ISSN: 2754-4958

Journal of Aquaculture & Livestock Production

Review Article

Open Access

Feeding and Nutritional Strategies to Reduce Methane Emission from Large Ruminants: Review

Diribi Mijena and Aman Getiso*

Ethiopian Institute of Agricultural Research, Wondo genet Agricultural Research Center 198, Shashemene, Ethiopia

ABSTRACT
Livestock are considered as a main source of GHGs emission by contributing approximately 9% of the total global emission and a major concern for global warming. Domestic animals account approximately 94% of the total global emissions of animals from these large ruminants (dairy and beef cattle) produce 30% and 35% of the livestock sectors' emissions. Most methane (CH4) that is emitted from livestock originates in the forestomach, also called the rumen, of ruminants. Minimizing amount of methane that comes from rumination can improve production efficiency of livestock and is environmentally a sound practice. The emission rate can be minimized by handling proper feeding and nutritional management strategies, which can reduce excretion of GHG during ruminant digestion process. Dietary manipulation, type of carbohydrates animals fed, forage quality and maturity, management of pasture land, nutrient composition of diet and feed intake, feeding frequency, fat supplementation, and inclusion of feed additives such as saponins, tannins and essential oils are among the best feeding and nutritional management strategies to minimize amount of methane produced during rumination. The aim of this review was to investigate feeding and nutritional management strategies used to reduce methane production from ruminants in general and large ruminants in particular.

***Corresponding author**
Aman Getiso, Ethiopian Institute of Agricultural Research, Wondo genet Agricultural Research Center 198, Shashemene, Ethiopia; E-mail: aman.getiso@yahoo.com.

Received: April 09, 2021; **Accepted:** April 15, 2021; **Published:** April 29, 2021

Keywords: Methane, Ruminant, Emission, GHGs

Introduction
Livestock contribute to global climate change by emitting Greenhouse gases (GHG) either directly (from enteric fermentation and manure management) or indirectly (from feed production and the processing and converting of forest into pasture). The carbon dioxide (CO2) that is emitted from livestock is not considered a net contributor to climate change because the animals consume plants that use CO2 during photosynthesis [1]. Consequently, methane (CH4) and nitrous oxide (N2O) are the most important GHGs from the animal production system and have very high global warming potentials (GWP) of 25 and 298 CO2 equivalent (eq), respectively [2]. Carbon dioxide (CO2), Methane (CH4), and Nitrous oxide (N2O) absorb heat from infrared rays coming from the sun and contribute to climate change; with a warming potential equivalent to 1, 28 and 265 times that of CO2 over a 100-year period, respectively (IPCC, 2013).

Methane (CH4), one of the three main GHGs besides of carbon dioxide (CO2) and nitrous oxide (N2O), have a global warming potential of 28-fold than that of carbon dioxide (CO2) [3]. Methane is expected to contribute approximately 18% of the total expected global warming within the next 50 years of which the contribution of livestock to the total global emission is approximately 9% domestic animals account approximately 94% of the total global emissions of animals [4]. Although emissions have decreased per unit of animal product, the total emission has increased from a vast animal population around the globe [5]. Most methane (CH_4) that is emitted from livestock originates in the forestomach, also called the rumen, of ruminants (cattle and sheep). This source of methane is called enteric CH_4. Only about 10% of the total CH_4 from ruminants in Canada is from manure. While the digestion process enables ruminants to convert forages into usable energy, a portion of the feed energy (3 to 12%) is used to produce enteric CH_4, and is released into the atmosphere as the animal breathes [6]. Minimizing the production of CH_4 can improve efficiency of livestock production and is an environmentally sound practice.

Agricultural sector is considered to contribute the biggest methane emission, which calculated around 50.6% from anthropogenic methane [7]. Within agriculture, the livestock sector contributes approximately 18% of the global anthropogenic GHG emission [1]. Among livestock, ruminant contributes about 81% of GHG due to massive methanogenesis by rumen microbes, which produce 90% of total CH_4 production from ruminants [8,9].

Globally, CH_4 emissions of large ruminants (dairy and beef cattle) denote 30% and 35% of the livestock sectors' emissions. However, buffalos and small ruminants are lower contributors, demonstrating 8.7% and 6.7% of sector emissions, respectively [10]. The CH_4 production in ruminants represents a gross energy loss from 2% to 14% of gross energy consumption [11]. Therefore, reduction of methane emission in animal conserves an energy and enhances productivity. By 2050, the total CH_4 emission from ruminant livestock is expected to increase significantly due to the growing demand of milk and meat for a rapidly growing world population [12]. Therefore, it is of utmost importance to mitigate CH_4 emission from the livestock industry, and there are several strategies for CH_4 mitigation from ruminants that have recently been reviewed and published [13-15].

Objective
To review feeding and nutritional strategies to reduce methane emission from large ruminants.

Literature Review

Definition of Methane
Methane (CH_4) is listed as one of the most important greenhouses gases in the Kyoto Protocol since 1997. In 2016, methane accounted for about 10 % of all greenhouse gas emissions in the EU 28, taking second place behind CO_2 in terms of quantity and effect. The formation of methane is an important process in the global carbon cycle. Methane is the main component of natural gas and is present as a gas hydrate in marine and permafrost soils. In addition, methane is produced during rotting and fermentation processes under anaerobic conditions (under exclusion of oxygen). Preferred habitats for methanogenic bacteria and thus natural methane sources are the stomachs of ruminants. In addition, methane is produced during rotting and fermentation processes under anaerobic conditions (under exclusion of oxygen). Preferred habitats for methanogenic bacteria and thus natural methane sources are the stomachs of ruminants. Photochemical oxidation processes in the atmosphere produce carbon monoxide (CO) and ozone (O_3) from methane. Due to its relatively short atmospheric residence time (less than 20 years), methane is one of the short-lived climate pollutants (SLCP).

Source of Methane Emission
Anthropogenic methane in Europe comes largely from agriculture. Other relevant methane emitters are waste management and the energy sector. These three essential sectors for methane emissions have contributed to methane reduction to varying degrees since 1990. Between 1990 and 2016, methane emissions decreased by 11 million tons to 18 million tons (equivalent to a reduction of about 39 %). Emissions in the energy sector fell significantly for about 56 %, also the emissions by waste management (minus 44 %) were reduced considerably. With the adoption of the Landfill Directive 1999/31/E C, the European Union has provided an effective instrument to reduce methane emissions by reducing the amount of biodegradable municipal waste, for the collection and incineration of landfill gas. The main driver for absolute decrease in agricultural methane emissions (minus 22 %) in EU 28 was the reduction of ruminant livestock numbers, particularly in newer member states. Accordingly, the share of sources in total methane emissions in Europe has shifted significantly. Since greater savings have been achieved in the other areas, agriculture increased its share to more than half of methane emissions, accounting for around 52 % in 2016 [17].

Enteric Methanogenesis in Ruminants
Methanogenesis is a process of CH_4 production in the rumen where H2 reduced the CO_2 with the help of methanogenic archaea. This is a dynamic process, in which methanogens strongly influence the metabolism of fermentative and acetogenic bacteria via interspecies hydrogen transfer [18]. Enteric CH_4 emission is produced as a result of microbial fermentation of feed components. Methane, a colorless, odorless gas, which is produced predominantly in the rumen (87%) and to a small extent (13%) in the large intestines [19].

Globally, ruminant livestock produce ~80 million tons of CH_4 annually accounting for ~33% of anthropogenic emissions of CH_4 [17]. Enteric CH_4 is produced under anaerobic conditions in the rumen, by methanogenic Archaea, utilizing CO_2 and H_2 to form CH4, thus reducing metabolic H2 produced during microbial metabolism [20]. If H_2 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 H_2 removal from the rumen as well [21].

Ruminants are unique in their ability to use forages as an energy source for maintenance, growth and milk production. Plant carbohydrates are broken down by the bacteria in the rumen, producing volatile fatty acids (VFA), the major energy source for the animal. The main VFAs are acetate, propionate, and butyrate. The proportions of each depend on the type of feed. Ruminal digestion generates hydrogen (H_2) as an end product; the amount of H_2 depends on the abundance and type of VFA produced. For example, the formation of acetate generates twice the amount of H_2 compared to the formation of butyrate, whereas the formation of propionate uses up H_2. The accumulation of H_2 in the rumen inhibits feed digestion

Microorganisms in the rumen, also referred to as methanogens, convert H_2 and carbon dioxide into CH_4 and water. This process lowers the amount of H_2 in the rumen. Methane production is the main way that H_2 is used in the rumen. Strategies to lower enteric CH_4 production involve reducing the production of H_2 in the rumen, inhibiting the formation of CH_4, or redirecting H_2 into products such as propionate.

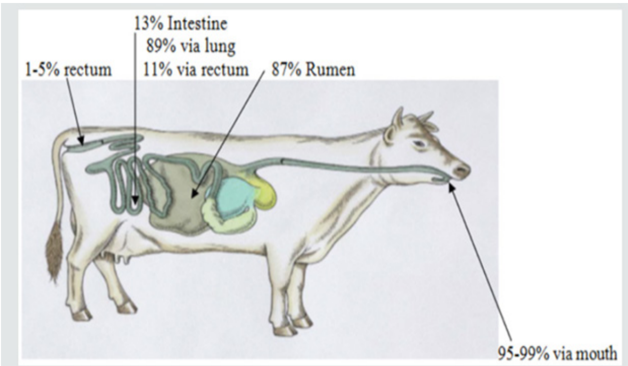

Figure 1: Emission of methane from Ruminants

Table 1: Typical ranges in CH_4 emissions from three classes of ruminant, energy lost as CH_4, with an estimate of effective annual grazing days lost.

Animal class	Average live weight (kg)	a CH_4 (kg/head/year)	b MJ CH_4 lost/head/day	c Average Daily Energy Requirement (MJ/head/day)	d Effective Annual Grazing days lost
Mature ewe	48	10-13	1.5-2.0	13	43-55
Beef	470	50-90	7.6-13.6	83	33-60
Lactating cow	550	91-146	13.6-22.1	203	25-40

Data drawn from studies reviewed below [a].

Assuming an energy density of 55.22 MJ/kg CH4 b (Brouwer,1965)
Effective annual grazing days lost d = c Daily Requirement/ [b] Energy lost x 365.25
(Standing Committee on Agriculture 1990) [c]

The major part of methanogenesis in ruminants occurs in the large fermentative chamber known as rumen. In here, methanogens utilize hydrogen and CO_2 to produce CH_4 [22].

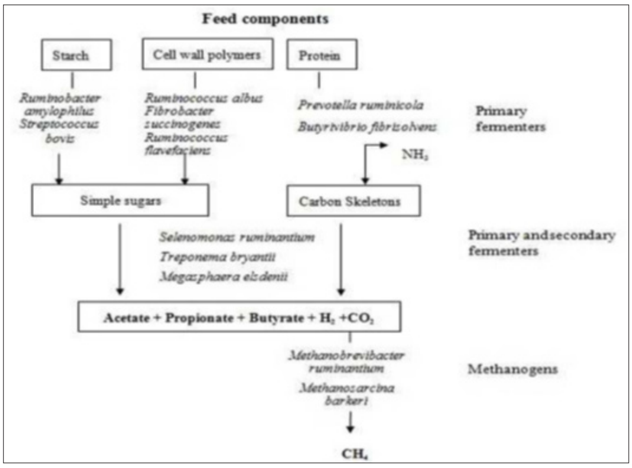

Figure 2: Process of Microbial Fermentation in the Rumen

Impact of Methane Emission on Global Warming

Short-lived climate pollutants (SLCPs) cause about 50 % of the global warming not induced by CO2 [23]. Methane is therefore an important climate driver. With a global warming potential (GWP100) of 28, methane has a 28 times stronger warming effect over 100 years than CO_2 (IPCC, 2014).

In addition, methane is an important precursor for the formation of ground-level ozone (EESI, 2013). Ground-level ozone is one of the most important air pollutants in Europe with negative health effects. Ozone also impairs the production capacity of natural, agricultural and forestry ecosystems. It damages agricultural crops and forests by limiting their growth rates (EEA, 2016). Exposure during the flowering phase leads to severe changes in plant composition and a reduction in biological diversity [24].

In the global worming view, CH4 is particularly the major greenhouse gas (GHG) which has a global potential 23 times that of carbon dioxide (IPPC,2007), and accounts for 16% of the total global GHGs emissions. From livestock, most CH_4 is produced from enteric fermentation, which is a natural process produced by ruminant animals, being responsible for one-third of methane from agriculture, and the enteric methane produced by ruminants has its origin in the rumen [25].

According to, over the past decades concern has arisen over the accumulation of gases in the atmosphere that are capable of trapping heat, leading to increased average global temperatures. It is highly likely that these so-called greenhouse gases have increased in concentration in the atmosphere due to the increased size of the human population and its concomitant activities [26].

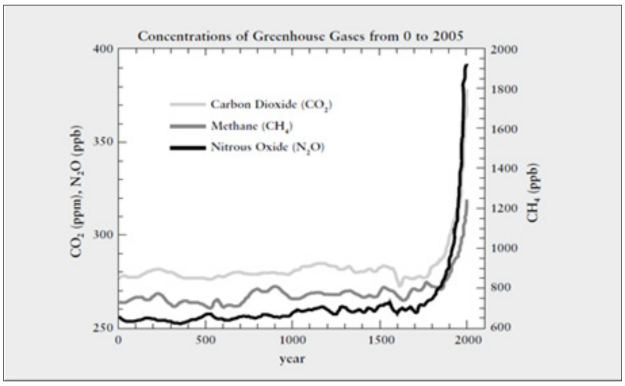

Figure 3: Atmospheric concentrations of the three main greenhouse gases carbon dioxide, methane and nitrous oxide in the period 0-2005 (Forster et al., 2007)

Quantitatively, the most important greenhouse gas is carbon dioxide and about 77% of global warming is attributed to the increased atmospheric concentration of this gas. Methane is the second most important gas involved in global warming and accounts for 14% of the human-induced production of greenhouse gases. To be able to compare greenhouse gases, their effect on global warming is usually expressed relative to CO_2. Methane has global warming potential that is 23-25 times larger than CO_2 and therefore contains 23-25 CO_2-equivalents.

Agricultural activities are responsible for 37% of anthropogenic methane emissions, with enteric methane emissions from ruminants representing the largest share (86 million tons or 23% of anthropogenic methane emissions; [1]. The global dairy sector has recently been estimated to contribute 4.0% of the globally produced greenhouse gases with more than 50% coming from methane (FAO, 2010). The relatively large contribution of enteric fermentation to the global production of greenhouse gases and the projected increase in demand for ruminant products have led to the initiation of many programs to assess strategies to reduce methane emissions from ruminants. Considering the increase in future demand for animal products, greenhouse gas emissions per unit of animal product will have to be more than halved in order to just maintain the current impact of animal husbandry on global warming [1].

Strategies to Reduce Enteric Methane Emission from Large Ruminants

Different strategies available to reduce CH_4 emission from enteric fermentation [27]. They categorize them as: dietary changes, direct rumen manipulation and systematic changes. The latter include considerations of breed, livestock numbers and intensiveness of production. More intensive production may result in lower CH_4 emission, but may be less desirable in terms of other environmental impacts. The amounts of CH_4 produced by ruminant animals are related to differences in levels of feed intake and extent of digestion, which are influenced by such factors as species, body weight (age), level of production, lactation stage, diet etc. Methane yield also tends to decrease as feed quality increases. For example, a six-fold decrease in CH_4 emission was observed when grazing cattle were switched to a high-quality feedlot diet in Canada observed that a reduction in forage in vitro organic matter digestibility (i.e., decline in forage quality) also resulted in an increase in CH_4 emissions when animals were fed ad libitum [28,29].

Existing strategies to lower enteric CH_4 emissions include increasing feed intake, proportion of concentrates in the diet, feeding high-quality forages or dietary supplements of plant and marine oils, oilseeds or specific fatty acids and ionophores. Decreases in enteric CH_4 emissions in response to increases in concentrate supplementation are thought to arise from several factors including a reduction in the molar acetate: propionate ratio of rumen volatile fatty acids, decreases in rumen pH and lowered protozoa numbers [13]. Therefore, implementation of certain animal feeding and grazing management practices could reduce CH_4 emissions and increase feed efficiency and cattle performance, as well as, mitigate. Regardless the specific target, the different mitigation options can be grouped into different 'levels of maturity' (GRA, 2014), indicating the readiness of the measure for implementation based on experiences in diverse settings

- Best practice: measure has been successfully implemented in diverse contexts, next step is scaling up.
- Pilot: pilot project has been carried out, next step is commercial development
- Proof of concept: the measure has been demonstrated in an experimental setting, next step is a pilot.
- Discovery: exploring promising concepts for future proof of concept.

Table 2: Those levels can be outlined as: CH4, a potential Win Situation

Mitigation strategy	Readiness	Main constraints for implementation
Forage Quality	Best practice	Farmers awareness and appropriate training (extension service) or social environment. Reluctant to change from traditional practices Commercial availability of appropriate genetic varieties for a given environment
Dietary ingredients	Best practice	Economic constraints (e.g. lipids)
Precision feeding	Best practice (intensive)	Economic costs of technology (animal id, feed supply)
Grass management	Best practice, Pilot (still knowledge gaps on some novel grass, mob grazing)	Dependency on weather conditions, knowledge gaps, Farmers awareness and appropriate training (extension service) or social environment Reluctant to change from traditional practices.
Additives, plant compounds		
Improving rumen function (essential oils, tannins)	Between Best practice and pilot	Consistency in effectiveness, lack of knowledge on mode of action (diet depending), lack of clarity in the market
Specific Methane inhibitors	Pilot	Safety, toxicology, commercial availability
Protected amino acids	Best practice	Cost, applicable to high-producing herds or individual animals at particular periods

Feeding and Nutritional Management Strategies

The type of feed allowed to a ruminant can have a major effect on methane production. Forage to concentrate ratio of the ration has an impact on the rumen fermentation and hence the acetate to propionate ratio [30]. It would therefore be expected that methane production would be less when high concentrate diets are fed [31].

According to, a high grain diet and/or the addition of soluble carbohydrates gave as shift in fermentation pattern in the rumen which give rise to a more hostile environment for the methanogenic bacteria in which passage rates are increased, ruminal PH is lowered and certain populations of protozoa, ruminal ciliates and methanogenic bacteria may be eliminated or inhibited [32].

The feed and nutrition-related interventions (supplementation with leguminous shrubs, use of urea molasses multi-nutrient blocks (UMMB), use of urea treated crop residues, supplementation with high protein or energy concentrate) result in a reduction in emission intensities between 16-44% [33]. Animals do not actually have a requirement for protein. Instead, they require the specific AA that are the building blocks that make up proteins [34]. In most situations, by selecting proper protein sources and judiciously using rumen protected amino acids (AAs), it should be theoretically possible to balance the amino acid needs of the cow while reducing crude protein intake. published a study that demonstrated that a ration with 16.1% CP and added RP-Met resulted in the same amount of milk as a 17.3% CP ration without RP-Met, and both rations resulted in higher milk production than an 18.3% ration. There are current studies underway to further refine this relationship. This nutritional strategy is normally used only for high yield animals [35].

Dietary Manipulation

Among the nutritional strategies of CH_4 mitigation, dietary manipulation is a simplistic and pragmatic approach that can ensure better animal productivity as well as a lower CH_4 emission. The schematic diagram of dietary manipulation, which alters the pathway of fermentation to reduce CH_4, is summarized in the following figure. Dietary manipulation can reduce CH_4 emission up to 40% depending the degree of change and the nature of the intervention [36]. Another study also indicated that CH_4 emissions can possibly be reduced up to 75% through better nutrition [37]. However, dietary manipulation is the most commonly practiced approach. Dietary strategies can be divided into two main categories. Firstly, improving the forage quality and changing the proportion of the diet, and the second one is dietary supplementation of feed additives that either directly inhibit methanogens or altering the metabolic pathways leading to a reduction of the substrate for methanogenesis.

Type of Carbohydrates

The type of carbohydrates in the diet can influence the proportion of individual VFA formed in the rumen and thus the amount of CH_4 produced. Fermentation of cell wall carbohydrates produces more CH_4 than fermentation of soluble sugars, which in turn produce more CH_4 than fermentation of starch [38].

Diets that are rich in starch favor propionate production and decrease CH_4 production per unit of fermentable organic matter in the rumen, whereas diets based on roughage favor acetate production and increased CH_4 production per unit of fermentable organic matter [5]. The decision to increase the utilization of grain in ruminant rations to reduce CH_4 production should consider not only economic matters, but also that ruminants have the ability to digest and convert fibrous feeds, unsuitable for human consumption, to high-quality protein sources (i.e., milk and meat). One option that should be explored is the development through breeding of tropical grass cultivars containing high levels of water-soluble carbohydrates to increase animal performance as a consequence reduce CH_4 per unit of product as has been shown with ryegrass genotypes in the UK [39]. The potential for CH_4 mitigation through the genetic improvement of forage species remains largely unexplored and has been the subject of a review recently published by the [4].

Forage Quality and Maturity

Forages are the feed ingredients with the largest variability in composition and have the largest impact on diet digestibility. Factors, such as plant species, variety, maturity at harvest and preservation can all affect forage quality and digestibility. In general terms, as the plant matures, the content in structural carbohydrates increases and that of more fermentable carbohydrates declines. Harvesting forages at the right time, depending on the type of forage, is important to maximize the amount and digestibility of nutrients supply by forages [7]. In general, CH_4 reductions are correlated with greater nutrient quality and digestibility, which are attributes for which forage type and maturity might be indicators. Increasing quality or digestibility of forages will increase production efficiency and this will likely result in decreased CH_4 provided a comprehensive review of the effects of silage quality on animal performance in various production systems in Ireland [40].

Forage Processing and Preservation

Supplementing forages whether of low or high quality, with energy and protein supplements, is well documented to increase microbial growth efficiency and digestibility [21]. Milk and meat production will increase as a result. The direct effect on methanogenesis is still variable and unclear, but indirectly, methane production per unit product will decline. Increasing the level of non-structural carbohydrate in the diet (by 25%) would reduce CH_4 production by as much as 20%, but this may result in other detrimental effects including acidosis, laminitis and fertility problems. In addition, many other factors which affect CH_4 production like season, age of animal, management of animal, and population of protozoa in the rumen [26].

Management of pasture land

Grasslands are an important source of low-cost and high-quality feed for ruminants in Europe. It is estimated that roughly half of the total dry matter intake by livestock at the global level comes from grass and other roughages, albeit with strong regional variations (GRA, 2014). Grassland soils also store large quantities of carbon and in many regions have the potential to sequester more carbon, while providing a range of other ecosystem services related to habitat and water quality. Improving management practices and breeding/adopting new species and cultivars can improve the quantity and quality of feed to animals and also, in some regions and systems, enhance soil carbon storage. However, the potential for carbon sequestration and techniques for achieving it are country/region specific, and differ across soil types, management practices and climate.

Developing grass varieties with specific traits aimed at improving feed efficiency or directly reducing emissions may be of significant importance for predominantly pasture-based ruminant production systems. The focus on development and subsequent uptake of the so-called 'high sugar' grasses in the UK is one example. These have been shown to improve N utilization by ruminants, which would result in less nitrogen excretion and therefore less subsequent N2O and ammonia emissions. They have also been shown in one UK trial to reduce enteric CH_4 emissions from grazing lambs by 20%, with the reduction hypothesized to be due to a combination of altered carbohydrate metabolism in the rumen towards propionate production (H-sink) and away from acetate formation (H-source) plus improved microbial growth through improved capture of N in the rumen, diverting surplus hydrogen away from CH_4 production and into microbial cells. However, was less conclusive on the effects of high sugar grasses and further research is needed to demonstrate both mechanism and effectiveness. Other targets for development include increasing the lipid content of grazed grasses, as lipids are known to suppress CH_4 production and to improve the quality/digestibility of the fibre content of grasses [41-43].

The inclusion of legumes in grassland for grazing or silage production has a direct benefit through the reduced requirement of fertilizer N input and therefore less direct N2O emissions associated with fertilizer use. In addition, there is also evidence of an effect of legumes in reducing enteric methane emissions although again this has not been shown consistently [44,45]. Including legumes in silage was reported to decrease methane by resulting from a lower fibre content and therefore higher passage rate through the rumen [46].

Potential pasture management practices to reduce emissions from grazing ruminants include shortening the duration of the grazing period (either a shorter period each day, or for a shorter season), removing grazing animals during conditions conducive to N2O emissions, avoiding the development of 'hot-spots' for soil emission of N2O or CH_4, and applying precision management techniques to the fertilization and utilization of pastures. The use of standoff pads in New Zealand grazing systems is increasing, where cattle are removed from the pasture for part of the day (particularly during wet soil conditions) and has been shown to be an effective measure for reducing N2O emissions [47]. However, there is a risk of increased NH_3 emissions from the management of the collected effluent, and these trade-offs must be considered in the context of system changes. Soil N2O and CH_4 emissions from 'hot spots' which develop through cattle poaching and disproportionately high excretal returns, for example around water troughs, gateways and tracks, can represent a substantial part of the entire GHG footprint of a farm [48]. Grazing management practices to avoid such 'hot spots might include regular movement of cattle between smaller paddocks (rotational grazing), regular movement of water troughs and temporary exclusion from poached areas. Precision pasture management techniques include the use of appropriate rates and timing of fertilizer N applications, planning of herbage production and quality in relation to livestock requirement through the season and managing livestock movement to ensure forage is grazed at optimum time in terms of quality and availability. These measures will improve production efficiency and reduce GHG emission per unit of production. Further discussion of mitigation through grassland management can be found in the Global Research Alliance report on Reducing greenhouse gas emissions from livestock [49].

Nutrient composition of diet and feed intake

Diet composition and intake of feed are main factors affecting CH_4 production by ruminants. Ruminant fed forages rich in structural carbohydrates produce more CH_4 than those fed mixed diets containing higher levels of non-structural carbohydrates per unit of fermented material in the rumen [50]. Generally, as the daily feed intake increases, CH_4 production also increases [51]. Most studies agree that dry matter intake (DMI) is the main driver of daily methane output although methane output per kilogram of DMI decreases with increasing feeding level, diet digestibility, and with increasing proportions of concentrates or lipids in the diet [52,53].

The composition of feed or the quality of forage influences CH_4 production in ruminants. Digestion in the rumen is dependent on the activity of microorganisms, which need energy, nitrogen and minerals [54]. Therefore, the quality of forage affects the activity of rumen microbes and CH_4 production in the rumen. Forage species, forage processing, proportion of forage in the diet, and the source of the grain also influence CH4 production in ruminants. Methane production tends to decrease as the protein content of feed increase and increases as the fiber content of feed increases. Methane production is positively related to diet digestibility and negatively related to dietary fat concentration, whereas dietary carbohydrate composition had only minor effects [50]. Production of CH_4 has a negative impact on animal productivity, resulting in lost energy ranging from 2% to 12% of the animal's GEI [55].

Feeding Frequency

Low meal frequencies tend to increase propionate production; reduce acetic acid production and lower CH4 production in dairy cows [56]. This effect is associated with the lowering of methanogens as a result of high fluctuations in ruminal pH, since low meal frequencies increase diurnal fluctuations in ruminal pH that can be inhibitory to methanogens [57]. On the other hand, investigate that, more frequent feeding was shown to increase the acetate: propionate ratio [58]. They observed that when concentrates were fed to Holstein cows in 12 equal portions at 2 hours intervals compared to two equal portions, the higher feeding frequency tended to elevate ruminal PH, increase acetate: propionate ratio and milk fat percentages. When lactating cows were supplemented with protein concentrate either two or five times daily, average rumen PH was higher and propionate lower in cows supplemented with five meals [59]. Producers are encouraged to increase their feeding frequency to reduce daily fluctuations in ruminal PH and to ensure efficient digestion and milk production. Thus, low frequency feeding as a strategy to reduce CH4 production would not be practical to producers.

Fat supplementation

Dietary fat is not fermented in the rumen and, consequently, less hydrogen per unit of feed is produced when higher fat levels are included in the diets for ruminants. Increasing the dietary fat content has therefore been proposed as a promising strategy to reduce methane emissions from ruminants [13,17]. Moreover, individual fatty acids have been considered to have specific anti-methanogenic properties, and methane production could be further reduced by using these specific fatty acids [60]. Lipids are an option for feed supplementation that has been studied for their effects on methanogenesis process [61]. Oils, such as coconut oil, was used in simulators against rumen fermentation and showed that the main component (lauric acid) inhibited methanogenesis. But it has negative effect on digestibility of feed so not feed lipid more than 10% to the animal [62].

Feed additives supplementation

Activities of the rumen will be disrupted if methane production is significantly decreased by directly inhibiting methanogenic archaea without the provision of alternative hydrogen sinks, which implies that methane production is unavoidable in ruminant production systems. However, recent work suggest that methane production ruminants can be significantly decreased by inhibiting the metabolism of methanogenic archaea with little effect on rumen function and diet digestibility [17]. Indeed, studies on the rumen transcriptome suggest that the methane-inhibited rumen adapts to high hydrogen levels by shifting fermentation to alternative H sinks and direct emissions of H_2 from the rumen [63,64].

Given that methane emissions can be significantly reduced without affecting production and health attention should focus on the practical means by which this might be achieved. The greatest progress has been in the areas of diet and dietary additives to mitigate against ruminal methane emissions,4 with decreases in excess of 60 % reported in cattle fed specific dietary additives [4-64]. Recent data suggest that, in many cases, additives enhance capacity to mitigate against ruminal CH_4 production. While perhaps technically possible to achieve considerable (above 50 %) reduction in methane emissions through the use of specific inhibitors, a number of practical issues need to be considered [65].

Some feed additives from plant extracts have been analyzed for their ability to reduce rumen CH_4 production [66]. Such plant extracts are saponins, tannins and essential oils, but in the last years many other feed additives were studied. used condensed tannins from Lespedeza cuneata against rumen CH_4 production and found that reduced methane emissions by up to 57% in terms of g/kg DMI [64]. Other authors found that sheep consuming 41g of tannin containing Acacia mearnsii per kg DM produced methane with 13% less than sheep feed normal forage [67]. Saponins containing Sapindussaponaria reduced methane emissions by up to 20% without affecting methanogens number [68]. In other studies, saponins were found to inhibit protozoa number in vitro and to limit hydrogen availability for methanogenesis [69]. It was found that essential oils present the same effect such as monensin by inhibiting gram-positive bacteria [57].

Conclusion

Any sustainable solution to lower on-farm CH_4 emissions should be practical, cost effective and have no substantial adverse effect on the profitability of livestock production. The amounts of CH4 produced by ruminant animals are related to differences in levels of feed intake and extent of digestion, which are influenced by such factors as species, body weight (age), level of production, lactation stage, diet etc. Reduction of ruminal methane production in ruminants is a difficult issue. However, we can achieve progress towards reducing methane production from biotechnologies, reducing the number by increasing the efficiency of animals, producing high quality forages and pastures, use of alternative forage and concentrate feeds which has high content of ingredients such as tannin and saponin, and also using of probiotics [70-78].

Manipulating diet composition to induce changes in rumen fermentation characteristics remains the most feasible approach to lower methane production. Implementation of certain animal feeding and grazing management practices could reduce CH_4 emissions and increase feed efficiency and cattle performance, as well as, mitigate CH_4, a potential Win Situation. Lowering CH_4 production per unit product over the lifetime of a ruminant should be seen as the central goal to decrease GHG from ruminant livestock systems.

References

1. Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, et al. (2006) Livestock's long shadow: Environmental issues and options. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).
2. Solomon S, Qin D, Manning M, Chen Z, Marquis M, et al. (2007) Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change.
3. Pachauri RK, Allen MR, Barros VR, Broome J, Cramer W, et al. (2014) Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change (p 151) Ipcc.
4. FAO (2007) The genetic improvement of forage grasses and legumes to reduce greenhouse gas emissions. (www.fao.org/ag/AGP/.../abberton_%20geneticimprovement.pdf).
5. Milich L (1999) The role of methane in global warming: where might mitigation strategies be focused? Glob Environ Change 9: 179-201.
6. Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, et al. (2013) Tackling climate change through livestock-a global assessment of emissions and mitigation opportunities. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).
7. Johnson KA, Johnson DE (1995) Methane emissions from cattle. Journal of animal science, 73: 2483-2492.
8. Karakurt I, Aydin G, Aydiner K (2012) Sources and mitigation of methane emissions by sectors: a critical review. Renewable energy 39: 40-48.
9. Hristov AN, Oh J, Lee C, Meinen R, Montes F, et al. (2013) Mitigation of greenhouse gas emissions in livestock production. In: Gerber PJ, Henderson B, Makkar HPS, editors. A review of options for non-CO2 emissions. Rome: FAO 226.
10. McAllister TA, Meale SJ, Valle E, Guan LL, Zhou M, et al. (2015) Ruminant nutrition symposium: use of genomics and transcriptomics to identify strategies to lower ruminal methanogenesis. Journal of animal science 93: 1431-1449.
11. Opio C, Gerber P, Mottet A, Falcucci A, Tempio G, et al. (2013) Greenhouse gas emissions from ruminant supply chains – a global life cycle assessment. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).
12. Johnson KA, Johnson DE (1995) Methane emissions from cattle. Journal of animal science, 73: 2483-2492.
13. Gerber PJ, Henderson B, Tricarico JM (2013) SPECIAL TOPICS-Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. J. Anim. Sci 91: 5045-5069.
14. Eckard RJ, Grainger C, de Klein CAM (2010) Options for the abatement of methane and nitrous oxide from ruminant production: a review. Livest Sci 130: 47–56.
15. Martin C, DP Morgavi, M Doreau (2010) Methane mitigation in ruminants: From microbe to the farm scale. Animal 4: 351-365.
16. Beauchemin KA, Kreuzer M, O'mara F, McAllister TA (2008) Nutritional management for enteric methane abatement: a review. Australian Journal of Experimental Agriculture 48: 21-27.
17. European Environment Agency EEA (2018) National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism (Data retrieved 13.2.2019).
18. Stams AJ, Plugge CM (2009) Electron transfer in syntrophic communities of anaerobic bacteria and archaea. Nat Rev Microbiol 7: 568-577.
19. Torrent J, Johnson DE (1994) Methane production in the large intestine of sheep. Pages 391–394 in J. F. Aquilera, eds. Energy metabolism of farm animals. EAAP Publication No. 76. CSIC. Publishing Service. Granada, Spain.
20. Beauchemin KA, Kreuzer M, O'mara F, McAllister TA (2008) Nutritional management for enteric methane abatement: a review. Australian Journal of Experimental Agriculture 48: 21-27.
21. McAllister T & Newbold CJ (2008) Redirecting rumen fermentation to reduce methanogenesis. Australian Journal of Experimental Agriculture 48: 7-13.
22. Joblin KN (1999) Ruminal acetogens and their potential to lower ruminant methane emissions. Australian Journal of Agricultural Research 50: 1307-1314.
23. Patra AK (2011) Enteric methane mitigation technologies for ruminant livestock: a synthesis of current research and future directions. Environ Monit Assess 184: 1929-1952.
24. Fuhrer J, Val Martin, M Mill, G Heald CL, Harmens H, et al. (2016) Current and future ozone risks to global terrestrial biodiversity and ecosystem processes. Ecology and Evolution 6: 8785-8799.
25. Moss AR, Jouany J, Newbold J (2000). Methane production by ruminants: its contribution to global warming. Annales De Zootechnie 49: 231-253.
26. Forster PV, Ramaswamy P, Artaxo T, Berntsen R, Betts DW, et al. (2007) Changes in atmospheric constituents and in radiative forcing. In: Climate change: The physical science basis. Contribution of working group i to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK.
27. Hopkins A, Del Prado A (2007) Implications of climate change for grasslands in Europe, impacts, adaptations and mitigation options: a review. Grass and Forage Science 62: 118-126.
28. Harper LA, Denmead OT, Freney JR, Byers FM (1999) Direct measurements of methane emissions from graing and

feedlot cattle. J. Anim. Sci. 77: 1392-1401.

29. Boadi, DA, Wittenberg KM (2002) Methane production from dairy and beef heifers fed forages differing in nutrient density using the Sulphur hexafluoride (SF6) tracer gas technique. Canadian Journal of Animal Science 82: 201-206.
30. Dana Olijhoek, Peter Lund (2017) Methane production by ruminants. Department of Animal science AU-Foulum. Aarhus University, Denmark.
31. Finlay BJ, Esteban G, Clarke KJ, Williams AG, Embley TM, et al. (1994) Some rumen ciliates have endosymbiotic methanogens. fems Microbial Lett 117: 157-162.
32. Van Soest PJ (1982) Nutritional ecology of the ruminant. O & B Books. Inc., Corvallis, OR 374.
33. Carolyn Opio (2017) Feeding strategies to reduce methane and improve livestock productivity. Broadening Horizones 39.
34. NRC (2001) Nutrient requirements of dairy cattle. 7th rev. ed. Natl. Acad. Press, Washington, DC.
35. Eugene MD, Masse J Chiquette, C Benchaar (2008) Short communication: Meta-analysis on the effects of lipid supplementation on methane production in lactating dairy cows. Can. J. Anim. Sci 88: 331-334.
36. Benchaar C, Pomar C, Chiquette J (2001) Evaluation of dietary strategies to reduce methane production in ruminants: a modelling approach. Can J Anim Sci 2001 81: 563–574.
37. Mosier AR, Duxbury JM, Freney JR, Heinemeyer O, Minami K,et al. (1998) Mitigating agricultural emissions of methane. Clim Chang 40: 39-80.
38. Johnson DE, Ward GW, Ramsey JJ (1996) Livestock methane: current emissions and mitigation potential. Nutrient management of food animals to enhance and protect the environment 219-234.
39. Lovett DK, McGilloway D, Bortolozzo A, Hawkins M, Callan J, et al. (2006) In vitro fermentation patterns and methane production as influenced by cultivar and season of harvest of Lolium perenne L. Grass and Forage Science 61: 9-21.
40. Keady TWJ, CM Marley, ND Scollan (2012) Grass and alternative forage silages for beef cattle and sheep: Effects on ani- mal performance. In: K. Kuoppala, M. Rinne, and A. Vanhatalo, editors, Proc. XVI Int. Silage Conf. Hameenlinna, Finland. MTT Agri food Research Finland, University of Helsinki 152-165.
41. Moorby JM, Evans RT, Scollan ND, Macraet JC, Theodorou MK (2006) Increased concentration of water-soluble carbohydrate in perennial ryegrass (Lolium perenne L.). Evaluation in dairy cows in early lactation. Grass Forage Sci 61: 52-59.
42. Defra (2010) Ruminant nutrition regimes to reduce methane and nitrogen emissions. Project AC0209 available at: http://randd.defra.gov.uk/
43. Parsons AJ, JS Rowarth, S Rasmussen (2011) High-sugar grasses. CAB Rev 6: 1-12.
44. Waghorn GC, Tavendale MH, Woodfield DR (2002) Methanogenesis from forages fed to sheep. In Proceedings of the New Zealand Grassland Association 167-171.
45. Hammond KJ, Hoskin SO, Burke JL, Waghorn GC, Koolaard JP, et al. (2011) Effects of feeding fresh white clover (Trifolium repens) or perennial ryegrass (Lolium perenne) on enteric methane emissions from sheep. Anim. Feed Sci. Technol 166-167: 398-404.
46. Dewhurst RJ (2012) Milk production from silage: comparison of grass, legume and maize silages and their mixtures. In: K. Kuoppala, M. Rinne and A. Vanhatalo, eds., Proc. XVI Int. Silage Conf. MTT Agrifood Research Finland, University of Helsinki, Hameenlinna, Finland 134-135.
47. Luo J, Ledgard SF, Lindsey SB (2008) A test of a winter farm management option for mitigating nitrous oxide emissions from a dairy farm. Soil Use Manage 24: 121-130.
48. Matthews RA, Chadwick DR, Retter AL, Blackwell MSA, Yamulki S (2010) Nitrous oxide emissions from small-scale farmland features of UK livestock farming systems. Agriculture, ecosystems & environment 136: 192-198.
49. GRA (2014) Reducing greenhouse gas emissions from livestock: Best practice and emerging options. Global Research Alliance and SAI Platform. Available at http://globalresearchalliance.org/wp-content/uploads/2014/12/LRG-SAI-Livestock Mitigation_web2.pdf
50. Sauvant D, S Giger-Reverdin (2009) Modélisation des inerac- tions digestives et de la production de méthane chez les ruminants. INRA Prod. Anim 22: 375-384.
51. Shibata M, Terada T (2010) Factors Affecting Methane Production and Mitigation in Ruminants. Animal Science Journal 81: 2-10.
52. Grainger C, Clarke T, McGinn SM, Auldist MJ, Beauchemin KA, et al. (2007) Methane emissions from dairy cows measured using the sulfur hexafluoride (SF6) tracer and chamber techniques. Journal of dairy science 90: 2755-2766.
53. Beauchemin KA, McGinn SM, Benchaar C, Holtshausen L (2009) Crushed sunflower, flax, or canola seeds in lactating dairy cow diets: Effects on methane production, rumen fermentation, and milk production. Journal of dairy science 92: 2118-2127.
54. Chianese DS, Rotz CA, Richard TL (2009) Simulation of methane emissions from dairy farms to assess greenhouse gas reduction strategies. Transactions of the ASABE, 52: 1313-1323.
55. Haarlem Van RP, Desjardins RL, Gao Z, Flesch TK, Li X (2008) Methane and Ammonia Emissions from a Beef Feedlot in Western Canada for a Twelve-Day Period in the fall. Canadian Journal of Animal Science 88: 641-649.
56. Sutton JD, Hart IC, Broster WH, Elliott RJ, et al. (1986) Feeding frequency for lactating dairy cows: Effects of rumen fermentation and blood metabolites and hormones. Br. J. Nutr 56: 181-192.
57. Shabi Z, Bruckental I, Zamwell S, Tagari H, Arieli A (1999) Effects of extrusion of grain and feeding frequency on rumen fermentation, nutrient digestibility, and milk yield and composition in dairy cows. J. Dairy Sci 82: 1252-1260.
58. French N, Kennelly JJ (1990) Effects of feeding frequency on ruminal parameters, plasma insulin, milk yield, and milk composition in Holstein cows. J. Dairy Sci 73: 1857-1863.
59. Casper DP, Maiga HA, Brouk MJ, Schingoethe DJ (1999) Synchronization of carbohydrate and protein sources on fermentation and passage rates in dairy cows. Journal of dairy science 82: 1779-1790.
60. Machmuller A (2006) Medium-chain fatty acids and their potential to reduce methanogenesis in domestic ruminants. Agric. Ecosyst. Environ 112: 107-114.
61. Hook SE, Wright ADG, McBride BW (2010) Methanogens: methane producers of the rumen and mitigation strategies. Archaea.
62. Kristensen T, Mogensen L, Knudsen MT, Hermansen JE (2011) Effect of Production System and Farming. Strategy

on Greenhouse Gas Emissions from Commercial Dairy Farms in a Life Cycle Approach. Livestock Science 140: 136-148.

63. Abecia L, Toral PG, Martín-García AI, Martínez G, Tomkins NW, et al. (2012) Effect of bromochloromethane on methane emission, rumen fermentation pattern, milk yield, and fatty acid profile in lactating dairy goats. Journal of dairy science 95: 2027-2036.
64. Mitsumori M, Shinkai T, Takenaka A, Enishi O, Higuchi K, et al. (2012) Responses in digestion, rumen fermentation and microbial populations to inhibition of methane formation by a halogenated methane analogue. British Journal of Nutrition 108: 482-491.
65. Haisan J, Sun Y, Beauchemin K, Guan L, Duval S, et al. (2013) Effect of feeding 3-nitrooxypropanol on methane emissions and productivity of lactating dairy cows. Adv. Anim. Biosci 4: 260.
66. Hristov AN, Oh J, Giallongo F, Frederick TW, Harper MT, et al. (2015) An inhibitor persistently decreased enteric methane emission from dairy cows with no negative effect on milk production. Proceedings of the national academy of sciences 112: 10663-10668.
67. Leahy SC, Kelly WJ, Altermann E, Ronimus RS, Yeoman CJ (2010) The Genome Sequence of the Rumen Methanogen Methanobrevibacter ruminantium Reveals New Possibilities for Controlling Ruminant Methane Emissions. PLoS ONE 5: e8926.
68. Tavendale MH, Meagher LP, Pacheco D, Walker N, Attwood GT (2005) Methane production from in vitro rumen incubations with Lotus pedunculatus and Medicago sativa, and effects of extractable condensed tannin fractions on methanogenesis. Animal Feed Science and Technology 123: 403-419.
69. Carulla JE, Kreuzer M, Machmüller A, Hess HD (2005) Supplementation of Acacia mearnsii tannins decreases methanogenesis and urinary nitrogen in forage-fed sheep. Australian journal of agricultural research 56: 961-970.
70. Hess HD, Beuret RA, Lotscher M, Hindrichsen IK, Machmuller A, et al. (2004) Ruminal fermentation, methanogenesis and nitrogen utilization of sheep receiving tropical grass hay-concentrate diets offered with Sapindus saponaria fruits and Cratylia argentea foliage. ANIMAL SCIENCE-GLASGOW THEN PENICUIK 79: 177-189.
71. Guo YQ, Liu JX, Lu Y, Zhu WY, Denman SE, et al. (2008) Effect of tea saponin on methanogenesis, microbial community structure and expression of mcrA gene, in cultures of rumen micro-organisms. Letters in Applied Microbiology, 47: 421-426.
72. Broderick GA (1995) Desirable characteristics of forage legumes for improving protein utilization in ruminants. --p. 2760-2773 (No. HEM). En: Journal of Animal Science 73: 9.
73. Brouwer E (1965) Report of sub-committee on constants and factors. In Proceedings of the 3rd symposium on energy metabolism of farm animals. European association for animal production 11: 441-443.
74. Environmental and Energy Study Institute EESI (2013) Short-Lived Climate Pollutants: Why are they important? Washington D.C.
75. European Environment Agency EEA (2016) Air quality in Europe-2016 report Copenhagen.
76. FAO (2010) Greenhouse gas emissions from the dairy sector. A life cycle assessment. Food and Agriculture Organization of the United Nations, Rome, Italy.
77. IPCC (2007) Climate change 2007-the physical science basis: Working group I contribution to the fourth assessment report of the IPCC (Vol. 4). Cambridge university press.
78. IPCC (2014) Summary for Policymakers. In: IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151: 9169-1432.