

Livestock and Climate Change: Mitigation Strategies to Reduce Methane Production

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1. Introduction

Global warming refers to a significant rise in the planets temperature making it uninhabitable. It happens thus: the earth is warmed by energy from the sun. In order to maintain its temperature, the earth must radiate some of that energy back into the atmosphere. However, certain atmospheric gases form a blanket around the earth, allowing solar radiation to penetrate, but preventing it from escaping. The more these green house gases, the hotter the earth (Sarmah, 2010).

Climate change is seen as a major threat to the survival of many species, ecosystems and the sustainability of livestock production systems in many parts of the world. Green house gases (GHG) are released in the atmosphere both by natural sources and anthropogenic (human related) activities. An attempt has been made in this article to understand the contribution of ruminant livestock to climate change and to identify the mitigation strategies to reduce enteric methane emission in livestock. The GHG emissions from the agriculture sector account for about 25.5% of total global radiative forcing and over 60% of anthropogenic sources. Animal husbandry accounts for 18% of GHG emissions that cause global warming. Reducing the increase of GHG emissions from agriculture, especially livestock production should therefore be a top priority, because it could curb warming fairly rapidly. Methane with the global warming potential of 25 and longer residence time is an important GHG (Wuebbles and Hayhoe 2002; Forster et al. 2007). The rising concentration of CH₄ is strongly correlated with increasing populations, and currently about 70% of its production arises from anthropogenic sources (Moss et al. 2000; IPCC 2007). Ruminant livestock such as cattle, buffalo, sheep and goats contributes the major proportion of total agricultural emission of methane. Although the reduction in GHG emissions from livestock industries is on high priorities, strategies for reducing emissions should not reduce the economic viability of enterprises if they are to find industrial acceptability.

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 (GHGs) are carbondioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O). CH₄ 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 as well as contributing to global warming. Enteric CH₄ emissions represent an economic loss to the farmer where feed is converted to CH₄ rather than to product output.

There is a growing interest in decreasing the potential threat of global warming by reducing emissions of GHGs into the atmosphere (Moss et al., 2000). Agricultural activities contribute significantly to global GHG emissions, namely CO₂, CH₄, N₂O and ammonia (NH₃), which are major GHGs contributing to global warming (IPCC, 2001). There is mounting awareness worldwide of the necessity to protect the environment (Meadows et al., 1992), minimize the contamination of air with CO₂, CH₄, NH₃, and N₂O and other GHGs that contribute to the radiative forcing (Tammaing, 1996). The consequences of increasing the atmospheric concentration of GHGs responsible for the radiative forcing are gradual elevation of average global temperatures, altered viability of plants, animals, insects and microbes with numerous adverse consequences to human well being. The degree to which these changes are projected to occur is dependent upon a reliable GHG policy models with a range of scenarios for the levels of GHG emissions (Moss et al., 2000).

Offering relatively fewer cost-effective options than other sectors such as energy, transport and buildings, agriculture has not yet been a major player in the reduction of GHG emissions (UNFCCC, 2008). Agriculture and livestock are nevertheless poised to play a greater role in post-2012 climate agreements (UNFCCC, 2008), and indeed wide-ranging policy action will certainly be needed (McAlpine et al., 2009). Adapting to climate change and reducing GHG emissions may require significant changes in production technology and farming systems that could affect productivity. Many viable opportunities exist for reducing methane emissions from enteric fermentation in ruminant animals and from livestock manure management facilities. To be considered viable, these emissions reduction strategies must be consistent with the continued economic viability of the producer, and must accommodate cultural factors that affect livestock ownership and management.

2. Sources of GHGs from agriculture and livestock

CH₄ is emitted from a variety of anthropogenic and natural sources. More than 70 percent of global CH₄ emissions are related to anthropogenic activities. Anthropogenic sources include fossil fuel production and use, animal husbandry (enteric fermentation in livestock and manure management), paddy rice cultivation, biomass burning, and waste management. Emissions from enteric fermentation of the domestic livestock contribute significantly to GHGs inventories. Emissions from animal facilities primarily consist of animal respiration and enteric fermentation. In addition, emissions from manure storage are also believed to be a potential source of CH₄ (Sejian et al., 2011a).

3. Impact of global warming

Many impacts of global warming are already detectable. As glaciers retreat, the sea level rises, the tundra thaws, hurricanes and other natural calamities occur more frequently, and penguins, polar bears, and other species struggle to survive (Topping, 2007), experts anticipate even greater increases in the intensity and prevalence of these changes as the 21st century brings rises in GHG emissions (Sarmah, 2010). The five warmest years since the

1890s were 1998, 2002, 2003, 2004, and 2005 (NASA, 2006). Indeed, average global temperature have risen considerably, and the Intergovernmental panel on climate change (IPCC, 2007a) predicts increases of 1.8-3.9°C (3.2-7.1° F) 2100. These temperature rises are much greater than those seen during the last century, when average temperatures rose only 0.06° C (0.12F) decade (NOAA, 2007). Since the mid -1970s, however, the rate of increase in temperature rise has tripled. The IPCC 's latest report (IPCC, 2007b) warns that climate change " could lead to some impacts that are abrupt or irreversible." According to FAOSTAT (FAO, 2008) globally approximately, 56 billion land animals are reared and slaughtered for human consumption annually, and livestock inventories are expected to double by 2050, with most increases occurring in the developing world (Steinfeld et al., 2006). As the numbers of farm animal reared for meat, egg and dairy production rise, so do their GHG emissions (Sarmah, 2010).

4. Livestock and climate change

The major global warming potential (GWP) of livestock production worldwide comes from the natural life processes of the animals. Table 1 describes the salient features of the three major GHGs. Methane production appears to be a major issue although it presently contributes only 18 % of the overall warming. It is accumulating at a faster rate, and is apparently responsible for a small proportion of the depletion of the protective ozone layer. Methane arises largely from natural anaerobic ecosystems, rice/paddy field and fermentative digestion in ruminant animal. In fact, CH₄ is considered to be the largest potential contributor to the global warming phenomenon (Johnson et al., 2002; Steinfeld et al., 2006). It is an important component of GHG in the atmosphere, and is associated with animal husbandry (Leng 1993; Moss et al., 2000). Much of the global GHG emissions currently come from enteric fermentation and manure from grazing animals and traditional small-scale mixed farming in developing countries. The development of management strategies to mitigate CH₄ emissions from ruminant livestock is possible and desirable. Not only can the enhanced utilization of dietary 'C', improve energy utilization and feed efficiency hence animal productivity, but a decrease in CH₄ emissions and also reduce the contribution of ruminant livestock to the global CH₄ inventory.

GHG	Chemical Formula	Lifetime (years)	Radiative efficiency (W m ⁻² ppb ⁻¹)	Global Warming Potential
Carbon dioxide	CO ₂	Up to 100 years	1.4 x 10 ⁻⁵	1
Methane	CH ₄	12	3.7 x 10 ⁻⁴	23
Nitrous Oxide	N ₂ O	114	3.03 x 10 ⁻³	310

Table 1. Global warming potential (GWP) of the GHGs

5. Enteric methane production

Livestock are reared throughout the world, and are an important agricultural product in virtually every country. CH₄ is emitted as a by-product of the normal livestock digestive process, in which microbes resident in the animal's digestive system ferment the feed consumed by the animal. This fermentation process, also known as enteric fermentation,

produces CH₄ as a by-product. The CH₄ is then eructated or exhaled by the animal. Within livestock, ruminant livestock (cattle, buffalo, sheep, and goats) are the primary source of emissions. Other livestock (swine and horses) are of lesser importance for nearly all countries. The number of animals and the type and amount of feed consumed are the primary drivers affecting emissions. Consequently, improvements in management practices and changes in demand for livestock products (mainly meat and dairy products) will affect future CH₄ emissions.

Among the livestock, cattle population contributes most towards enteric CH₄ production (Johnson & Johnson, 1995). Enteric fermentation emissions for cattle are estimated by multiplying the emission factor for each species by the relevant cattle populations. The emissions factors are an estimate of the amount of CH₄ produced (kg) per animal, and are based on animal and feed characteristics data, average energy requirement of the animal, the average feed intake to satisfy the energy requirements, and the quality of the feed consumed. The district or country level emission from enteric fermentation is computed as a product of the livestock population under each category and its emission coefficient (Chhabra et al. 2009). The emission coefficients for CH₄ emissions from enteric fermentation are country-specific, and these coefficients should conform to IPCC guidelines (IPCC, 2007b).

5.1 Contribution of ruminants to GHGs through enteric methane emission

Ruminant livestock such as cattle, buffalo, sheep and goats contributes the major proportion of total agricultural emission of methane (Leng, 1993; Lassey, 2007; Chhabra et al., 2009). Ruminants are categorized by the presence of rumen, a special digestive organ, in the body. Besides having unique ability to digest fibrous and low grade roughages/plant material, it is also a major producer of methane, a potent green house gas. The enteric fermentation in rumen is highly useful for humankind because it converts coarse and fibrous plants into food and fiber for humankind. However, enteric fermentation in rumen also produces methane through bacterial breakdown of feeds called as methanogenesis. The animals release methane into atmosphere through exhaling or ruminating through mouth or nostrils. Methane production and release accounts for release of digestible energy to atmosphere and therefore inefficient utilization of feed energy. Enteric fermentation also produces volatile fatty acids. Among the volatile fatty acids, acetate and butyrate promote methane production. Global emission of methane from the digestion process of ruminants is about 80 Million tones per year (Gibbs & Johnson, 1994) and considered to be single largest source of anthropogenic methane emission (IPCC, 2001). Methane emission from ruminants provides enough scope of easy and practical management for reduction in methane emission (McMichael et al., 2007).

5.2 Enteric fermentation-process description

Enteric fermentation is the digestive process in herbivores animals by which carbohydrates are broken down by micro-organisms into simple molecules for absorption into the bloodstream. CH₄ is produced as a waste product of this fermentation process. CH₄ production through enteric fermentation is of concern worldwide for its contribution to the accumulation of greenhouse gases in the atmosphere, as well as its waste of fed

energy for the animal. CH₄ is produced in the rumen and hindgut of animals by a group of *Archaea* known collectively as methanogens, which belong to the phylum *Euryarcheota*. Among livestock, CH₄ production is greatest in ruminants, as methanogens are able to produce CH₄ freely through the normal process of feed digestion. Ruminant animals are the principal source of emissions because they produce the most CH₄ per unit of feed consumed. What makes ruminant animals unique is their “fore-stomach” or rumen, a large, muscular organ. The rumen is characterized as a large fermentation vat where approximately 200 species and strains of micro organisms are present. The microbes ferment the plant material consumed by the animal through a process known as enteric fermentation. The products of this fermentation provide the animal with the nutrients it needs to survive, enabling ruminant animals to subsist on coarse plant material. CH₄ is produced as a byproduct of the fermentation and is expelled. “Monogastric” animals produce small amounts of CH₄ as the result of incidental fermentation that takes place during the digestion process. “Non-ruminant herbivores” produce CH₄ at a rate that is between monogastric and ruminant animals. Although these animals do not have a rumen, significant fermentation takes place in the large intestine, allowing significant digestion and use of plant material.

Methane producing bacteria reside in the reticulo-rumen and large intestine of ruminant livestock. These bacteria, commonly referred to as methanogens, use a range of substrates produced during the primary stages of fermentation to produce CH₄, thus creating generated energy required for their growth. All methanogen species can utilize hydrogen ions (H₂) to reduce CO₂ in the production of CH₄ as this reaction is thermodynamically favorable to the organisms. Availability of H₂ in the rumen is determined by the proportion of end products resulting from fermentation of the ingested feed. Processes that yield propionate and cell dry matter act as net proton-using reactions, whereas a reaction that yields acetate results in a net proton increase. Other substrates available to methanogens include formate, acetate, methanol, methylamines, dimethyl sulfide and some alcohols, however, only formate has been documented as an alternative CH₄ precursor in the rumen. Figure 1 describes the number of factors affecting methane production from rumen.

The principal methanogens in the bovine rumen utilize hydrogen and carbon dioxide, but there is a group of methanogens of the genus *Methanosarcina* that grow slowly on H₂ and CO₂ and therefore maintain a distinct niche by utilizing methanol and methylamines to produce CH₄. Formate, which is formed in the production of acetate, can also be used as a substrate for methanogenesis, although it is often converted quickly to H₂ and CO₂ instead. Volatile fatty acids (VFA) are not commonly used as substrates for methanogenesis as their conversion into H₂ and CO₂ is a lengthy process, which is inhibited by rumen turnover. Therefore, methanogenesis often uses the H₂ and CO₂ produced by carbohydrate fermentation, as VFAs are formed. By removing H₂ from the ruminal environment as a terminal step of carbohydrate fermentation, methanogens allow the microorganisms involved in fermentation to function optimally and support the complete oxidation of substrates. The fermentation of carbohydrates results in the production of H₂ and if this end product is not removed, it can inhibit metabolism of rumen microorganisms.

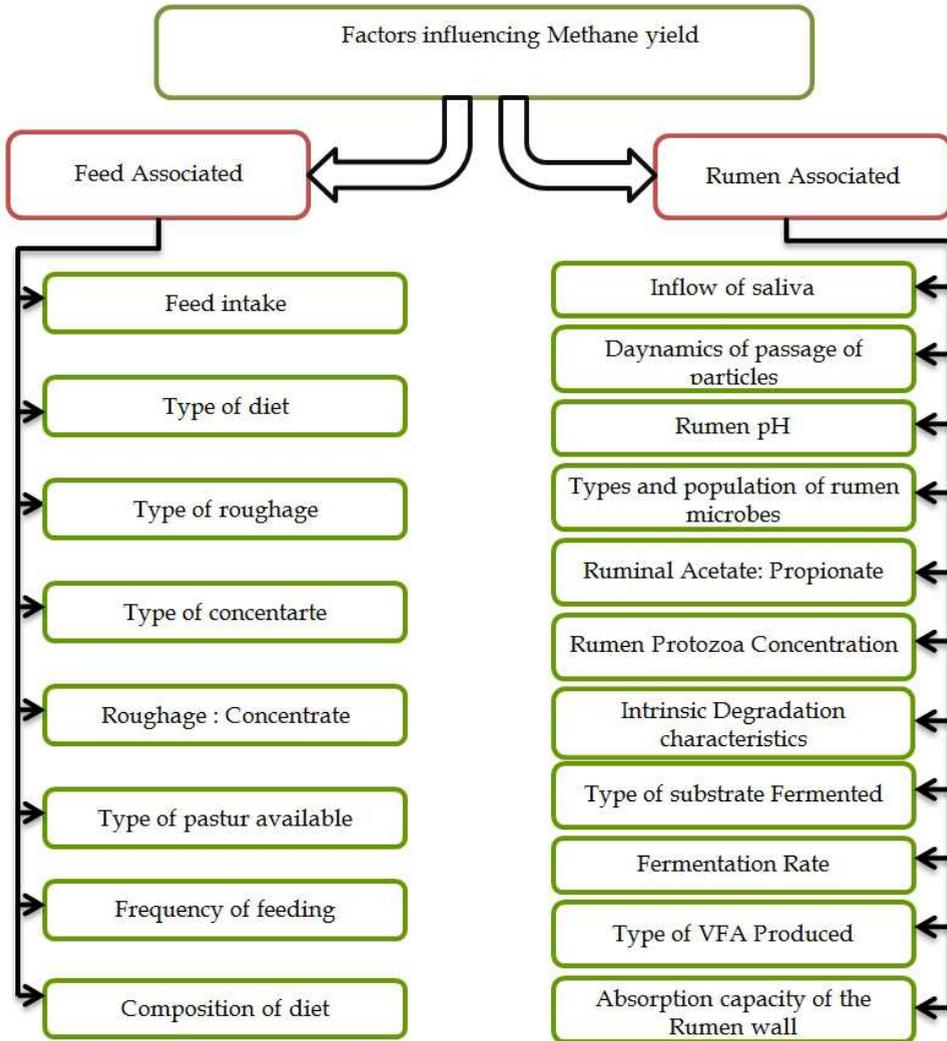


Fig. 1. Different factors influencing enteric methane production

5.3 Different prediction model for enteric methane emission

5.3.1 Empirical models

Although many statistical models have been fairly successful in predicting CH₄ production, many variables in these models are not commonly measured which may lead to difficulties in predicting CH₄ production outside the range of values used for model development (Johnson et al., 1996). These problems may be addressed by using equations with common input variables and by developing models with minimum input variables from multiple

sources. The limitation of using some of the extant models, such as the equation of Moe & Tyrrell (1979), is the difficulty of obtaining reliable model input variables, which might have compromised the predictive ability of the model in the study. Ellis et al. (2007) formulated the most accurate equations which could be useful to the livestock industry for accurately predicting CH₄ production from a minimum set of inputs. Although the extant models evaluated performed well, the new equations developed in the study was more user-friendly and reliable prediction than extant models and therefore a preferable model for generating national CH₄ emissions inventory. Sejian et al. (2011a) have described the different types of regression/prediction equations for enteric methane emission for domestic livestock.

5.3.2 Mechanistic models

There are various emission models available to predict accurately enteric methane emission for farm households (Sejian et al., 2011a). Yan et al. (2000) improved on the earlier representation of methanogenesis in the mechanistic model, and outlined some likely reasons for the differences between observed and predicted values for CH₄ production. One of these is the error attributable to dietary composition, not only in the analysis, but also due to variation in nutrient composition between samples of the same feedstuff. This knowledge of the dietary components, not only of typical feeds but also alternative feeds that are under consideration for CH₄ emission reduction purposes, is a prerequisite for successful use of the models to compare the effect of different feeds on CH₄ production (Palliser & Woodward, 2002). Nonlinear mechanistic model of CH₄ production provides a significant opportunity to enhance scientific ability to estimate CH₄ emissions from cattle (Mills et al., 2003; Kebreab et al., 2008). In addition researchers identified that mechanistic models can be used to generate Y_m values that can be used in national CH₄ emission inventory models. It was suggested that if incentives are introduced to mitigate CH₄ emissions at farm level, mechanistic models would be excellent tools to make reliable estimates of enteric CH₄ emissions. The advantage of mechanistic models compared with empirical models is that mitigation options implemented at a farm or national level can be assessed for their effectiveness.

5.3.3 Whole farm model (WFM)

Computer simulation can provide a cost-effective and efficient method of estimating CH₄ emissions from dairy farms and analyzing effects of management strategies on CH₄ emissions. Invariably all whole farm models (WFM) are mechanistic models. A commonly used simulation is the one proposed by Rotz et al. (2007). The model is an Integrated Farm System Model (IFSM) which is a potential tool for simulating whole-farm emissions of CH₄ and evaluating the overall impact of management strategies used to reduce CH₄ emissions. The IFSM was further refined into a process-based whole-farm simulation including major components for soil processes, crop growth, tillage, planting and harvest operations, feed storage, feeding, herd production, manure storage, and economics (Rotz et al., 2009). Incorporation of the CH₄ module with IFSM in addition to modules simulating N₂O emissions, provides an important tool for evaluating the overall impact of management strategies used to reduce GHG emissions in dairy farms.

Farm System Simulation Framework (FSSF) is another type of WFM which uses pasture growth and cow metabolism for predicting CH₄ emissions in dairy farms. Also included in the WFM is climate and management information. Some other WFMs are also developed by Neil et al. (1997), and Bright et al. (2000). However these models are adequate only for predicting CH₄ production by non-lactating Holstein cows. Prediction rates for lactating cows are less accurate and WFMs currently described in the literature seem inappropriate (IPCC, 1997). Hence development of WFMs are required for the prediction of nutrient and GHG emissions and better estimates of enteric CH₄ production. Currently available WFMs may incorrectly estimate CH₄ emission levels because they cannot predict the wide range enteric CH₄ emissions as affected by DMI and diet. The low prediction accuracy of CH₄ equations in current WFMs may introduce substantial error into inventories of GHG emissions and hence lead to incorrect mitigation recommendations. If regression equations examined here and elsewhere continue to explain only a small fraction of the variation in observed values, moving towards regression equations including more nutritional informations and details on a subanimal level, or towards a dynamic mechanistic description of enteric CH₄ emission, will improve predictions (Ellis et al., 2010).

6. Manure methane production

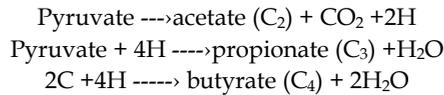
Manure from confined livestock operations is most often stored in solid or liquid form before being applied to agricultural land. Increasingly, however, manure is composted before land application or anaerobically digested to produce CH₄ as bio-fuel. Methane emissions from anaerobic digestion can be recovered and used as energy by adapting manure management and treatment practices to facilitate methane collection. Depending on the management system used, greenhouse gas emissions (mainly CH₄ and N₂O) from manure vary considerably. Strategies to mitigate net emissions aim to change manure properties or the conditions under which CH₄ and N₂O are produced and consumed during manure storage and treatment. The selection of successful methane emissions reduction options from manure depends on several factors, including climate; economic, technical and material resources; existing manure management practices; regulatory requirements; and the specific benefits of developing an energy resource (biogas) and a source of high quality fertilizer.

7. Mechanism of methane reduction

There are two mechanisms available by which methane production can be reduced in livestock. These mechanisms influence the availability of H₂ in the rumen and subsequent production of enteric CH₄ emissions by livestock. Processes that yield propionate act as net proton-using reactions while those that yield acetate result in a net increase in protons. Hence mitigation strategies aiming at reducing CH₄ production must work towards increasing the propionate production. This will reduce CH₄ production by removing some of the H₂ produced during ruminal fermentation. Another mechanism by which CH₄ production may be reduced during the rumen fermentation process is through the provision of alternative hydrogen acceptors or sinks. Another mechanism widely accepted is to supplement anti-methanogenic agents which will inhibit the process of methanogenesis either by directly inhibiting the methanogenic microbe in the rumen or by increasing more propionate production. In addition, strategies to mitigate net emissions from livestock

manure aim to change manure properties or the conditions under which CH₄ and N₂O are produced and consumed during manure storage and treatment. Such strategies aim to manipulate livestock diet composition and/or include feed additives to alter manure pH, concentration and solubility of carbon and nitrogen, and other properties that are pertinent to CH₄ and N₂O emissions.

In the anaerobic conditions prevailing in the rumen, the oxidation reactions required to obtain energy in the form of ATP release hydrogen. The amount of hydrogen produced is highly dependent on the diet and type of rumen microbes as the microbial fermentation of feeds produces different end products that are not equivalent in term of hydrogen output. For instance, the formation of propionic acid consumes hydrogen whereas the formation of acetic and butyric acids releases hydrogen.



From this it can be concluded that if ruminal fermentation patterns are shifted from acetate to propionate, both hydrogen and methane production will be reduced. This relationship between methane emissions and the ratio of the various VFA has been well documented and it provides opportunities to reduce methane emissions. This ratio may, for example, be influenced by the type of carbohydrate consumed by the animal. Cereal-based diets that are high in starch favour propionate production and consequently tend to produce less methane per unit of feed consumed than forage-based diets.

Another mechanism by which methane production may be reduced during the rumen fermentation process is through the provision of alternative hydrogen acceptors or sinks. Compounds such as unsaturated fatty acids provide alternative hydrogen acceptors, consuming hydrogen in limited quantities, during biohydrogenation. Dicarboxylic acids (such as fumaric and malic acids), which are intermediates in the propionic acid pathway, may also serve as alternative electron sinks for H₂. If H₂ accumulates, re-oxidation of NADH is inhibited inhibiting microbial growth, forage digestion and the associated production of acetate, propionate and butyrate. Thus any mitigation strategy aimed at reducing methanogen populations must include an alternative pathway for H₂ removal from the rumen as well. It should therefore be possible to reduce CH₄ production by inhibiting H₂ liberating reactions or by promoting alternative H₂-using reactions or routes for disposing of H₂ during fermentation.

8. Methane mitigation strategies

CH₄ mitigation strategies can be broadly divided into preventative and 'end of pipe' options. *Preventative measures* 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. Alternatively, '*end of pipe*' options reduce—or inhibit—the production of CH₄ (methanogenesis) within the system of animal husbandry (Sejian et al., 2011a). Any reduction strategies must be confined to the following general framework viz.,

development priority, product demand, infrastructure, livestock resource and local resources. The most attractive emissions mitigation projects must balance the needs in all of these areas, so that no one factor creates a constraint on continued improvement in production efficiency, and the resulting CH₄ emissions reductions. Within this framework, CH₄ emissions mitigation options for enteric fermentation can encompass a wide range of activities across these areas. However, underlying these activities must be specific options for improving the production efficiency of the livestock. Without these options, CH₄ emissions cannot be reduced. The technologies that can reduce the amount of methane production in rumen or total release of methane into atmosphere are useful for efficient use of feed and making the environment more favourable. Several options have been considered for mitigating methane production and emitting in atmosphere by the livestock. All approaches point towards either reduction of methane production per animals or reduction per unit of animal product. There are several factors which need to be considered for selection of best options for methane emission reduction: these include climate, economic, technical and material resources, existing manure management practices, regulatory requirements etc. Generally the methane mitigation strategies can be grouped under three broader headings viz., managerial, nutritional and advanced biotechnological strategies (Sejian et al., 2011a). Figure 2 describes the salient enteric methane mitigation strategies.

8.1 Dietary manipulation

The chemical composition of diet is an important factor which affects rumen fermentation and methane emission by the animals. Methane production was significantly lower in the sheep fed on green sorghum and wheat straw in the ratio of 90:10 as compared to where the ratio was 60:40 (31.5 vs 46.91/kg). Improvement in the digestibility of lignocellulose feeds with different treatments also resulted in lower methanogenesis by the animals (Agrawal & Kamra, 2010). Wheat straw treated with urea (4kg urea per 100kg DM) or urea plus calcium hydroxide (3kg urea+3 kg calcium hydroxide per 100kg DM) and stored for 21 days before feeding, reduced methane emission from sheep. The treatment of straw with urea and urea molasses mineral block lick caused a reduction of 12-15% methane production and the molar proportion of acetate decreased accompanied with an increase in propionate production (Agrawal & Kamra, 2010). On inclusion of green maize and berseem in the ration, methanogenesis decreased significantly. By increasing the concentrate level in the paddy straw based diet there was a depression in methane production accompanied with an increase in propionate concentration in the rumen liquor. Castor bean cake and karanj cake inhibited methanogenesis significantly, but these two oil cakes also affected in *in vitro* dry matter degradability of feed adversely, which might be due to the presence of anti-nutritional factors (kumar et al., 2007). Fumaric acid is a precursor of propionic acid in the fermentation of feed in the rumen and can act as an alternate sink for consumption of hydrogen generated in the rumen. The levels of fumaric acid required to inhibit methanogenesis to a significant extent may cause a drop in P^H which might affect feed fermentation adversely. Free fumaric acid (10% in the ration) and an equivalent amount of encapsulated fumaric acid decreased methane emission to the extent of 49% and 75% compared to control sheep without supplementation of fumaric acid (Agrawal & Kamra, 2010).

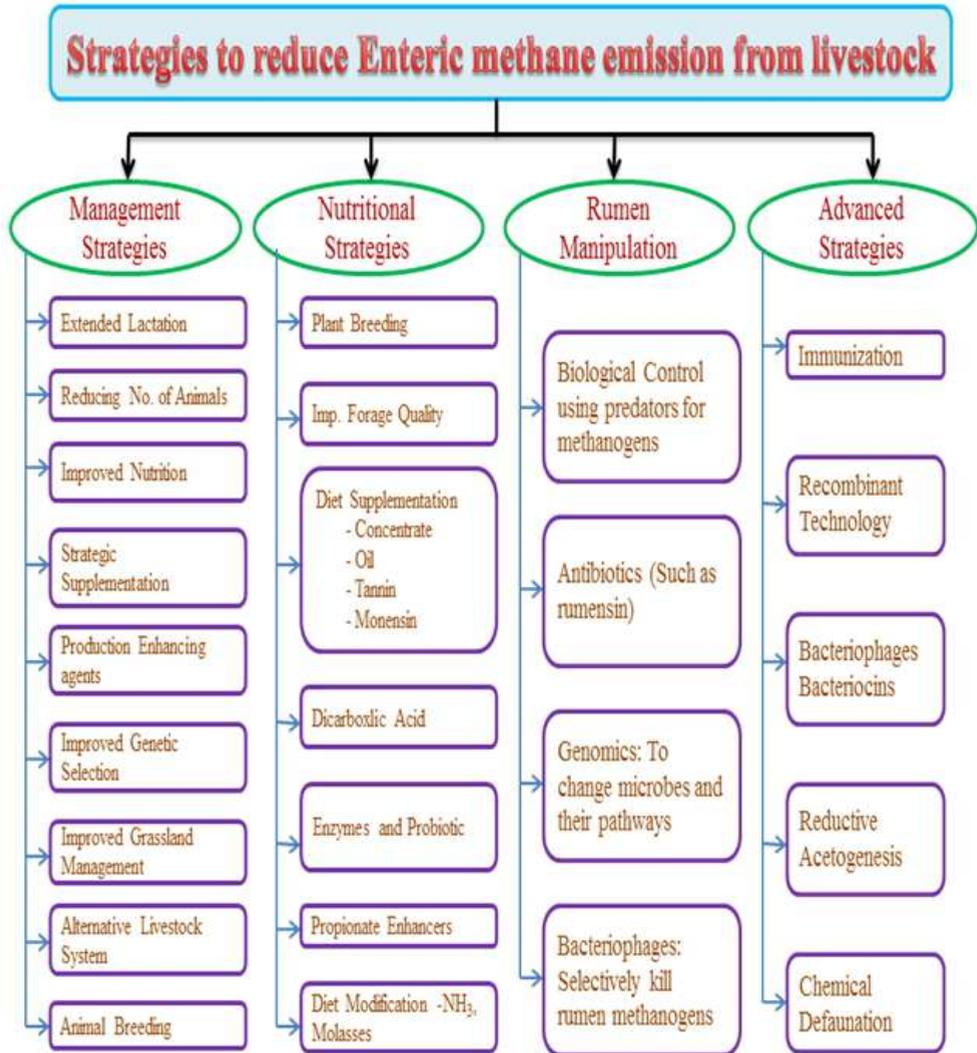


Fig. 2. Different enteric methane mitigation strategies

8.2 Increased proportion of concentrates in the diet

A higher proportion of concentrate in the diet leads to a reduction in CH₄ emissions as a proportion of energy intake (Yan et al., 2000). The relationship between concentrate

proportion in the diet and methane production is curvilinear (Sauvant & Giger-Reverdin, 2007) with a marked decrease in methane observed when dietary starch is higher than 40%. Replacing plant fibre in the diet with starch induces a shift of VFA production from acetate towards propionate occurs, which results in less hydrogen production (Singh, 2010). A positive response to high levels of grain based concentrate on methane reduction has also been reported by others (Beauchemin & McGinn 2005; McAllister & Newbold, 2008). The metabolic pathways involved in hydrogen production and utilization and the activity of methanogens are two important factors that should be considered when developing strategies to control methane emissions by ruminants. Reduction of hydrogen production should be achieved without impairing feed fermentation. Reducing methanogens activity and/or numbers should ideally be done with a concomitant stimulation of pathways that consume hydrogen to avoid the negative effect of the partial pressure increase of this gas. Many mitigating strategies proposed have indeed multiple modes of action (Martin et al., 2008). Hydrogen gas produced during microbial fermentation of feed is used as an energy source by methanogens, which produce methane. Efficient H₂ removal is postulated to increase the rate of fermentation eliminating the inhibitory effect of H₂ on the microbial degradation of plant material (McAllister & Newbold, 2008). The rate of CH₄ formation is determined by the rate at which H₂ passes through the dissolved pool, and the amount of CH₄ formed is determined by the amount of H₂ that passes through the pool. The absolute amount of CH₄ formed per animal on different diets is related to characteristics of the feed in complex ways including the nature and amount of feed, the extent of its degradation, and the amount of H₂ formed from it (Singh, 2010).

8.3 Adding lipid to the diet

Dietary fat seems a promising nutritional alternative to depress ruminal methanogenesis without decreasing ruminal pH as opposed to concentrates (Sejian et al., 2011b). Addition of oils to ruminant diets may decrease CH₄ emission by up to 80% *in vitro* and about 25% *in vivo* (Singh, 2010). Lipids cause depressive effect on CH₄ emission by toxicity to methanogens, reduction of protozoa numbers and therefore protozoa associated methanogens, and a reduction in fibre digestion. Oils containing lauric Acid and myristic acid are particularly toxic to methanogens. Beauchemin et al. (2008) recently reviewed the effect of level of dietary lipid on CH₄ emissions over 17 studies and reported that with beef cattle, dairy cows and lambs, for every 1% (DMI basis) increase in fat in the diet, CH₄ (g/kg DMI) was reduced by 5.6%. In another review of fat effects on enteric CH₄, (Martin et al., 2010) compared a total of 67 *in vivo* diets with beef, sheep and dairy cattle, reporting an average of 3.8% (g/kg DMI) less enteric CH₄ with each 1% addition of fat (Singh, 2010).

8.4 Ionophores

Ionophores (e.g. monensin) are antimicrobials which are widely used in animal production to improve performance. Tadeschi et al. (2003) reported in a recent review that on feedlot and low forage diets, tend to marginally increase average daily gain whilst at the same time reducing DMI, thus increasing feed efficiency by about 6%. Monensin should reduce CH₄ emissions because it reduces DMI, and because of a shift in rumen VFA proportions towards propionate and a reduction in ruminal protozoa numbers (Singh, 2010). *In vivo*

studies have shown that animals treated with monensin emit reduced levels of CH₄ (e.g. McGinn et al., 2004; van Vugt et al., 2005) but others have reported no significant effect (e.g. Waghorn et al., 2008 van Vugt et al., 2005). Monensin causes a direct inhibition on H-producing bacteria (Russell and Houlihan, 2003) that results in a decrease in methane production due to shortage of molecular H. Monensin also favours propionate producing bacteria (Newbold et al., 1996).

8.5 Plant secondary metabolites

The term plant secondary metabolite is used to describe a group of chemical compounds found in plants that are not involved in the primary biochemical processes of plant growth and reproduction (Agrawal & Kamra, 2010). These compounds might function as a nutrient store and defence mechanisms which ensures survival of their structure and reproductive elements protecting against insect or pathogen predation or by restricting grazing herbivores. Several thousand of plant secondary metabolites have been reported in various plants and many of them have found their use in traditional Indian and Chinese system of medicine (Kumar et al., 2007).

8.5.1 Saponins

Numerous studies have demonstrated that Saponins and Saponin -containing plants have toxic effects on protozoa. Forages containing condensed tannins have been shown to decrease methane production by the ruminants. Tannins present in *Calliandra calothyrsus* reduced nutrient degradation and methane release per gram of organic matter degraded in *in vitro* experiments with rumen simulation technique (RUSITEC) (Hess et al., 2003). Woodward et al. (2002) investigated the effect of feeding of sulla on methane emission and milk yield in Friesian and Jersey dairy cows. Cows feed sulla produced less methane per kg DM intake (19.5 vs. 24.6 g) and per kg milk solid yield (243.3 vs. 327.8 g). Similar trends in methane emission and milk production have been observed in sheep fed on lotus silage (Woodward et al., 2001).there was also 16 % reduction in methane production in lambs fed on *Lotus pedunculatus* (lotus), which might be due to the presence of condensed tannins (Waghorn et al., 2002). Another condensed tannins containing forage *Sericea lespedeza* (17.7% CT) decreased methane emission (7.4 vs. 10.6 g/d and 6.9 vs. 16.2 g/kg DMI for *sericea lespedeza* and crabgrass /tall fescue, respectively) in angora goats (Puchala et al., 2005; Agrawal & Kamra, 2010). *Bergenia crassifolia*, *Emblica officinalis*, *Peltiphyllum peltatum*, *Populus deltoids*, *Quercus Incana*,*rheum Undulatum*, *Terminalia belerica*, *Terminalia chebula* and *Vaccinium vitis-idaea* are some other plants containing high tannin contents and have a potential to inhibit *in vitro* as well as *in vivo* methane emission by the rumen microbes (Patra et al., 2006; kumar et al., 2009).

8.5.2 Essential oils

Allium sativum, *Coriandrum sativum*, *Eucalyptus globules*, *Foeniculum vulgare*, *Mentha piperita*, *Ocimum sanctum*, *Populus deltoids* and *Syzygium aromaticum* are some of the plants which contain high concentration of essential oils and are effective against methane emission and protozoa growth in the rumen, but some of them also have adverse effects on degradability of feed and nutrient utilization by the animals. The results of *in vivo*

experiments with these plants are also variable and need further experimentation before their practical application in the livestock production (Agrawal & Kamra, 2010).

8.6 Bacteriocins

Some bacteriocins are known to reduce methane production *in vitro* (Callaway et al., 1997, Lee et al., 2002). Nisin is thought to act indirectly, affecting hydrogen producing microbes in a similar way to that of the ionophore antibiotic monensin (Callaway et al., 1997). A bacteriocin obtained from a rumen bacterium, bovicin HC5, decreased methane production *in vitro* up to 50% without inducing methanogens adaptation (Lee et al., 2002). Klieve and Hegarty (1999) also suggested the use of archaeal viruses to decrease the population of methanogens.

8.7 Organic acids

Organic acids are generally fermented to propionate in the rumen, and in the process reducing equivalents are consumed. Thus they can be an alternative sink for hydrogen and reduce the amount of hydrogen used in CH₄ formation. Newbold et al. (2005) reported fumarate and acrylate to be the most effective in batch culture and artificial rumen. There have been some recent *in vivo* studies. Newbold et al. (2002) reported a dose-dependent response to fumarate in sheep. Wallace et al. (2006) described a proportional reduction of 0.4-0.75 when encapsulated fumaric acid (0.1 % of diet) was fed to sheep. While the level of reduction in CH₄ emissions that could be achieved is somewhat uncertain, the main impediment to this strategy is the current cost of organic acids which makes their use uneconomical. Integrated research investigating animal, plant, microbe and nutrient level strategies might offer a long term solution of methane production. At the animal level, genetic selection is the area of research with the best chance of finding a solution. At the microbe level, vaccination and probiotics are the promising approaches for future research. Any mitigation strategy that reduces methanogen populations must also include an alternative pathway for H₂ removal from the rumen. Improvement and breeding of plants is another helpful way to control of methanogenesis, but the estimation of time required must be realistic. Strategies must however suit particular classes of livestock. Advances brought about through rumen metagenomic projects and the utilization of new technologies will broaden our understanding of the mechanisms involved in methanogenesis and other metabolic H₂- consuming and releasing processes, and will help find new tools for mitigation (Morgavi et al., 2010). The sustainability of methane suppressing strategies is an important issue. There is an urgent need for support model that is capable of evaluating the effectiveness of both existing and new technologies for reducing methane emission.

9. Methane mitigation strategies from livestock manure

Manure from confined livestock operations is most often stored in solid or liquid form before being applied to agricultural land. Increasingly, however, manure is composted before land application or anaerobically digested to produce CH₄ as bio-fuel. Methane emissions from anaerobic digestion can be recovered and used as energy by adapting manure management and treatment practices to facilitate methane collection. This methane

can be used directly for on-farm energy, or to generate electricity for on-farm use or for sale. The other products of anaerobic digestion, contained in the slurry effluent, can be utilized in a number of ways, depending on local needs and resources. Successful applications include use as animal feed and aquaculture supplements, in fish farming, and as a crop fertilizer. Additionally, managed anaerobic decomposition is a very effective method of reducing the environmental and human health problems associated with manure management. The controlled bacterial decomposition of the volatile solids in manure reduces the potential for contamination from runoff, significantly reduces pathogen levels, removes most noxious odors, and retains the organic nitrogen content of the manure.

Depending on the management system used, greenhouse gas emissions (mainly CH₄ and N₂O) from manure vary considerably. Strategies to mitigate net emissions aim to change manure properties or the conditions under which CH₄ and N₂O are produced and consumed during manure storage and treatment. The selection of successful methane emissions reduction options depends on several factors, including climate; economic, technical and material resources; existing manure management practices; regulatory requirements; and the specific benefits of developing an energy resource (biogas) and a source of high quality fertilizer.

One such strategy is to manipulate livestock diet composition and/or include feed additives to alter manure pH, concentration and solubility of carbon and nitrogen, and other properties that are pertinent to CH₄ and N₂O emissions.

Another manure management option is to change the material used for bedding the animals, which could also affect manure pH and soluble C and N levels, and thus the emissions during manure storage and treatment.

Composting technology, control of aeration, use of amendments, or co-composting livestock manure with other organic waste could also potentially modify conditions for GHG production and emission. The use of covers may also help retain N nutrients during storage.

Manure mitigation includes both low-tech strategies like covering and cooling manure lagoons during storage and alternative techniques for manure dispersion and application (Weiske et al., 2006; IPCC, 2007b). More advanced technologies include frequent manure removal from animal housing into covered storage using scraping systems (Weiske et al., 2006) as well as farm scale or centralized digesters for biogas generation and utilization (DeAngelo et al., 2006, USEPA, 2006). In small-scale farm digesters, biogas from local manure may be used for electricity and/or heat production. Larger, centralized digesters can also take in additional organic wastes. There are many different digester designs ranging from low-tech small-scale to high-tech large-scale models, for example polyethylene bag or covered lagoon digesters for cooking fuel, light flexible-bag digesters, and large-scale dome digesters (USEPA, 2006). With the use of liquid-based systems, the primary method for reducing emissions is to recover the methane before it is emitted into the air. Methane recovery involves capturing and collecting the methane produced in the manure management system. This recovered methane (a medium Btu gas with about 500-600 Btu/ft³) can be flared or used to produce heat or electricity. Because most of the manure facility methane emissions occur at large confined animal operations (primarily dairies and hog farms), the most promising options for reducing these emissions involve recovering the

methane at these facilities and using it for energy. Three methane recovery technologies are available:

9.1 Covered anaerobic digesters

These are the simplest form of recovery system, and can be used at dairy or swine farms in temperate or warm climates. Manure solids are washed out of the livestock housing facilities with large quantities of water, and the resulting slurry flows into an anaerobic primary lagoon. The average retention time for the manure in the lagoon is about 60 days. The anaerobic conditions result in significant methane emissions, particularly in warm climates. The covered lagoons are air-tight and provide the anaerobic conditions under which methane is produced and recovered which can be used as energy. Lagoons are most commonly used at large confined dairy and swine facilities in North America, Europe, and regions of Asia and Australia.

9.2 Complete mix digesters

This type of digesters presents a methane recovery option for all climates. They are heated, constant-volume, mechanically-mixed tanks that decompose medium solids swine or dairy manure (3-8% total solids) to produce biogas and a biologically stabilized effluent. The manure is collected daily in a mixing pit where the percent total solids can be adjusted and the manure can be pre-heated. A gas-tight cover placed over the digester vessel maintains anaerobic conditions and traps the methane that is produced. The produced methane, representing about 8 to 11 percent of the total manure, is removed from the digester, processed, and transported to the end use site.

9.3 Plug flow digesters

This type of digesters only works with dairy scraped manure and cannot be used with other manures. These are constant volume, flow-through units that decompose high solids dairy manure (>11% solids) to produce biogas and a biologically stabilized effluent. The basic plug flow digester design is a long tank, often built below ground level, with a gas-tight, expandable cover. A gas-tight cover collects the biogas and maintains anaerobic conditions inside the tank. The amount of methane produced is about 40 cubic feet per cow per day.

10. Conclusions

Given that the livestock production system is sensitive to climate change and at the same time itself a contributor to the phenomenon, climate change has the potential to be an increasingly formidable challenge to the development of the livestock sector. Responding to the challenge of climate change requires formulation of appropriate adaptation and mitigation options for the sector. Although the reduction in GHG emissions from livestock industries are seen as high priorities, strategies for reducing emissions should not reduce the economic viability of enterprises if they are to find industry acceptability.

11. Future scope of research

Prioritized research need to address using of advanced molecular technology to reduce livestock methane emission. Both conventional and non-conventional feed resources need to

be tried for their potential to affect methane emission by the animals. Further, the research addressing chemical feed additives need to ensure that there are no side effects on feed utilization and no residues left in the livestock products like meat and milk. In addition, while attempting to use plant secondary compounds to reduce enteric methane emission care needs to be taken to ensure optimum dose of such compounds so that there is no toxic effects on rumen microbes. Finally, in depth research need to be undertaken to identify the microbial feed additives such as reductive acetogenic bacteria, yeasts and other microbes which may manipulate rumen fermentation and reduce methane emission.

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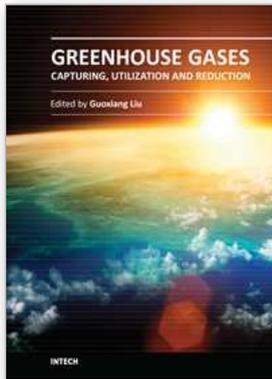
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