Livestock and Climate Change: Nutritional Strategies to Reduce Methane Emission from Ruminant

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Abstract: This review aimed to assess methane mitigation options with special consideration to ruminant dietary modification. Greenhouse gas emission which results in elevating global temperature is an important subject of worldwide ecological and environmental concern. Among greenhouse gases, methane is considered a potent greenhouse gas with 21-23 times more global warming potential than carbon dioxide. Worldwide, ruminant livestock produce about 80 million metric tons of methane each year, accounting for about 30% of global emissions from agricultural related activities. The rumen microbial ecosystem produces methane as a result of anaerobic fermentation. Methanogenesis in the rumen is thought to represent a 2-12% loss of energy intake and is an economic loss to the farmer where feed is converted to CH₄ rather than to product output. Mitigation of methane production from ruminants is generally required to minimize global greenhouse gas emissions and to enhance animal performance by improving feed conversion efficiency. Many alternative approaches to reducing methane are considered, both in terms of reduction per animal and reduction per unit of animal product. Manipulation of rumen fermentation processes for reducing methane production by ruminants to improve the production performance of ruminants is the current major target of many animal nutritionists. The nutritional approaches include dietary manipulation of different concentrate diets; different forage level and types, intake level, organic acids, tannin, probiotic, feed additives supplementation and feed processing methods are some of the methods to improve nutrition and animal performance as well as mitigates methane from ruminants.

Key words: Enteric Fermentation · Methanogenesis · Mitigation Strategies · Ruminants.

INTRODUCTION

Global warming refers to a significant rise in the planet temperature making it uninhabitable. 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 (GHG), the hotter the earth [1]. In fact greenhouse gases in the atmosphere are essential for maintaining life on earth, as without them the planet would be permanently frozen because all of the incoming heat from the sun would be radiated back into space by the earth’s surface [2]. The threshold concentration of these gases at which their green house effect would be minimized is not known, but it is accepted that their concentrations in the atmosphere should not be allowed to continue to rise. 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. GHG are released in the atmosphere both by natural sources and anthropogenic (human related) activities [3]. The three major GHGs are carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O).

Methane (CH₄) is the second most important greenhouse gas after carbon dioxide and contributes for 18% of the total greenhouse gas emissions globally [3]. The global warming potential of methane is 21-23 times more than carbon dioxide [4]. Globally, about 80 million tons of CH₄ is produced annually from enteric fermentation mainly from ruminants [5,6]. Cattle can produce 250–500 liter of methane per day per animal [7]
and generally lose 2–12% of their ingested energy as eructated methane [8]. Enteric CH4 emissions represent an economic loss to the farmer where feed is converted to CH4 rather than to product output. The development of management strategies to mitigate CH4 emissions from ruminant livestock is possible and desirable. Nevertheless, controlling methane losses from ruminants has environmental as well as economical benefits. Less methane means a lower concentration of greenhouse gases in the atmosphere. Also, less methane means increased efficiency of livestock production and increased income for farmers. A greater amount of methane production can be controlled by modifying the composition of the animal feed [6]. This review paper presents some promising methane mitigation options with special consideration to ruminant dietary modification.

**Consequences of the Greenhouse Effect on Our Environment:** The consequences of the increase of the gases that generate the greenhouse effect causes the rise of the average global temperatures along with many consequences on human life. By the year 2030, the world is likely to be 1–2°C warmer than today, although given the full range of uncertainties, the range could be from 0.5°C to 2.5°C and also the Intergovernmental Panel on Climate Change [9] predicted an increase of 1.8-3.9°C (3.2-7.1°F) by the year 2100. These temperature rises are much greater than those seen during the last century, when average temperatures rose only 0.06°C (0.12°F) decade [10]. Since the middle of 1970s, however, the rate of increase in temperature rise has tripled. The concomitant rise in global mean sea level is 17 to 26 cm, with a full range of 5 to 44 cm, due mainly to thermal expansion of the oceans and increased melting of ices in the Arctic and Antarctic areas.

The IPCC's latest report [11] warns that climate change “could lead to some impacts that are abrupt or irreversible.” According to FAO Statistical Databases (FAOSTAT) [12] 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 [13]. As the numbers of farm animal reared for meat, egg and dairy production rise, so do their GHG emissions [1].

**Sources of Ghs from Agriculture and Livestock:** Methane is emitted from a variety of anthropogenic and natural sources. More than 70 percent of global CH4 emissions are related to anthropogenic activities [14].

![Methane emission rates from agricultural sources](image-url)

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. Agriculture is considered to be responsible for about two-thirds of the anthropogenic sources [15]. Agriculture contributes about 21–25, 60 and 65–80% of the total anthropogenic emissions of carbon dioxide, methane and N2O respectively [16, 17]. Agriculture is also thought to be responsible for over 95% of the ammonia, 50% of the carbon monoxide and 35% of the nitrogen oxides released into the atmosphere as a result of human activities [17]. An estimated 205 to 245 million tons of methane were release per year from agricultural sources [18]. Methane emission rate from agricultural sources is shown in Figure 1.

Emissions from enteric fermentation of the domestic livestock contribute significantly to GHGs inventories, it accounting for about 30% of global emissions from human related activities [19].

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 [19]. Ruminant livestock such as cattle, buffalo, sheep and goats contributes the major proportion of total agricultural emission of methane [21, 22]. 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 greenhouse gas. Methane production released due to the release of digestible energy to atmosphere and therefore inefficient utilization of feed energy. Methane emission from ruminants provides enough scope of easy and practical management for reduction in methane emission [23].
Fig. 2: Possible fermentation pathways of methane production [25].

**Methane Producing Pathways in the Rumen:** Enteric fermentation is the digestive process in herbivores animals by which organic matter are broken down by microorganisms into simple molecules for absorption into the bloodstream. Methane is produced as a result of anaerobic fermentation in the rumen and the hindgut. Microbial enzymatic activity in the rumen hydrolyses much of the dietary organic matter to amino acids and simple sugars. These products are then an aerobically fermented to volatile fatty acids (VFA), hydrogen and CO$_2$. Some of the CO$_2$ is then reduced through combination with hydrogen to produce methane (CO$_2$ + 4 H$_2$ → CH$_4$ + 2 H$_2$O). CH$_4$ is produced as a waste product of this fermentation process [24]. The enteric fermentation in rumen is highly useful for human kind because it converts coarse and fibrous plants into food and fiber for human kind. However, enteric fermentation in rumen also produces methane through bacterial breakdown of feeds called as methanogenesis [3]. The animals release methane into atmosphere through exhaling or ruminating through mouth or nostrils.

The rumen can be thought of as a kind of anaerobic fermentation tank, in which many living microorganisms, rumen microorganisms, affect each other. Nutritional components such as carbohydrates, proteins and lipids in feedstuffs are degraded by rumen microorganisms and are converted into microbial cells, which include proteins and carbohydrates and VFAs and gasses [25]. Because hydrogen derives mainly from carbohydrates and is supplied for methane production in the rumen (Figure 2), carbohydrate degradation is often the focus of efforts to abate methane production from livestock rumens. CH$_4$ is produced as a byproduct of the fermentation and is expelled. “Monogastric” animals produce small amounts of CH$_4$ as the result of incidental fermentation that takes place during the digestion process. “Non-ruminant herbivores” produce CH$_4$ 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 [3].

The carbohydrate-fermenting bacteria and protozoa in the rumen produce CO$_2$, H$_2$ and VFAs. It is known that CO$_2$ and H$_2$ are major precursors of CH$_4$; formate is also a precursor of CH$_4$ (Figure 1). Methane production from formate is estimated to comprise approximately 15-20% of the total methane production in the rumen [26-28].

Alternatively, hydrogen can be used in the formation of some VFA or incorporated into microbial organic matter. The formation of main VFA is shown in the following equations:

**2H Producing Reactions:**

1. Glucose → 2 pyruvate + 4H
   (Embden-Meyerhof-Parnas pathway)
2. Pyruvate + H$_2$O → acetate (C2) + CO$_2$ + 2H
2\text{H} \text{ using reactions:}

\begin{align*}
\text{Pyruvate} + 4\text{H} &\rightarrow \text{propionate (C3)} + \text{H}_2\text{O} \\
2 \text{C2} + 4\text{H} &\rightarrow \text{butyrate (C4)} + 2\text{H}_2\text{O} \\
\text{CO}_2 + 8\text{H} &\rightarrow \text{methane (CH4)} + 2\text{H}_2\text{O}
\end{align*}

**Strategies to Reduce Methane Emissions from Ruminants:** Since methane is a final product of rumen fermentation, strategies for reducing methane emissions from the rumen involve altering patterns of rumen fermentation. Diet composition can influence rumen fermentation and reduce methane production as a result of more propionate present or less degradation of feed consumed in the rumen.

**Effect of Concentrate Proportion in the Diet:** A positive response to high levels of grain based concentrate on methane reduction has also been reported [29, 30]. Cereal grains, which contain much more storage carbohydrates than forage, are easily digested by rumen microorganisms such as starch-fermenting bacteria. Higher proportions of concentrates in the feed decrease methane emissions [25,31]. A diet comprising 45% starch decreased methane production by 56% compared to diets containing 30% starch without affecting animal health. For every gram of cellulose digested, methane emissions are nearly five times that of the soluble residue [32]. In high-starch diets the percentage of methane corresponding to the gross energy intake can be as low as 3% as compared to 6 to 8% in diets with forages as the main feed component. However, this marked decrease is only observed at levels of intake that are equal or above 2.5 times the intake required for maintenance and when the concentrate represents more than 50% of the ration [33-35].

Starch in cereal grains is readily fermented by rumen microorganisms. The reduction of methane in diets rich in rapidly fermentable carbohydrates was explained by an increased production of propionate at the expense of acetate, pathways consuming and producing dihydrogen, respectively, by a decrease in rumen pH, by a decrease in the concentration of protozoa, high producers of dihydrogen, or by a combination of these three factors [35, 36]. While some starch-digesting bacteria produce significant amounts of propionate, many fiber-digesting bacteria produce large amounts of succinate, which is finally converted to propionate [37] and the same author also reported that when large amounts of concentrates are present in the diet, 23% of propionate is produced from pyruvate via acyl CoA (the acrylate pathway), whereas, in a forage-based diet, 92% of propionate is produced from pyruvate via succinate [25].

**Effect of Concentrate Type:** Little work has been done to compare the production of methane from various types of concentrates. The study of Yurtseven and Ozrurk [38] had shown that the amount of methane derived from corn was less than that obtained from barley. A mathematical model of rumen digestion made by Dijkstra et al. [39] and modified by Benchaar et al. [40] was used to simulate the effect of different nutritional strategies on methane production. The simulations were conducted for 500kg body weight cow. Diets consisted of 30% alfalfa hay and 70% of either barley or corn grain. Substitution of barley with corn in the diet depressed total methane production by 14% and as a part of energy loss, methane production reduced by 16% and 17% of GE and DE, respectively. Utilization of slowly degraded starch rather than rapidly degraded starch reduced ruminal methane production. Tammings et al. [41] concluded that all carbohydrate fractions reduce methane production but that the soluble carbohydrates were more efficient than the starch. This is due to a partial shift in the site of digestion.

**Effect of Forage Type:** The composition and quality of forage along with level of intake significantly influences the rumen fermentation [6, 7]. Ruminants fed low quality roughages could release large amount of methane. Feeding crop residues to ruminants is a common practice in many developing countries due to which methane emission from ruminants especially cattle is significant. When viewed in isolation, increasing forage digestibility increases daily methane emissions because of increased intake. However at high intake levels, the proportion of energy lost as methane decreases as the digestibility of the diet increases [6,7]. In addition, improving forage digestibility will improve productivity because DM and energy intake are increased. Benchaar et al. [40] speculated 15% reduction in methane production by increasing the digestibility of forages and 7% by increasing feed intake was observed. Ryegrass varieties containing high soluble sugar contents (i.e. 20.5 g/kg DM) have been shown to decrease methane production per kg of live weight gain by up to 25% in growing lambs [35,42]. Also, Ulyatt et al. [43] showed that methane yield from sheep grazing kikuyu grass (Pennisetum clandestinum) a sub-tropical C4 plant, decreased when the pasture had higher content of soluble sugars and lower proportion of fiber.
A diet consisted of 100% timothy hay harvested at full inflorescence stage or alfalfa hay harvested at vegetative stage. When express relative to DE, replacing timothy hay with alfalfa hay decreased methane production by 21%. Methane production depressed with the utilization of legume (alfalfa) instead of grass (timothy) hay the reduced emissions could result from a modified ruminal fermentation pattern combined with higher passage rates [40]. Within a forage species, there may be potential to select cultivars that result in reduced methane production. One in vitro work [44] has demonstrated differences between cultivars of perennial ryegrass in their methanogenic potential (Figure 3). The differences were significantly related to chemical composition of the cultivars, but differences between cultivars could also be due to differences in contents of organic acids, as outlined below. Mirzaei-Aghsaghali et al. [45] and Afshar et al. [46] reported that methane (g per day, g per kg BW and g per kg BW0.75) in grass hay were significantly higher than that of legume hay.

**Effect of Forage Processing Method:** Grinding and pelleting operations of roughages decrease methane production by improving passage rate and reducing time of feed [6,47]. The shifting of animals from low to high digestible pasture significantly reduced methane production per gram of live weight gain [48]. The use of forages meant for improving animal performance can reduce methane emissions per unit of feed intake. Importantly, pasture improvement can be a good choice if fewer animals are used [5].

According to Santoso et al. [49], sheep fed diets consisted of either timothy silage or hay and a commercial concentrate (85:15, on DM basis) per day and when rumen was fistulated, methane production as either g/kg DMI or g/day was higher (7.43 % of GE intake) in silage-based diet than (6.35%) in hay-based diet. The higher CH4 production with the silage-based diet may be a result of increased fiber digestibility resulting from microbial activity through ensiling. This finding is also supported by greater fibrous carbohydrate fraction that is associated with longer retention time of feed in the rumen, consequently higher NDF digestibility and therefore higher CH4 output.

**Forage Quality and Feed Intake:** To predict the possibilities for methane reduction potential of a dairy cow herd, the strategy of dairy cow feeding was analyzed [50]. One of the most important factors affecting the amount of produced methane gas of dairy cows is the amount of the food eaten. Encouraging a cow to eat large amounts of feed is the key to productive and efficient milk production. For every 2 kg of milk yield a cow has to eat at least 1 kg of dry matter. If the feed dry matter digestibility decreases from 75 % to 55 %, then the dry matter intake of a dairy cow drops from 4.3 kg to 2.5 kg per 100 kg of live weight.

Roughages are feeds high in fiber (e.g., hay, haylage and corn silage). Milk cows can consume 1.8 to 2.2 % of body weight daily as DM from average quality dry roughage [50]. Roughage quality is partly determined by fiber levels and high fiber forage is less digestible than high quality material. Undigested feed cannot pass out of the rumen. The cow cannot consume more feed until the feed in the rumen is digested. High fiber forages reduce DMI. A cow can eat 3 % of body weight as DM from excellent hay but only 1.5 % from poor hay [51].

The amount of produced methane gas increases by increasing the feed intake. It should, however, be noted that although the total amount of the produced methane gas increases, the energy, used by the cow and lost in the form of methane gas, decreases. As a result of the increase in dry matter intake the feed energy efficiency is increasing and methane gas per liter of produced milk is reduced [52].

Forage quality significantly affects methane production. Fodder quality has a significant effect on methane production and if the feed quality is poor, the production of methane gas is increasing. This is the main cause of the loss of cow energy and, if it could be avoided, it would lead to an increase in the milk yield. By improving the forage quality it is possible to increase the dry matter intake (DMI) ability and reduce its residence time in the rumen, thereby promoting a more efficient use of energy in the outermost feed digestion.
processes and reducing the proportion of energy that is converted to methane gas. The feed milling and granulation can reduce methane emissions by 40%, but practicing these types of feed preparation should be done to pre-assess the economic benefits [52-54].

**Effect of Lipid Supplementation:** Lipids and lipid-rich feeds are among the most efficient and emerging options for methane mitigation. Lipid inclusion in the diet reduces methane emissions by decreasing fermentation [6, 7]. Particularly fats with C₆ to C₁₆ chain length [17, 55]. At ruminal temperature, an increasing chain length of medium chain fatty acids seems to reduce their efficiency in inhibiting methanogens and methane formation due to lower solubility [5, 56]. In addition, fatty acids are not fermented in the rumen and hence they do not contribute dihydrogen and other substrates for methanogenesis. A decrease in methane production of 2 to 4% has been reported for every percent increase in lipid content in the ration [35, 36, 57, 58]. The long term efficacy of lipid supplementation in reducing enteric methane emissions was also demonstrated in dairy cows receiving extruded linseed for more than a year [60].

The toxic effects of certain oils on rumen protozoa contributed to reduced methane production [60]. Beauchemin *et al.* [61] reviewed the practical application of lipids supplementation to diet decreased methane emission by up to 80% *in vitro* [62] and about 25% *in vivo* [63]. Defaunation represents the process that eliminates protozoa population from the rumen. This treatment has been used to investigate the role of protozoa population in rumen and to study the effect on methane production [64, 65]. It is known that methanogens in rumen are attached on protozoa and they share a symbiotic relationship with participation in hydrogen transfer [66]. Methanogens species that are associated with protozoa are responsible for 9 to 37% of the methane production in the rumen [66] and for this reason treatments that affect protozoa population in rumen may have an effect on methanogenesis process [64]. Hegarty *et al.* [67] suggested that defaunation treatment reduced methane with 13% but this impact varied with the diet.

Eugène *et al.* [57] reported that methane output with lipid supplementation in lactating dairy cows and found that 1% of lipids decreased methane production with 2.2%. In one study on sheep and cattle, addition of lipids on diet, decreased methane production with 5.6% [61]. In another study with beef cattle has shown it to be effective in reducing methane emissions at 0.045 coconut oil per DM intake, that the response is linear from low to moderate levels (Figure 4) [7]. In addition canola oil supplementation at 0%, 3.5% or 7% to the diets of sheep reduced the number of rumen protozoa by 88–97% [6,60]. The detrimental impact of unsaturated fatty acids has also been reported by inclusion of sunflower oil to the diet of cattle resulted in 22% decrease of methane emissions [68]. However, fats and oils may pose numerous negative impacts to the animals. Dietary oil supplementation caused lower fiber digestibility [6, 68].

**Effect of Propionate Enhancers:** 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 [3]. The organic acids such as malate, fumarate, citrate, succinate, etc. are propionate precursors, *in vitro* [70, 71] and *in vivo* [71] their addition to the diet reduces methane production. Fumarate is a direct metabolic precursor of propionate and thus, it has the potential to decrease methane emissions by directing H into succinate rather than into methane.

Diet supplemented with fumaric acid at 2% of DMI in maize fodder based diet to lactating cows, there was 20.70% methane production reduction. *in vitro* studies [27, 28], sodium fumarate reduces methane production by diverting H and stimulates proliferation of cellulolytic bacteria and the digestion of fiber.

**The Use of Ionophores (Monensin):** The most affective ionophore in ruminant fermentation is monensin, although other such as nigercin, gramicidin and lasalocid are available [72]. Monensin is do not alter the diversity and quantity of rumen methanogens [37, 65]. It shifts the bacterial population from gram-positive to gram negative and this means a change in rumen fermentation from acetate to propionate [16]. This is the reason why...
monensin does not affect methane production by altering the methanogens population, but instead inhibits the growth of bacteria and protozoa [64]. When monensine is supplied to the ruminant diet, the rumen fermentation pattern is a shift from acetate and butyrate to propionate [73]. Bacteria that produce lactic, acetic, butyric and formic acids and hydrogen are susceptible to ionophores whereas succinic and propionic acid producing bacteria are resistant.

Beauchemin et al. [74] included monensin in diets at a dose of <20 mg kg-1 but this dose did not affect the methane production. In higher doses such as 24-35 mg kg-1 diet, monensin decreased methane production by 4-10% [65, 75]. A diet supplemented with 33 mg/kg DM monensin to growing beef cattle for 24-days methane production was decreased by 9% [68]. A decrease by up to 30% was been reported by Guan et al. [76] when they used a dose level of 33 mg kg-1 diet of monensin [77]. Ionophores (e.g. monensin) are antimicrobials which are widely used in animal production to improve performance. Tedeschi et al. [77] and Giuburunca et al. [65] reported in a 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 [78]. Notably, ionophores are banned within the European Union due to the fears of residues appearing in the milk [79].

**Effect of Condensed Tannin:** Plant compounds such as tannins (inhibiting methanogens) and saponins (inhibiting protozoa), which reduce the digestibility of dietary fibre and organic acids such as fumarate, malate and acrylate which act as an alternative hydrogen acceptor, but results for effects on methane production and animal performance are variable [79]. Tannins reduce methane due to their inhibitory effect upon methanogens, protozoa and other hydrogen-producing microbes [35, 80, 81]. Plants rich in tannins have been shown to reduce methane production by up to 30% [82, 83]. The same author reported that methane emission was reduced by 30% for Does consumed Sericea lepedeza pasture (having 17.7% condensed tannin at DM) than Crabgrass (0.5% condensed tannin). Condensed tannins, a constituent of some legumes, have been associated with reduced enteric CH₄ emissions.

**Use of Probiotics:** Yeast cultures of *Saccharomyces cerevisiae* are widely used in ruminant diets to improve rumen function and milk production. Laboratory studies suggest that some live yeast strains can stimulate the use of hydrogen by acetogenic strains of ruminal bacteria, thereby enhancing the formation of acetate and decreasing the formation of CH₄ in the rumen. Reductive acetogenesis acts as an important hydrogen sink in hindgut fermentation. The effects and modes of action of yeast on rumen fermentation have been extensively studied [84, 85]. The same authors review identified three main effects of yeast on rumen development: improvement of rumen maturity by favoring microbial establishment, stabilizing rumen pH and increasing fibre degradation. Live yeast also showed beneficial effects on the growth and H₂-utilisation of acetogenic bacteria *in vitro* [86]. Being an aerobic organism, the above mentioned effects may be due to the ability of yeast to remove the trace amounts of oxygen present in the rumen and/or due to the micronutrients present in the yeast itself [86]. According to Odongo et al. [75] probiotics (acetogens and yeast) have been found to reduce methane output, mainly through improving digestion efficiency.

Lila et al. [87] report, yeast cultures of *Saccharomyces cerevisiae*, the methanogenic strain isolated from a sheep rumen (MF2) and Acetogenic bacteria isolated from 20 h old lambs (Ser 8), were grown in media. As a result, in the absence of *S. cerevisiae*, only 19% of hydrogen was used in acetate synthesis while in the presence of yeast cells, the acetogenic bacterial species was stimulated and more efficient in hydrogen utilization (70%) of the hydrogen was used for acetate production, it reduce the methane production by 20%. The use of yeasts as ruminant feed additives could help these bacteria to compete with methanogens.

**Increased Animal Productivity:** According to Mirzaei-Aghsaghali et al. [45], the concept of increasing animal productivity to reduce methane emissions from ruminants is based on the maintenance of overall production output and as a result, increased production of useful product would mean methane production per unit product would decline. Increasing animal productivity will generally reduce methane emissions per kg of product (milk or meat) because the emissions associated with maintenance are spread over a larger amount of product. However, daily emissions and thus emissions per animal per year are usually increased because the higher productivity is
usually associated with higher intake. Methane production is closely related to dry matter (DM) intake [88]. Kirchgessner et al. [89] suggest an annual methane production rate of 110 kg from a dairy cow producing 5000 kg milk/year; doubling milk production only adds 5 kg to the methane production, as increasing milk yield from 4000 to 5000 kg/year increases annual methane emissions, but will decrease emissions per kg of milk by 0.16 for a 600 kg cow (Table 1). A further increase to 6000 kg/year would decrease emissions per kg of milk by a further 0.128. Johnson et al. [91] reported that for Wisconsin and New Zealand dairy herds demonstrate that there is still a reduction in total farm emissions from higher animal productivity after all these factors (Manure CH₄, CO₂, N₂O, Enteric CH₄) have been taken into account [90].

## CONCLUSION

The strategies discussed above and many others can have a potential effect on ruminal methane production. Proper management and utilization of dietary nutrient is an effective way of decreasing methane emissions per unit of animal product. Improving forage quality and the overall efficiency of dietary nutrient use is an effective way of decreasing GHG emissions per unit of animal product. Several feed supplements have potential to reduce enteric CH₄ emission from ruminants and some are may not be economically feasible in developing countries. Maybe farmers are unlikely to adopt some strategies and technologies unless they are cost-effective. One of effective and recommended approaches for improving animal productivity and reducing GHG emissions per unit of product is a reduction of herd size, which increases feed availability and productivity of individual animals and the total herd, thus lowering CH₄ emission per unit of product. Careful selection and combination of different feedstuffs can be an effective way to manipulate rumen fermentation in the desired direction. Therefore, methane mitigation strategies in ruminants should be focused on obtaining economic as well as environmental benefits.

Table 1: Estimates of methane emissions (kg/year and kg/kg milk in parentheses) from dairy cows as affected by annual milk yield and body weight [89]

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<td>100(0.02)</td>
<td>105(0.0175)</td>
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## REFERENCES


