emission per unit dry matter intake or milk yield by 10–11% on exogenous enzyme supplementation with endoglucanase and xylanase activity.

8.2.3.14 Defaunation

Ten per cent decrease in enteric methane emission has been reported on defaunation. However, defaunation may have a negative impact on feed digestibility, animal productivity and milk fat content. Practically, it is not possible to maintain defaunated livestock as possibility of the animals getting refaunated always exists.

8.2.4 Advanced Strategies

Advanced strategies can be adopted in technologically advanced livestock farms to mitigate enteric methane emission. Some of the advanced strategies are precision feeding, vaccines that target methanogens, genetic transformation of rumen bacteria and transferring rumen microbiome of low methane emitting ruminants.

8.2.4.1 Precision Feeding

Precision feeding is feeding the livestock with the right feed at the right time, so that it satisfies its nutritional requirement at that point of time. Precision feeding

combines the genetics of the animal with feed management. Precision feeding will improve feed digestibility, feed efficiency and livestock productivity and hence indirectly reduce enteric methane emission. Precision feeding can be adopted only in high value livestock farms that are highly advanced technologically.

8.2.4.2 Vaccines that Target Methanogens

Vaccines have been developed that specifically target methanogens in the rumen. There are immunogenic fractions on the surface of methanogens and antibodies developed against these could curtail methanogenic activity in ruminants (Wedlock et al. 2013). However, the majority of the vaccines have failed due to poor efficacy and low cross-reactivity. The reverse vaccinology technology has provided solution for identifying conserved vaccines. Moreover sequencing the genome of *Methanobacterium ruminantium* has provided data for identifying conserved vaccine targets.

8.2.4.3 Genetic Transformation of Rumen Bacteria

Genetic modification of rumen microorganisms is aimed to alter their fermentation characteristics. Extensive characterization of the molecular genetics of rumen bacteria with high precision is needed for the success of this genetic modification. Even then the viability of the altered organisms in the natural environment is doubtful. Moreover, the product obtained/organism used has to be approved by both national and international regulatory standards.

8.2.4.4 Transferring Rumen Microbiome of Low Methane Emitting Ruminants

Another possibility of mitigating enteric methane emission is through transferring the microbiome of low methane emitters to the rumen of high methane producing ruminants. Such intervention when made in the early stage of life of the calf may have greater stability. Better understanding of host microbiome relations is needed for the success of such a venture.

8.2.4.5 Farmer-Friendly Approaches to Mitigate Enteric Methane Emission

As discussed earlier in this chapter, feeding strategies such as pasture improvement, feed processing, increasing concentrate in ration and strategic supplementation are practical approaches to mitigate enteric methane emission. Farmers can be advised to chaff the forage before feeding it to their livestock. Chaff cutters are available with the farmers, or farmers can purchase them at subsidized cost. Increasing concentrate in ration and strategic supplementation can be achieved through ration balancing. Ration balancing is considered as the practical approach to mitigate enteric methane in the Indian context.

Indian livestock are grazed on very poor-quality tropical pastures or fed on crop residues having a very low nutritive value. Hence the productivity of animals is far below their genetic potential. Improving per animal productivity is a potent tool in reducing enteric methane emission per unit of product produced. Feeding balanced

diets reduced enteric methane emission in terms of g/d and g/kg milk yield by 10.1 and 13.5% respectively, which further reduced the part of dietary gross energy loss as methane by 10.3%. Intestinal flow of microbial nitrogen increased by 51.4 g/d whereas, faecal nitrogen excretion reduced by 19.4% (Garg et al. 2013). Ration balancing shifts the rumen fermentation more towards propionate production and microbial protein production; thus enteric methane emission is reduced. Rumen fermentation efficiency can be improved through critical nutrient supplementation.

8.3 Conclusion

Mitigating enteric methane emissions in ruminants will assist not only in the achievement of international commitments that benefit climate change but also in the improvement of energy utilization efficiency and the performance of livestock. Increasing livestock productivity across production systems increases food security and improves livelihood of farmers. In the perspective of GHG emission management, enteric methane emission reduction through significant gain in productivity is construed as a “lowest-cost option”, and it has positive economic repercussions to the farmers dependent on livestock (Gerber et al. 2013). A country like India cannot afford the energy loss as methane in livestock, as it demands additional feed resources to compensate the loss (Malik et al. 2016).

Livestock farming in India is a low productivity venture. But the demand for livestock products is ever rising. In order to meet the consumer demand for livestock products, farmers rear a large number of livestock, larger than the number that would be economically viable with the available feed resources. More pressure is thus created on availability of feed, and livestock productivity declines further. In this context any increase in productivity resulting in an increased livestock product will lead to increase in employment in livestock enterprises for marketing and distribution of livestock products.

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