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Synopsis

Factors Affecting Mitigation of Methane Emission from Ruminants: Management Strategies

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Abstract. Nowadays, 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 times more global warming potential than carbon dioxide. Worldwide, ruminant livestock produce about 80 million metric tons of methane each year, accounting for about 28% of global emissions from human related activities. Therefore it is impelling animal scientists to finding solutions to mitigate methane emission from ruminants. It seems that solutions can be discussed in four topics including: nutrition (feeding), biotechnology, microbiology and management strategies. We have already published the first review article on feeding strategies. In the current review, management strategies such as emphasizing on animals - type and individual variability, reducing livestock numbers, improving animal productivity and longevity as well as pasture management; that can be leads to decreasing methane production from ruminant animal production are discussed.

Key words: global warming, methane, enteric fermentation, ruminant, management.

Abbreviations: GHG - greenhouse gas; WSC - water soluble carbohydrate; MCR - methane conversion rate; F:C ratio - forage to concentrate ratio; CT - condensed tannins; DMI - dry matter intake; PEG - polyethylene glycol; VFA - volatile fatty acids; FA - fatty acid; bST - bovine somatotrophin; OSHF - Overseas Holstein; FCCC - framework convention on climate change.

Introduction

Climate change is a subject of global environmental concern. Increased anthropogenic Greenhouse Gas (GHG) emissions have increased the global temperature the last 100 to 200 years (MIRZAEI-AGHSAGHALI & MAHERI-SIS, 2011). Methane is considered a potent greenhouse with capability of trapping 21 times more heat (Global Warming Potential) than carbon dioxide also its life time in the atmosphere is 9-15 years and over the last two centuries, methane atmospheric concentrations have more than doubled arising 1% yearly in comparison with 0.5% of carbon dioxide. Worldwide, ruminant livestock produce about 80 million metric tons of methane each year (representing 11% sheep and goat), accounting for about 28% of global emissions from human related activities (MURO-REYES *et al.*, 2011; UMEGHALU & OKONKWO, 2012; SHRESTHA *et*

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al., 2013). Under the Climate Change, the UK Government is legally required to reduce greenhouse gas (GHG) emissions across the UK economy by 80% of 1990 levels, by 2050. The agriculture sector is committed to playing its part in meeting this national goal and will need to demonstrate an 11% reduction on 2008 levels, by 2020. To support the industry's position and efforts, better data are required on the carbon footprint of milk production from dairy farms. Focusing on more efficient use of inputs will also help reduce costs of production, as well as enhance the environmental credentials of the dairy industry (DAIRY CO, 2012).

Ruminant animals (particularly cattle, buffalo, sheep, goat and camels) produce significant amount of methane under the anaerobic conditions of the digestive processes (SEJIAN *et al.,* 2011a; ASSAN, 2014; ASSAN, 2015). Methane produced during anaerobic fermentation in the rumen represents 2-12% gross energy loss and emission from livestock contributes approximately 15% of the total atmospheric methane flux (ZHI-HUA *et al.,* 2012; MAHESH *et al.,* 2013). CH_4 is considered a 'greenhouse gas' and emission of the global cattle population of 1-3 billion are estimated to be 58 million tonnes/year, or 73% of the emissions from all livestock species according to the US Environmental Protection Agency (1994) (TIEMANN *et al.,* 2008; KURIHARA *et al.,* 1999). As indicated before, dietary changes are a promising means to reduce CH_4 losses. Such changes may well affect the composition of the products (WAGHORN & WOODWARD, 2004).

With appropriate strategy and potential future technologies and management practices could reduce CH_4 emissions per unit of animal product by 25–75% (MOSIER *et al.,* 1998). However, except for the improved feeding management, the present technologies to control CH_4 emission from ruminants are seen with pessimism (JOHNSON *et al.,* 1996; SEJIAN *et al.,* 2011b).

Important manure management factors affecting CH_4 formation during storage are the dry matter (DM) content of manure and its storage duration, and also the ambient temperature (STEINFELD *et al.,* 2006; MIRZAEI-AGHSAGHALI & MAHERI-SIS, 2008).

This review looks more closely at the reasons for, and the consequences of, methane production from ruminant livestock which in turn is dependent on management strategies.

To discuss factors relation to emissions of GHG's (specific methane gas) from ruminants, we divided them in four groups, nutrition, management, biotechnology and microbiology. In this article, we will discuss factors relation management strategies and factors relation to biotechnology and microbiology will discuss in further article.

1. Animals - type and individual variability

The decrease in emissions through low CH_4 producing animals has been debated in the last few years. It has been established by several research groups that between-animal variability, at the same level of performance and using similar diets, is high.

Methane production from individual animals may vary over time, even when animals are fed a constant amount of the same quality feed each day. Within animal variation in absolute CH_4production from day-to-day in sheep and cattle has been reported to be approximately 7% (coefficient of variation, CV) when animals were fed a constant amount of consistent quality feed. One group of researchers reported that the CV for day-to-day variation in CH_4 production was approximately 27% whether animals were fed ad libitum or on a restricted diet (JOHANNES, 2008, New Zealand, pers. comm.).

Intensification of livestock production through better breeding and/or feeding to decrease global greenhouse gas emissions needs to be carefully assessed and will remain a hot debate in the foreseeable future (MARTIN *et al.,* 2010). Calorimetric studies have reported between-animal differences (CV) in daily CH_4 production of 7-8% and 11.7% when animals were fed a constant diet and 17.8% for lactating daily cattle fed ad libitum (GRAINGER *et al.,* 2007).

DADO & ALLEN (1994), investigate the variation in and relationships among feeding, chewing, and drinking variables for lactating dairy cows. In this experiment twelve Holstein cows (63 DIM; 6 primiparous) were offered a common diet and monitored for 21 d (11 d of adaptation, 10 d of collection) with a data acquisition system to measure continuously feed and water intakes and chewing behavior and reported coefficients of variation across cows ranged from 5 to 41% for the variables studied as coefficient of variation in their eating time of 17% (mean 301 min/day), 16% for ruminating time (mean 457 min/day) and 24% for their water intake (mean 78 L /day) (DADO & ALLEN, 1994).

BLAXTER & CLAPPERTON (1965) reported a 7.2% CV for day-to-day variation based on 989 24-h determinations of CH_4 for sheep and cattle. They also reported a CV between animals of 5.0 to 7.5% for sheep given a fixed amount of feed. The CV between animals, however, appears to be larger in chamber studies when intake is not restricted (BLAXTER & CLAPPERTON, 1965).

Further, grazing animals may differ in the diet eaten by selectively grazing certain parts of the sward (BRAND, 2000). Salivation rates also differ, with typical quantities of saliva produced per day of 150 liters in cattle and 10 liters in sheep, although estimates vary from 38 to 190 L/day for non-lactating dairy cattle (JACQUES *et al.*, 1989). Saliva is essentially a bicarbonate-phosphate buffer with a pH around 8, and the large volumes secreted provide an aqueous medium for the rumen organisms and help to jeep the rumen contents at near neutrality (HOBSON & STEWART, 1997). Feeding rate, drinking rate, and quantity of produced will affect the time spent in the rumen of both fluid and particulate matter. The CH_4 yield was negatively correlated to the particulate with the quantity of rumen organic matter and rumen fill. The latter author reported that the rumen particulate outflow rate accounted for approximately 57 % of the between-sheep variation (JOHANNES, 2008, New Zealand, pers. comm.).

WAGHORN & WOODWARD (2004) showed mean methane production from four highest and four lowest producing sheep (selected from a random group of 20 animals) over a four month period was 3.75 vs. 5.15% of gross energy intake. Earlier reports found 86% of variation in methane production by sheep consuming 900-1700 g DM day-1 was due to animal variation and only 14% was attributable to diet.

Also, ULYATT *et al.* (2002a), investigate the effect of seasonal variation in methane emission from dairy cows and breeding ewes grazing ryegrass/white clover pasture in New Zealand and this experiment Daily methane emission from 12 Romney-cross-bred ewes and 10 lactating Friesian dairy cows, rotationally grazed on perennial ryegrass/white clover dominant pastures, was measured during four seasons of a year (September, November, March, and June/ July).the result of this experiment suggested that 71 – 95% of variation between days was attributable to animals even though intakes and composition of each diet were relatively constant (ULYATT *et al.*, 2002b).

The impact of genotype was highlighted in a trial involving New Zealand Friesian (NZHF) and Overseas Holstein (OSHF) cows fed either pasture or total mixed rations produced 8-11% less methane, as a percentage of gross energy (GE) intake, compared to New Zealand genotypes. The OSHF genotypes produced 8-11% less methane, as a percentage of gross energy (GE) intake, compared to New Zealand genotypes at both 60 and 150 days of lactation (ROBERTSON & WAGHORN, 2002).

WAGHORN & WOODWARD (2004) showed sheep with high CH_4 yields had larger rumen volumes, a slower particulate outflow rate, higher fibre digestibility and longer retention times than sheep with low CH_4 kg^{-1} DM intake. Methane yield was best predicted as a function of particulate fractional outflow rate, organic matter intake (g kg $LW^{-0.75}$) and molar proportion of butyrate (r^2 = 0.88). Differences between animals may be affected by salivation, feed comminution (or eating rate) as well as rumen pool size, turnover and outflow.

Trials conducted at the University of Manitoba suggest that as much as 27 % of the variation in CH_4 emission for cattle consuming forage diets is related to animal-to-animal variation (BOADI & WITTENBERG, 2002). Work has not been done to determine whether these differences are related to intake behavior, or to potential anatomical and physiological differences in the gastrointestinal tract of cattle or the heritability of this trait. However, the degree of variability suggests that there is potential to select for low methane emitting animals.

Differences in intake explain only a part of the variability: in sheep consuming the same amount of DM, LASSEY *et al.* (1997) noted extreme daily CH_4 emissions of 14.6 and 23.8 g between animals (MARTIN *et al.*, 2010).

The factors responsible for animal-to-animal variation in CH_4 emission by ruminants fed fresh forages are scarce. In contrast to lactating cows, animals in this study (non-lactating, non-pregnant) lacked the feeding drive to maximize feed intake, and previous large differences in CH_4 yields were much reduced. Absolute emissions were strongly associated with feed intake (especially of digestible fiber) but the implication of salivation on animal differences warrants further investigation. The absence of anticipated differences between cows in CH_4 yield per unit of feed intake limited the establishment of relationships with rumen pool size and rumen digesta retention time observed previously with sheep. The data support previous conclusions that effects of animal-related factors are most apparent at high intake levels, for example during lactation. The ranking of animals in CH_4 production per kg DM intake differs between physiological stages with a change in diet (PINARES-PATINO *et al.*, 2007).

These latter authors evaluated the repeatability (i.e. between animals/total variations) as 47% and 73% according to the diets. Collectively, these results suggest that the genetic component of CH_4 production is low. However, data obtained on fattening cattle show that animals having a high feed efficiency, measured as the residual feed intake, produced, 20% less CH_4 than the less efficient ones (NKRUMAH *et al.*, 2006; HEGARTY *et al.*, 2007). Differences between these animals could be due to individual differences in rumen microorganisms associated to the rate of degradation processes and fermentation parameters and/or to intrinsic animal characteristics such as retention time of particles in the rumen (MARTIN *et al.*, 2010).

GUAN *et al.* (2008) reported that the bacterial profiles were more likely clustered within a certain breed, suggesting that host genetics may play an important role in rumen microbial structure. The correlations between the concentrations of volatile fatty acids and feed efficiency traits were also observed. Significantly higher concentrations of butyrate and valerate were detected in the efficient steers. The results of this experiment show that link between the diversity of the rumen bacteria and VFA pattern with the feed efficiency in cattle.

In dairy cows, body weight, milk yield, and type of roughage influence CH_4 production.

An equation between CH_4 production and milk yield has been calculated from numerous measurements of CH_4 production in dairy cows of different milk yields and fed according to their requirements. Calculations by KIRCHGESSNER *et al.* (1994) showed that a considerable amount of CH_4 (216 g/d) seems to be released independently of milk production.

Using today's current calculation practices, it can be concluded that the increase in cow productivity results in a decrease in CH_4 emission per kg milk, due to cow nutrition in present dairy systems. However, it should be noted that CH_4 emissions during a cow career should be split between milk and meat productions. The meat produced should take into account not just the cow but also that from the (male) offspring (MARTIN *et al.*, 2010).

Between-sheep variation in CH_4 emission has long been recognized from measurements in respiration chambers and in vitro, and recently confirmed under grazing conditions. The latter authors reported that about 85% of the variation in daily CH_4 production (g/day) from sheep grazing temperate pastures was due to variation between animals. If such between-animal variability is persistent in the long term, and the animal trait(s) that account for such variation is (are) inherited, breeding of animals for low CH_4 emission might be viable (PINARES-PATINO *et al.,* 2003).

2. Reducing livestock numbers

As methane emissions from livestock are the predominant source of greenhouse gases reducing livestock numbers would be one way of meetingframework convention on climate Change FCCC commitments. However, such countries are heavily dependent on their livestock industries for generating national income and imposition of regulations aimed at reducing livestock numbers would be politically unacceptable. Reducing livestock numbers through normal market processes can be effective. For example, in New Zealand sheep farming has become less profitable over the past ten years and farmers have reduced sheep numbers and used the land for alternative enterprises, such as forestry. Sheep numbers have reduced from 57.9 million in 1990 to 45.2 million in 2000, while dairy cattle and beef cattle numbers have increased slightly. The net outcome has been a decline in ruminant methane emission from 1.45 to 1.31 Tg/year from 1990 to 2000. Livestock numbers will respond positively to improved economic conditions and if sheep farming becomes more profitable an increase in stock numbers and thus CH_4 emission is a possibility (ULYATT & LASSEY, 2001).

Total GHG emissions from livestock are positively related to the numbers of livestock. It is likely that our systems will be under political and social pressure to reduce livestock numbers to reduce the levels of emissions. Additionally, lower numbers of more productive animals will also contribute to more efficiency of production relative to emissions. Globally, one of the main issues relates to numbers of livestock, in particular numbers of livestock for a given level of off take (animal product). There are large differences between developed and developing countries in this respect. Taking beef cattle as the example, developing countries have twice the numbers of cattle of the developed countries (858 versus 410 million) yet the annual meat off take is only half (15.2 vs. 34.6 million tones) giving in excess of a 4 fold difference in efficiency. However, it is important to remember, that in developing countries livestock at often about more than just production they have a multi- purpose role. Globally, we are likely see differences in adaptation between developing and developed countries with developed countries perhaps seeing fewer, more productive animals producing quality products for niche local markets. However there remains the requirement to meet the ever increasing global demand for livestock products associated with the combination of increased human population and growing affluence fueling the Livestock Revolution (ROWLINSON, 2008).

The more lambs born and raised per ewe, the less methane is produced per lamb by the ewe. Therefore, the number of lambs per ewe is an important factor to consider when calculating emissions from sheep farms. In Sweden, breed differences in this aspect exist, but this alone should not be the reason for choosing a specific breed in a herd, the type of breed should instead primarily be adapted to the production system used. See Figure 9 for the number of lambs born and raised per ewe depending on the breed (ALLARD *et al.,* 2009).

3. Animal productivity

The improvement of animal productivity was suggested by FAO (2010) as an efficient way to increase world production of animal products and meet the increasing world demand, without increasing the use of land or the emission of globalgreenhouse gas (DOURMAD *et al.,* 2008).

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. A reduction in total emissions of methane would only result if total output levels (e.g. total milk or beef produced) remained constant and livestock numbers were reduced. Possible options for increasing ruminant productivity are discussed in the following sections (ANGELA *et al.*, 2000).

The primary method for reducing methane emissions from enteric fermentation is to improve production efficiency, which reduces methane emissions per unit of product (e.g., methane emissions per kilogram of milk produced). As part of the improvement in production efficiency, a greater portion of the energy in the animal feed is directed towards the creation of useful products (milk, meat, power) so that methane emissions per unit product are reduced. This increase in production efficiency also leads to a reduction in the size of the herd required to produce a given level of product. Because many countries are striving to increase production from ruminant animals (primarily milk and meat) improvements in production efficiency will help these goals to be realized while simultaneously avoiding increases in methane emissions (FAO, 2010; GWORGWOR *et al.*, 2006).

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 (O'MARA, 2004).

KIRCHGESSER *et al.* (1995) 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. A further increase to 6000 kg/year would decrease emissions per kg of milk by a further 0.128. Thus, there are quite significant reductions in methane emissions to be made by improved productivity in dairy cows as long as the number of cows is reduced to compensate for the increased milk yield. It should also be noted that the decline in methane emissions per kg of milk in response to increasing milk yield is curvilinear because the maintenance cost becomes increasingly diluted. Thus in high yielding herds, the reduction in methane emissions from further increases in milk yield will be relatively small (KIRCHGESSNER *et al.*, 1995).

JOHNSON *et al.* (2002) 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 CH_4, CO_2, N_2O, Enteric CH_4) have been taken into account (JOHNSON *et al.*, 2002).

Management systems designed for high milk output per cow will tend to result in lower emissions per unit of milk produced. In contrast, more extensive systems require more animals to produce a given quantity of milk-- resulting in higher methane output per litre. The opportunities to reduce methane emissions by increased animal productivity are larger in the extensive systems compared to the intensive systems with already high milk production levels per cow (FAO, 2010).

4. Longevity

The longer that cows stay in a herd, the lower number of replacements required, and thus the lower the total farm methane emissions. An example of a 100 cow farm is presented in Figure 1, where the average number of lactations varies from 2.5 to 5. It is assumed that dairy cow emissions are 118 kg/yr while the rearing of a replacement heifer to calve at 2 years old results in methane emissions of 100 kg. Figure 1 shows that total farm emissions of CH_4 from enteric fermentation decline from 15,800 kg/yr to 13,800 kg/yr (0.127 less) as the average number of lactations increases from 2.5 to 5. This does not factor in the higher yield of the older cows which would further reduce emissions per kg of milk. Thus any measures which reduce involuntary culling should be encouraged. There will also be corresponding reductions in methane and nitrous oxide emissions from manure, and in nitrous oxide emissions from soil (less fertilizer N usage due to lower stocking rate). Reducing the replacement rate will also leave more calves available for beef production (instead of cull cows) (O'MARA, 2004).

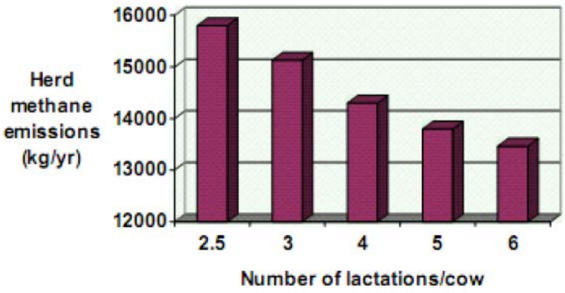

Fig. 1. The effect of number of lactations per cow on annual total herd (100 cows plus replacements) emissions of methane from enteric fermentation.

Similarly if improved animal performance leads to animals reaching target slaughter weight at a younger age, then total lifetime CH_4 emissions are reduced. On the other hand, going for increased performance may reduce longevity and thus even increase total lifetime emissions when accounting for rearing for replacement (O'MARA *et al.*, 2008).

Longevity will lower greenhouse gases /product because growing and maintenance are non productive periods of a life cycle. Improved production will not necessarily lower total emissions but more food could be produced whilst retaining profitability (WAGHORN, 2008).

Cow longevity might also be improved from the current level of 25% replacement rate, meaning fewer replacements would need to be reared. Replacements are a necessity to maintain production but each heifer consumes feed and emits methane for at least two years prior to producing any milk. As such, an increase in the average number of lactations the cows achieve is more carbon efficient, when set against an increase in the number of heifers reared each year. A conscious effort is made to keep on top of herd health. The herd has been managed as a predominantly closed system and the key areas of mastitis and foot health have been tackled to the benefit of longevity and milk production. When cattle are bought, they are typically yearling heifers to allow them time to adapt to the conditions and disease challenges specific to the farm, prior to bulling and calving (DAIRY CO, 2012).

5. Strategies to Reduce Greenhouse Gas Emissions through pasture management

Improving pasture quality is often cited as a means of reducing emissions, especially in less developed regions, because of improvements in animal productivity, as well as a reduction in the proportion of energy lost as CH_4 due to a reduction in dietary fibre. However, there is evidence that the impact of pasture quality on CH_4 emissions per kg of pasture consumed is small in temperate, well-managed swards (O'MARA *et al.*, 2008).

MOLANO & CLARK (2008) investigate the effect of level of intake and forage quality on methane production by sheep and reported no difference in CH_4 emissions per kg of grass dry matter intake (DMI) between lambs fed pasture with OM digestibility of 666 or 766 g/kg (MOLANO & CLARK, 2008).

The effect of pasture improvement in Australian sheep farms was recently modelled by ALCOCK & HEGARTY (2006), who reported only a small reduction in CH_4 output per kg live weight. But in their case, the assumed individual sheep productivity was already quite high, and the pasture improvement was calculated to lead mainly to an increase in stock numbers. In addition, the simulation showed little effect on digestibility of the forage, but rather gave an increase in the quantity of forage available. One group of researchers modelled dairy production systems in contrasting soil types (wet and impermeable vs dry and free-draining) and reported that the drier soils with a substantially longer grazing season supported milk production with significantly lower GHG emissions per kg of milk produced (O'MARA *et al.*, 2008).

WAGHORN *et al.* (2002) fed sheep a wide range of fresh cut, good quality forages and observed a two-fold range in emissions from

11.5g CH_4/kg dry matter intake (DMI) with lotus to 25.7g CH_4/kg DMI with pasture and a 16% reduction in methane production due to the Condensed tannins in lotus. This range in emissions from good quality forages represents a loss of about 7-11% of metabolisable energy and presents a clear direction for future research to better utilise the feeding value of pastures and reduce greenhouse gas (GHG) emissions from agriculture. All forages were delivered to the animal daily and had a DM digestibility of 70 % or greater. Animals grazing on pasture have the ability to be more selective than animals in this feeding trial, therefore the possibility exists that differences between forage species is even greater for pastured animals. Condensed tannins, a constituent of some legumes, have been associated with reduced enteric CH_4 emissions. Also these researchers reported that the impact of Condensed tannins on methanogenesis is small but significant (a 16% reduction). In addition to the impact on methanogenesis, Condensed tannins have beneficial effects on ruminant nutrition and production such as the reductions in the incidence of bloat and lowered intestinal worm burdens (WAGHORN *et al.*, 2002).

SEJIAN *et al.* (2011a,b) investigate forage and flax seed impact on enteric methane emission in dairy cows. The result of the experiment showed that both high proportion forage feeding and flax seed supplement reduced the enteric methane emission.

Legumes have higher nutritive value and voluntary intake than grasses, and steer gains are higher on legume-grass mixtures than on N-fertilized grass monocultures. However, most legumes can cause bloat. In a uniform stand, a maximum of 50% bloat-causing legume is considered bloat-safe, but bloat has been reported in mixtures with less than 15% bloat-causing legume where selective grazing could occur. The low digestibility of tropical legumes has been attributed to their high tannin content. Well-managed temperate grass-legume pastures, however, can have excessive CP and therefore animal performance can benefit from the presence of moderate concentrations of condensed tannins that control bloat and decrease ammonia and methane production in the rumen while increasing rumen undegradable protein (MACADAM *et al.*, 2006; MAHERI-SIS *et al.*, 2007).

MIRZAEI-AGHSAGHALI *et al.* (2008) reported that methane (g per day, g per kg BW and gr per kg $BW^{0.75}$) were similar in legume (two Iranian alfalfa varieties) hay, whereas methane production (g per day, g per kg BW and gr per kg $BW^{0.75}$) in grass hay were significantly higher than that of legume hay.

OLSON & WALLANDER (2002) compared five forage stands on foothill rangeland in Utah. Treatments included native rangeland and pastures seeded to Hycrest crested wheat grass (*Agropyron desertorum* x *A. cristatum*), Nordan crested wheat grass (*A. desertorum*), Vinall Russian wild rye (*Psathrostachys junceus*) and Syn-A Russian wild rye. There were three replicates each forage, pastures being established in a complete block design. When non lactating beef cows grazed these pastures in October, the native mixture compared favorably with improved species. Methane emissions by lactating cows on these same pastures in the following spring again showed that native pasture resulted in the highest CH_4 emissions and was the least productive. Olsen's work, although preliminary, suggests that variation does exist among grass species and that the choice of species may depend on the season of pasture use. Whether using rotational or continuous grazing strategies, there is tremendous fluctuation in for age quality during the grazing season which affects fermentation efficiency and enteric methane emissions. Grain supplementation has been recommended as a means of improving the efficiency of fermentation for cattle when forage quality is poor.

Results of a study recently completed by BOADI & WITTENBERG (2002) found grain supplementation for pastured yearling steers did result in increased DM intake and rates of gain, but there was no benefit relative to enteric emissions. That study clearly demonstrated forage quality to be the major factor influencing enteric emissions for pastured cattle. For example, the lowered quality and availability of forage from the time cattle entered a paddock to the time they were removed from that paddock in a rotational grazing system resulted in a 58 % reduction in forage DMI, but daily methane emissions remained the same (WITTENBERG, 2008, Winnipeg, pers. comm.).

Emissions from grazing livestock can be hard to predict, the exact feed intake is hard to estimate and the nutritional value of the pasture differs within the season. Several studies with grazing sheep have though been conducted (ALLARD *et al.*, 2009).

5.1. Management to Mitigate Methane in Grazing Animals

Effective management to mitigate methane could be viewed in terms of animal productivity vs. animal methane emissions. Expression could be on an annual basis to avoid short term bias, for example cows grazing ryegrass pastures produced 11.7, 19.4 and 24.3 g CH_4 kg^{-1} milk at day 60, 150 and 240 of lactation. The difference in emissions was largely due to a live weight loss contributing energy to milk synthesis in early lactation and use of dietary energy to restore live weight in late lactation. A similar scenario applies to sheep, with very high CH_4 emissions associated with wool growth (typically 10-12 g day^{-1}) in adult animals, but a lesser emission cost associated with growing lambs and reproduction. Mitigation can be achieved by minimizing maintenance costs as a proportion of feed intake and maximizing the productive worth of livestock. High intakes of high producing animals dilute their maintenance cost and lower the methane emissions per unit of production. This will be best achieved by offering high quality diets to animals of high genetic merit and imposing good livestock and pasture management practices. These effects are illustrated for 30 kg lambs growing at 100, 200 and 300 g day^{-1} with methane emissions of 166, 115 and 98 g kg^{-1} live weight gain respectively. Comparative values for 450 kg grazing dairy cows producing 12, 20 or 24 kg milk day^{-1} were 17.2, 13.6 and 12.7 g CH_4 kg^{-1} milk. The methane emissions associated with production increased from 49 to 61 and 66% for the respective treatments. Animal performance can be improved by selection for a high metabolic efficiency or by using rumen modifiers to alter products of digestion. Any factor able to improve feed conversion efficiency will lower CH_4 emissions $unit^{-1}$ production. However farmers need to achieve a balance between increasing efficiency of feed utilisation and the efficiency of pasture utilization (WAGHORN & WOODWARD, 2004).

Several Canadian research studies have examined the impact that pasture and grazing management has on enteric CH_4 emissions. A study by MCCAUGHEY *et al.* (1997) reported that CH_4 production was greatest for steers continuously grazing at low stocking rates (1.1 steer ha-1; 307 L d^{-1}) and least for steers grazing continuously at high stocking rates (2.2 steers ha-1; 242 L d-1). A possible explanation for these observed results for the higher stocking rate may be due to lower forage availability and intake for the grazing animal. When pastures were rotationally grazed, stocking rates had no effect on CH_4 production. At low stocking rates, CH_4 production was 9% lower on rotational grazing than continuous grazing. Measurements of CH_4 production from grazing beef cows found a 25% reduction in CH_4 losses with alfalfa + grass pastures (7.1% of gross energy intake) compared to grass-only pastures (9.5% of gross energy intake) (MCCAUGHEY *et al.*, 1997). Other researchers observed early grazing of alfalfa+grass pastures reduced CH_4 production by 29 to 45% in steers compared to grazing at mid and late seasons. Pasture quality is the critical factor in ensuring lower CH_4 emissions from grazing animals in any particular grazing system (IWAASA, 2007).

LASSEY *et al.* (1997) investigate the methane emissions measured directly from grazing livestock in New Zealand with the ERUCT technique. The pasture was a typical improved one with mostly perennial ryegrass and white clover (LASSEY *et al.*, 1997).

ULYATT *et al.* (2002a) was measured methaneemission from 10 dairycows and 12 wethersheep grazing kikuyu grass in New Zealand two different years, 1997 and 1999. In 1997, the same CH_4 yield could be found for both cattle and sheep. The pasture in year 1999 had a better nutritional value compared to the one in 1997 and the emissions were lowered for both species of animals, but the reduction was clearer marked in the sheep. The authors suggested that the extra low values in 1999 could be a result of the pasture containing compounds that could inhibit methanogenic bacteria, and not only of the pasture's better quality. Kikuyu grass (subtropical C4-plant) have a lower digestibility than C3-plants, resulting in higher CH_4 emissions from rumen fermentation, thereby also the lower digestibilities compared to the other pastures (ULYATT *et al.*, 2002a).

ULYATT *et al.* (2005), compared four groups of sheep were grazed on four late summer/autumn pastures: southern North Island summer moist hill country (Ballantrae); good quality perennial ryegrass/white clover dominant pasture in the Manawatu (Aorangi); severe late summer drought pasture in Hawke's Bay (Poukawa sheep); and after drought conditions in Canterbury (Springston). Mature ewes were used at Springston, while young wethers were used at all the other sites. The study was conducted over the years 1997-1999 and variations in the weather sometimes made the conditions somewhat unusual for the season for all cases except Poukawa sheep, resulting in higher feeding values than normal in some cases. The mature ewes grazing in Springston had the highest emissions, which could be explained by the fact that mature sheep probably cause higher CH_4 emissions than younger sheep. But the method used for measurements was not the same as for the other sheep in the study and therefore the results should not be directly compared to each other. The higher emissions for the Poukawa sheep than the Aorangi and Ballantrae sheep could be explained by the lower digestibility of the dead matter grazed at Poukawa (ULYATT *et al.*, 2005).

ULYATT *et al.* (2002b) investigate the impact of seasonal variations on methane emissions using a perennial ryegrass/white clover pasture in New Zealand and found the highest emissions of methane from sheep grazing in November. In this experiment, Daily methaneemission from 12 Romney-cross-bred ewes and 10 lactating Friesian dairycows, rotationally grazed on perennial ryegrass/whiteclover dominant pastures, was measured during four seasons of a year (September, November, March, and June/July).Methaneemission was measured from each animal for 5 consecutive days in each measurement period using the sulphur hexafluoride tracer gas technique. This is in accord with the low feeding value of pastures in New Zealand at this time of the year, but the authors found no explanation to the low values in July. They concluded that seasonal variation in the chemical composition of pastures had little importance in this study for the rate of methane emitted. They could also see that cows and sheep had about the same efficiency of utilizing the feed. They saw that the emissions from grazing dairy cows and grazing ewes were about the same expressed in g CH_4/kg digestible dry matter intake with values of 26.6 and 25.2 for cows and sheep respectively (ULYATT *et al.*, 2002b).

A cow-calf study at Brandon, Manitoba compared performance and enteric emissions of alfalfa-grass and grass only pastures over the course of a grazing season. Dry matter intake was greater for cows grazing alfalfa-grass pastures than for grass-only pastures (11.4 vs. 9.7 kg d^{-1}), however, methane production, adjusted for differences in body weight, was the opposite (0.53 vs. 0.58 g kg BW d^{-1}, respectively). Energy lost as enteric methane emissions were 7.1 % of gross energy intake for alfalfa-grass vs. 9.5 % of gross energy intake for grass-only pastures. An 11 % increase for calf growth rates on the legume-grass pasture would serve as further incentive to consider legume incorporation as a mitigation strategy. The lowered methane loss observed with legumes is attributed to the lower proportion of structural carbohydrates and faster rate of passage of legumes, which will shift the fermentation pathway towards higher propionate production. The extent to which forage species can influence enteric methane emissions of pastured ruminants is not known under Canadian conditions (MCCAUGHEY *et al.*, 1999).

LASSEY *et al.* (1997) measured emission in March in cows from the same herd fed similar pasture as in the present work at 262.8 g/day at an estimated DM intake of 12.9 kg/day (20.4 g CH_4/kg DMI; MY 6.2%), compared with 181.5 g/day and 14.9 kg/day (12.3 g CH_4/kg DMI; MY 3.7%) respectively in the present work.

MURRAY *et al.* (2001) could see that sheep grazing on a pasture with both clover and perennial ryegrass had significantly higher emissions of methane, than sheep grazing only grass which received fertilizer. But as the digestibility of the feeds were not included in the calculations this could mean that per unit of production such as growth or lactation, the emissions measured from the sheep grazing clover could be of another value. Clover pastures often have better digestibility than grass pastures. Therefore the total amount methane emitted may be higher for a certain intake of gross energy but not of digestible energy intake (ALLARD *et al.*, 2009).

Several Canadian research studies have examined the impact that pasture and grazing management has on enteric CH_4 emissions. BOADI & WITTENBERG (2002) observed early grazing of alfalfa+grass pastures reduced CH_4 production by 29 to 45% in steers compared to grazing at mid and late seasons. Pasture quality is the critical factor in ensuring lower CH_4 emissions from grazing animals in any particular grazing system (IWAASA, 2007).

BOADI & WITTENBERG (2002) reported methane production as a percent of gross energy intake (GEI) was not influenced by diet, as CH_4 emissions of 6.0, 7.1 and 6.9% of gross energy intake (GEI) from beef and dairy heifers fed ad libitum legume and grass hays containing 41.8, 58.1 and 68.8% NDF in the DM, respectively methanogenesis was not related to feed quality.

The associated basal feedstuffs used may also influence this value. With dry forages, methane losses are a little higher (0.01%/GE) than with grass silages. No statistical difference appeared for peas, faba beans, sugar beet pulp and sorghum when tested with either gramineae hays or with maize silage. Kinds of concentrates do not seem to statistically modify the methane losses of the basal feed. In conclusion, reciprocal influence of feeds sometimes exists, but generally it might be smaller than the incertitude of measurements. Methane variation losses were significantly decreased with the increase of ether extract or of one of the cell wall constituents (NDF, ADF or ADL). Lignin (ADL) was the best chemical predictor in methane variation losses and explained 61% of the variations of gross energy losses as methane (GIGER-REVERDIN & SAUVANT, 2000).

5.2. Grassland management and grazing

Lucerne is another component of the shorter-term grass leys. As a legume, it is a nitrogen fixer and the deep root network means lucerne will remain productive in dry spells. The forage containing the lucerne/clover/ grass mix is high in dietary protein and fibre. The dry periods in summer often mean fertilizer application offers less than it might do in less dry regions; this is reflected in below-average fertilizer use.

Evolution Farming consultant, Oliver Hall, identifies grassland management as a key area. The aim is always to produce quality over quantity and the M.E. average across all cuts should exceed 11.5MJ/ kg. High energy forage will result in smaller volumes of methane being emitted by each cow. Also, by producing quality grass silage, a greater proportion of the milk can be generated from this grass, reducing the need for high volumes of purchased feeds to push yields up. Fertilizer use is above average Ammonium Nitrate is the only product used on the dairy supporting area. The tonnage used indicates an average of 160kg of N per Ha (64kg per acre) is supplied from artificial fertilizer across the total land allocated to the dairy. Fertilizer is both an economic and carbon costly product and so can have a big effect on the carbon footprint of a business, therefore reinforcing the importance of using manures and slurry as efficiently as possible. The slurry lagoon is allowed to crust which reduces the greenhouse gas emissions to air. The slurry is spread by contractors using a splash plate. It may be worth considering other methods of slurry application so that the slurry is applied at the base of the plant. If the slurry is applied according to crop demand, it may be possible to reduce the amount of bagged fertilizer required (DAIRY CO, 2012).

5.3. The Impact of Different Pasture Species

Most species of pasture grasses and legumes the predominant pastures plants are perennial. Perennials offer several advantages over annual crops grown for feed, such as corn, soybeans, and sorghum. For example, well managed perennials provide groundcover throughout the year, reducing pollution runoff and soil erosion (GURIAN-SHERMAN, 2011).

Grass species may differ in their effect on methane emissions. However, these differences are usually narrower than those between grasses and legumes. Feeding forage legumes to ruminants grazing grass-dominant pastures will improve animal performance and lessen the reliance on a single species to meet all nutritional requirements (WAGHORN & CLARK, 2004).

MOURINO *et al.* (2003) investigate the animal performance and pasture composition from 1998 to 2000. Some legume species may improve pasture quality by competing better with grasses. The lower NDF of kura clover–grass indicates that steers on this pasture had greater intake potential than those on red clover grass pasture. Neutral detergent fiber concentration was fairly constant for the kura clover–grass pasture while it increased (P0.08) 64 g kg^{-1} from1998 to 2000 in red clover grass and the average daily weight gain of steers on pastures with mixed grass and kura clover (*Trifolium ambiguum*) in Wisconsin, for example, was 22 percent higher than that of steers on pastures with grass and red clover (another legume) - the latter a common mixture in the United States. The analysts attributed this difference to the fact that the percentage of kura clover was higher than that of red clover in the pastures. In addition, kura clover–grass pasture had lower levels of fiber, higher protein concentration, and better digestibility than the red clover grass pasture. As a result, kura clover–grass pastures displayed greater average daily gain and gain per hectare than red clover grass pastures (MOURINO *et al.*, 2003).

BURNS & STANDAERT (1985) reported that average daily gain and gain per hectare are usually greater on legume–grass systems until N clover mono application rates on N–grass systems exceed 200 kg ha_1.

MIN *et al.* (2006) investigate the Effects of condensed tannins supplementation level on weight gain and in vitro and in vivo bloat precursors in steers grazing winter wheat and reported that daily supplementing quebracho condensed tannins to steers grazing wheat forage improved animal performance and minimized bloat frequency without deleterious effects to the animals. Quebracho condensed tannins supplemented ruminal fluid incubated with minced wheat forage led to less *in vitro* gas and methane production. Quebracho condensed tannins supplementation is a potentially effective feed additive for decreasing bloat impacts and increasing ADG in stocker cattle-wheat systems common to the Southern Great Plains (MIN *et al.*, 2006).

PUCHALA *et al.*, (2005) investigate the effect of condensed tannin-containing forage on methane emission by goats and reported that Methane emission expressed as both quantity per day or relative to DMI was lower ($P < 0.001$) for Sericea lespedeza than for crabgrass/tall fescue (7.4 vs. 10.6 g/d and 6.9 vs. 16.2 g/kg DMI). Substantial differences between the forages in condensed tannins concentration and methane emission by Angora goats suggest that condensed tannins decreased methane emission (PUCHALA *et al.*, 2005).

WOODWARD *et al.* (2001) reported that in sheep, methane emission relative to digestible DMI was decreased by 24 to 29% when the CT-containing forage Lotus pedunculatus was fed compared with ryegrass or lucerne.

Legumes tend to be less resilient in the face of trampling by cattle, and grass species often out-compete legumes over several years, reducing their percentage in the pasture. Good management is therefore critical to maintaining legumes in pastures. Different legumes also grow best in different types of soil and climates. For example, alfalfa grows best in neutral, well-drained soil, while birdsfoot trefoil can tolerate more flooding (GURIAN-SHERMAN, 2011).

Legumes are important components of pastures. Legumes not only fix atmospheric nitrogen (N_2) for their own use when properly inoculated, they provide nitrogen (N) for associated grasses and forbs. A range from 150 to 240 lb N per acre is needed to equal the contribution of legume N in legume-grass mixtures. Using a legume reduces the purchase and application costs of N fertilizer and may reduce soil acidification and N losses to the environment. Many legumes are deep-rooted and therefore more drought-tolerant than grasses. Under grazing, legumes are more commonly used as a component of mixtures with grasses than as monocultures. This is because fibrous-rooted grasses are valuable sources of soil organic matter, they provide better protection from soil erosion, are more resistant to grazing and treading damage than legumes, and well-managed grass-legume mixtures provide more than adequate levels of crude protein (CP) for highly productive livestock (MACADAM *et al.*, 2006).

Management of soil acidity for temperate and tropical regions has often differed but increasingly depends on acid-tolerant legume cultivars and rhizobia, with soil liming only to a pH at which Al and Mn are no longer toxic. Legumes are often grown after corn or rice and are seeded toward the end of the growing season. They may have short growing seasons and may be subject to intermittent or terminal drought. Progressive soil chemical and physical degradation and acid soil conditions may also limit their productivity (GRAHAM & VANCE, 2003).

5.4. Using Harvested Forages: Silage and Pelleting

Harvested forages silage and hay are an important component of pasture beef farms in many parts of the country. Cattle may eat harvested forages when pastures are dormant or have matured, and are growing slowly or not at all. BENCHAAR *et al.* (2001), suggested that intake of NDF was lower (–11%) with alfalfa silage than with alfalfa hay. Ruminal digestion of OM and NDF (% of intake) were also reduced (–21 and –9%, respectively) when alfalfa was preserved as silage rather than hay. Ruminal microbial efficiency was slightly enhanced (+9%) by the utilization of alfalfa silage. Ruminal pH was higher for alfalfa silage. The intensity of ruminal fermentation was quantitatively influenced by the method of preservation of alfalfa; total and individual VFA productions were lower with alfalfa silage compared to alfalfa hay. Total methane production (Mcal d^{-1}) was depressed (–33%) by the utilization of alfalfa silage instead of alfalfa hay. Fractions of GE intake and DE lost as methane were also lower (–32 and –28%, respectively) with alfalfa silage than with alfalfa hay (BENCHAAR *et al.*, 2011).

VARGA *et al.* (1985) reported a decrease in methane production from cattle consuming alfalfa silage compared to orchardgrass silage. The utilization of less-mature herbage has been shown to lower methane yields.

Methane production, dry matter digestibility and urinary energy loss were reduced when first-cut alfalfa was pelleted but pelleting had no influence on these parameters with second-cut alfalfa. Methane and CO_2 production and O_2 utilization increased sharply after feeding. There were interactions between type of feed (chopped vs. pelleted) and cut of alfalfa in CH_4 (1 kg^{-1} feed DM) and CO_2 production and O_2 utilization. Energy digestibility and CH_4 losses were similar at maintenance and 1.6 times maintenance level of feeding. Although methane production was lower in cattle fed pellets in three out of four comparisons of pelleted and chopped hay diets, the decline in energy loss as CH_4 due to pelleting was not sufficient to justify the extra energy expended to pellet diets from an environmental or economic point of view (HIRONAKA *et al.*, 1996).

5.5. Better pasture management: rotational grazing

Managed rotational grazing (MRG) also known as managed intensive rotational grazing—boosts the productivity of pasture, and can improve the nutritional quality of pasture forages. In MRG, beef producers rotate grazing cattle often among several fenced paddocks within a pasture. MRG prevents cattle from overgrazing, which curbs the ability of pasture plants to grow, and allows paddocks to recover between grazing periods. MRG also promotes more uniform grazing, so pasture plants can grow at optimal rates. Under continuous grazing, in contrast, cattle graze anywhere on a pasture at will. However, the data on the effect of MRG on methane emissions are ambiguous, and insufficient to draw clear conclusions about the impact on climate change (GURIAN-SHERMAN, 2011).

DERAMUS *et al.* (2003) investigate methane emissions of beef cattle on forages and reported that CH_4 annual emissions in cows reflect a 22% reduction from best management practices when compared with continuous grazing in this study. With the best management practices application of management-intensive grazing, less methane was produced per kilogram of beef gain.

MCCAUGHEY *et al.*, (1997) reported that voluntary intake and CH_4 production, adjusted for differences in body weight, were unaffected by grazing management, sampling period or by monensin controlled release capsule administration and averaged 0.69 ± 0.1 L kg BW^{-1} d^{-1} across all grazing management treatments. The results obtained in this study indicate that it will not be easy to manipulate CH_4 production of steers grazing alfalfa/grass pastures through changes in grazing management. On the improved pastures used in this experiment, CH_4 production and voluntary intake remained relatively constant regardless of variations in diet quality.

6. Vaccine

One technology to reduce methane emissions currently patented and being investigated by CSIRO is a methanogen vaccine. The vaccine stimulates antibodies, which are active against the methanogens. Preliminary results of this work have found a significant reduction of in vitro methane emissions along with increased animal production. It may also be possible to develop vaccines against rumen protozoa. The major advantage of this sort of technology is the potential for use in extensive grazing systems due to the expected long-term efficacy of the treatments. There is also little likelihood of consumer resistance to this technology as the approach uses the immune system of the animal to inhibit the methanogens (REYENGA & HOWDEN, 1999).

There is also research being conducted to develop a vaccine, which stimulates antibodies in the animal that are active in the rumen against methanogens. The problems with some of these mitigation strategies to reduce CH_4 are potential toxicity to the rumen microbes and the animal, short-lived effects due to microbial adaptation, volatility, expense, and a delivery system of these additives to cows on pasture (ISHLER, 2008).

WRIGHT *et al.* (2004), investigate the reducing methane emissions in sheep by immunization against rumen methanogens and this experiment thirty mature wether sheep were randomly allocated to three treatment groups (n=10). One group received an immunization of adjuvant only on days 0 and 153 (control), a second group received an immunization with a 3-methanogen mix on days 0 and 153 (VF3+3), and a third group received an immunization of a 7-methanogen mix on day 0 followed by a 3-methanogen mix on day 153 (VF7+3). Four weeks post-secondary immunization, there was a significant 7.7% reduction in methane production per kg dry matter intake in the VF3+3 group compared to the controls. However, methane emissions from sheep immunized with VF7+3 were not significantly different when compared to the sheep in the control group.

WRIGHT *et al.* (2007) expressed, it is difficult to draw any conclusions about whether the geographical isolation between these two herds of cattle or differences between the two diets directly influenced community structure in the rumen. However, if there were a geographical effect, then there should be unique phylogenetic groupings of methanogens that have been identified from sheep in Australia, Canada, Japan, New Zealand, Scotland, and Venezuela; rather, they are scattered throughout the tree.

CALLAWAY *et al.* (1997) reported that some bacteriocins (nisin and monensin) are able to inhibit ruminal methane, decrease acetate to propionate ratios and prevent amino acid deamination. Nisin and monensin have similar effects on carbohydrate fermentation, but nisin is a more potent inhibitor of obligate amino acid fermenting ruminal bacteria. LEE *et al.* (2002) reported that the bacteriocins may provide an alternative strategy for decreasing ruminal methane production. The compound(s) in question reduced numbers of methanogens, but, like many other inhibitors that are efficient in vitro, the effect was lost in sheep after continuous administration for a few days (NOLLET *et al.*, 1998). And other researchers also suggested the use of archaeal viruses to decrease the population of methanogens, but, to our knowledge, no bacteriophages active against rumen methanogens have been isolated so far (MARTIN *et al.*, 2010).

A vaccine developed from a three-methanogen mixture produced a 7.7% reduction (kg^{-1}DM) in methane emissions from sheep (P=0.051) despite only one antigen being effective against the methanogenic species in the sheep. The vaccine was much more effective than the seven methanogen mix tested previously and was able to increase saliva and plasma antibody titres by 4 – 9 folds over the seven methanogen mixture. Successful elevation of antibody titres in saliva and a significant reduction in methane emissions offers real potential for a widespread application to ruminants in all environments. At present vaccines do not have sufficient efficacy for commercial use and funding has recently been curtailed. Opportunities through rumen additives, defaunation and specific compounds targeting methanogens provide several routes for reducing methane production. However these agents have not addressed the inevitable production of hydrogen from fermentation of fibre. Ruminants are able to utilize fibre because of their microflora and hydrogen production is an unavoidable consequence. Excess hydrogen accumulation will inhibit microbial growth, but acetogens offer an opportunity for production of acetate as well as removing accumulated hydrogen. Acetogens are present in moderate concentrations in the digestive tract of horses, llamas and buffalo (104 – 105 ml^{-1}) but values for sheep and cattle have been very low (WAGHORN & WOODWARD, 2004).

Conclusion

Significant mitigation of greenhouse gas emission is a critical subject of biological, ecological and environmental research area in the world. Due to higher global warming potential of the methane, it is subjected to many studies in recent years. From the view point of methane emission, ruminant animals are consequential than that of other animal species owing to higher fermentation activities. Integral management strategies in ruminant production such as consideration of animals -type and individual variability, reducing livestock numbers, improving animal productivity and longevity, valid pasture management as well as vaccination against methanogenic microbes; can be results in mitigating methane production. It is notable that, other than management related strategies, three important strategies including nutritional, biotechnological and microbiological strategies are required for controling and decreasing methane emission.

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