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Strategies for Reducing Methane Emissions from Ruminants

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A B S T R A C T

There is irrefutable evidence that human activities are affecting the global climate through the production of Green House Gases (GHG) of which methane (CH_4) has a high warming potential. Enteric fermentation and manure from ruminants represent about 30 to 40% of the total anthropogenic CH_4 emissions. This paper summarizes existing technologies to reduce enteric CH_4 emissions in ruminants given emphasis to dietary and rumen manipulation, animal selection/ breeding and improvement of production systems. Differences in enteric CH_4 production among animal species based on anatomy of the GI tract, digestive physiology, rumen fermentation and grazing habits are also discussed. Inhibition of enteric CH_4 emission is possible through the use of ionophores, organic acids and oils. Feeding plants containing secondary metabolites (i.e. tannins and saponins) can reduce CH_4 production. Breeding for improved feed conversion efficiency (lower residual feed intake) is likely to reduce total and per unit product CH_4 emissions. Results using the IPCC Tier II model predict that goats and high producing dairy cattle can potentially produce less CH_4 emissions per unit of milk than Cebu cattle or sheep, while small ruminants (goats and sheep) produce less CH_4 per unit of live weight gain (meat) than cattle. The introduction of improved high quality forages and the implementation of efficient pasture utilization practices (grazing system and stocking rate) can result in most cases in improved animal production and in increased absolute CH_4 emissions, but in reduced CH_4 per unit of animal product.

Keywords: climate change, greenhouse gases, cattle, sheep, goats, dietary manipulation, rumen manipulation, animal breeding, intensification, modelling

Estratégias para a Redução da Emissão de Metano por Ruminantes

R E S U M O

Há fortes evidências que as atividades humanas estão afetando o clima global por meio da produção de Gases de Efeito Estufa (GEE), dos quais o metano (CH4) tem elevado potencial de aquecimento. A fermentação entérica e o esterco dos ruminantes representam cerca de 30 a 40% do total das emissões antropogênicas de CH4. Este artigo traz um resumo de tecnologias existentes para reduzir as emissões de CH4 entéricas dos ruminantes, com ênfase à manipulação dietética e ruminal, à seleção/reprodução animal e à melhoria dos sistemas de produção. As diferenças na produção de CH4 entérica entre as espécies animais com base na anatomia do trato gastrointestinal, fisiologia digestiva, fermentação ruminal e nos hábitos de pastejo também são discutidas. A inibição da emissão de CH4 entérica é possível por meio do uso de ionóforos, ácidos orgânicos e óleos. Plantas alimentares contendo metabólitos secundários (taninos e saponinas i.e.) também podem reduzir a produção de CH4. O uso de animais reprodutores para melhorar a eficiência de conversão alimentar (menor consumo residual) pode contribuir com a redução da emissão total de CH4, além de reduzir a emissão por unidade de produto. Resultados utilizando o modelo IPCC nível II prevê que caprinos e vacas de elevada produção leiteira podem apresentar menor emissão de CH4 por unidade de produto em comparação com animais zebuínos e ovinos, enquanto os pequenos ruminantes (caprinos e ovinos) produzem menos CH4 por unidade de ganho de peso corporal (carne), em relação aos bovinos. A melhoria da qualidade das forragens e a implementação de práticas eficientes de uso das pastagens (sistema de pastejo e taxas de lotação) podem na maioria dos casos promover maior produção animal e incrementar a emissão absoluta de CH4, mas também reduzir a emissão de CH4 por unidade de produto animal.

Palavras - chave: mudanças climáticas, gases do efeito estufa, bovinos, ovinos, caprinos, manipulação da dieta, manipulação ruminal, criação de animais, intensificação, modelagem.

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC), convened by the United Nations has reported that human activities over the past 50 years have influenced global climate through the production of Green House Gases (GHG). The most important GHG's are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), which have different global warming potential. The warming potential of CO_2, CH_4 and N_2O is 1, 23, and 298, respectively (Ramaswany *et al*. 2001; Solomon *et al*. 2007)

Reports from the IPCC (2007) indicate that global atmospheric CH_4 concentration has increased by 250% (715 ppb to 1774ppb) between pre-industrial times and 2005 mainly due to agriculture activities. The role of livestock in CH_4 emission is well recognized given that enteric fermentation and manure represent 80% of agricultural CH_4 emissions and about 30 to 40% of the total anthropogenic CH_4 emissions (FAO, 2007).

Feed consumed by ruminants is fermented in the reticulo- rumen by bacteria, protozoa, and fungi and as a result polysaccharides in the feed are converted into volatile fatty acids (VFA) and microbial protein, which is accompanied by the release of gaseous by-products (CO_2 and H_2) (Kamra, 2005). In ruminants H_2 does not accumulate as a gas given the presence of methanogenic archaea and other hydrogen utilizing microbes in the rumen. The symbiosis between bacteria that ferment polysaccharides and produce H_2 and the methanogens which utilize H_2 to reduce CO_2 and produce CH_4 results in enhanced digestion of feed and microbial biomass production. As a result of this process, ruminants loose between 2–12% of the gross dietary energy in the form of CH_4, depending on the quality and quantity of the diet offered and consumed (Johnson and Johnson, 1995).

Approximately 87% of the enteric CH_4 is produced in the rumen and the remaining 13% is released in the large intestine (Lockyer and Jarvis 1995; Lassey *et al*., 1997).Thus it is essential to look for alternatives feeding strategies to reduce enteric CH_4 emissions in the rumen and by doing so contribute to less GHG and at the same time improve feed conversion efficiency, which should translate into economical profits for livestock producers.

Several reviews on mitigation of enteric CH_4 production have been published in recent years (Robertson and Waghorn, 2002; Boadi *et al*., 2004; Gworgwor *et al*., 2006; Beauchemin *et al*., 2008; Lascano and Cardenas, 2010). In most reviews strategies to reduce enteric CH_4 emissions were classified as a) dietary manipulation, b) direct rumen manipulation and c) intensification of production systems.

In this paper we summarize existing technologies or technologies being researched to reduce CH_4 emissions in ruminants given emphasis to dietary and rumen manipulation, animal selection and breeding and improvement of production systems. We also discuss differences in enteric CH_4 production among animal species based on anatomy of the GI tract, digestive physiology, rumen fermentation and grazing habits.

2. Development

2.1 DIETARY MANIPULATION

Increasing intake: It is well documented that when feed intake increases, CH_4 production increases by 5 to 15% for each multiple of intake above maintenance requirements (Blaxter and Cloppertone, 1965). It is also well established that CH_4 production per unit of DMI can be reduced with high quality forages mainly due to increased rate of passage of feed out of the rumen (Mathison *et al*., 1998; Ulyatt and Lassey, 2000; Hegarty 2001). As a result of increased passage rate, the extent of access of rumen microbes to organic matter is decreased and this in turn reduces the extent and rate of feed digestibility (Mathison *et al*. 1998). Also, a rapid passage associated with high intake rate favors propionate production, which is a competitive pathway for the use of H_2. Lower CH_4 production has also been observed with forage legumes as compared to grasses due to lower proportion of structural carbohydrates, which results in greater intake, faster rate of passage and a shift in fermentation pattern towards higher propionate production (Johnson and Johnson 1995; Eckard *et al*., 2010).

Type of carbohydrates fed**:** 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 (Johnson et al. 1996). It is well documented that diets 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 (Johnson and Johnson, 1995). The decision to increase the utilization of grain in ruminant rations to reduce CH_4 production should take into account not only economical 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 (Lovett et al., 2006). 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 FAO (2007) entitled "The genetic improvement of forage grasses and legumes to reduce greenhouse gas emissions.

Feeding processed and conserved forages**:** Grinding or pelleting forages used to supplement grazing ruminants can decrease CH_4 production per unit of feed intake by 20 to 40% (Johnson *et al*., 1996). A reduction in fiber digestibility and a faster rate of passage associated with ground or pelleted forages can be associated with a decline in CH_4 production (LeLiboux and Peyraud, 1999). Feeding ground diets also reduces acetic acid and increases the proportion of propionic and valeric acids (LeLiboux and Peyraud 1999).

There is limited information on how forage conservation affects enteric CH_4 production. In some studies CH_4 production (% of GEI) was shown to be lower when forages were ensiled than when dried, which was due to reduced rumen digestion associated with fermentation during silage making (Sundstol, 1981). Additives such as bacterial inoculants and organic acids used to enhance the quality and palatability of ensiled forages have been shown to lower acetic acid and increase propionate production in the rumen when compared to formic acid, which should result in lower CH_4 production when feeding treated silage (Shingfield *et al*., 2002).

2.2 RUMEN MANIPULATION

Supplementing fats: In numerous studies the addition of fats in the supplements fed to ruminants has resulted in reduced CH_4 production (Dong *et al*., 1997; Machmuller and Kreuzer 1999; Dohme *et al*., 2000). However, CH_4 production following the addition of fats varies with the type of fat used. In this respect medium chain fatty acids (C12: 0 - C14: 0) found in coconut oil, palm kernel oil, high-laurate canola oil or pure myristic acid are effective in reducing CH_4, especially for high-concentrate and low Ca diets (Machmuller *et al*., 2003). Medium chain saturated fatty acids found in coconut oil appear to reduce CH4 production through a toxic effect on protozoa and methanogens (Dong *et al*., 1997; Machmuller and Kreuzer 1999). On the other hand, long-chain fatty acids are non-fermentable and therefore may also decrease CH_4 emissions through reduced fiber digestion (McGinn *et al*. 2004; Beauchemin *et al*., 2007) and decreased DMI (Jordan *et al*., 2006a; Jordan *et al*., 2006b).

A limitation associated with excessive fat supplementation (more than 5-6% of the ration) is that it reduces intake, depresses fiber degradation in the rumen, and reduces acetate production and milk fat content (Tackett *et al*., 1996; Ashes *et al*., 1997; Dong *et al*., 1997; Mathison *et al*., 1998). Fats increase the energy density of the diet, which can lead to improved animal performance, in some but not all situations (Lovett *et al*., 2003; Jordan *et al*., 2006a; Jordan *et al*., 2006b).The negative effects of fat feeding are less evident when low-fiber diets are included in the diet.

From the results reviewed it is evident

that vegetable and animal fats are an alternative to reduce enteric CH_4, but it is not clear if this reduction is long or short term. It is also not well defined if the effect of oils on methanogenesis is due to reduced intake, to the inhibiting effect of oils on protozoa and methanogens or to a reduction of dietary fiber digestion.

Supplementing ionophores: Numerous studies have shown that the antibiotic monensin, the most commonly studied ionophore, improves the efficiency of feed utilization and decreases CH_4 production (Mathison *et al*.,1998).The observed increase in propionate production and decrease in CH_4 production that results from monensin feeding have been associated with selective reduction of Gram-positive ruminococci, and the proliferation of the Gram-negative bacteria that is accompanied with a shift in the fermentation from acetate to propionate production (Newbold *et al*., 1988). However, several studies have shown that CH_4 production was not suppressed with prolonged or repeated use of ionophores (McCaughey *et al*., 1997; Sauer *et al*., 1998). The poor persistence of monensin in suppressing CH_4 activity may be due to the development of resistance to the antibiotic, since strains of rumen methanogens differ in susceptibility to monensin and prolonged use of antibiotic may select for non-susceptible strains (Chen and Wolin, 1979).

In general, the supplementation of ionophore is an alternative for reducing CH_4, but of particular concern is that they could accumulate in animal products and that rumen bacteria could get adapted to the antibiotic. Thus the use of ionophores to mitigate CH_4 production might not be the best option now days given the public and health concerns on the use of antibiotics as feed additives.

Supplementing yeast and enzymes: Dietary supplements based on yeast cultures of *Saccharomyces cerevisiae* can potentially stimulate acetogenic bacteria in the rumen that utilize H_2 to form acetate. However, experimental results are strain dependent (Newbold *et al*., 1996) and variable in their impact on CH_4 production in the rumen (McGinn *et al*., 2004).

Enzymes in the form of cellulases and hemicellulases added to the diets of ruminants are known to improve ruminal fiber digestion (Beauchemin *et al*., 2003) and reduce CH_4 production in vitro (28%) and in vivo (9%), probably by reducing the acetate: propionate ratio. These enzymes could be available in large quantities at reasonable cost since they are used in food processing, textile and paper industries. However, further research is required to screen yeast strains and enzymes to isolate those that confer both a production benefit and CH_4 reduction potential.

Supplementing chemical compounds: A number of organic acids (malate, fumarate, and pyruvate) are needed as precursors to propionate and if their concentration in the rumen could be increased, propionate production would increase and CH_4

production would decline. Malate is the organic acid most studied in relation to CH_4 production but fumarate has also been the subject of some work. In vitro studies conducted by Martin e Streeter (1995) demonstrated that malate increased propionate production and decreased CH_4 output. The same workers subsequently found that inclusion of malate in the diet of finishing steers improved feed conversion efficiency (Martin *et al*., 1999), but no reports were found on how malate affects CH_4 emissions. The supplementation of fumarate has not been shown to decrease CH_4 production in vivo (Beauchemin e McGinn, 2006).

Chemical products such as bromochloromethane (a halogenated compound) are potentially strong inhibitors of CH_4 production in ruminants. For example, when added to ruminant diets at a rate of 5 g per day, bromochloromethane was shown to reduce CH_4 production for up to 15 hours after treatment (McCrabb *et al*., 1997). In addition to reducing enteric CH_4 emissions these compounds reduce intake and have little effect on live weight gain, which results in increased feed conversion efficiency (McCrabb, 2000). In Australia, a compound containing bromochloromethane and cyclodextrin was found to have a very large effect on enteric CH_4 production (May et al., 1995). When bromochloromethane and cyclodextrin was fed to cattle at hourly intervals CH_4 production was completely reduced (McCrabb *et al*., 1997) and when fed twice daily to cattle over an eight week period, it reduced CH_4 output by 54% (McCrabb, 2000). A potential problem with halogenated compounds is that microbial populations may adapt and as result CH_4 inhibition may be short term (van Nevel and Demeyer, 1996). They are also unstable compounds which are potentially toxic to ruminants and humans.

Although organic acids divert H_2 towards propionate formation, there use in practice is problematic because of their acidic properties that restrict the quantity which can be fed. This in addition to their high cost makes it unlikely that direct supplementation of organic acids to ruminant diets is an economical option. However, organic acids are present at relatively high concentrations in the leaf tissue of plants and it may be possible to select and breed forages with higher levels of these compounds. Studies from the USA with Lucerne, Bermuda grass and Tall Fescue indicate that concentrations of organic acids vary among species and cultivars of the same species (Callaway *et al*., 1997). However, from the information available in the literature it is not possible to conclude if differences in organic acid concentrations found among forage species and cultivars are large enough to influence CH_4 production by ruminants.

<u>Feeding forage plants with tannins</u>: Several studies (in vitro and in vivo) have shown that with temperate legumes (*Hedysarium coronarium*, *Lespedeza cuneata*, *Lotus*

corniculatus and *L.uliginosus*) and tropical legumes (*Calliandra calothyrsus*, *Flemingia macrophylla*) that contain secondary compounds such as condensed tannins (CT) it is possible to reduce methanogenesis. It is possible that tannins can be toxic to some rumen fiber degrading bacteria and methanogenic archaea, and as a result methanogenesis in the rumen can also be reduced

In a review by Ramirez-Restrepo and Barry (2005) on alternative forages containing secondary compounds for improving sustainable production of grazing ruminants, they indicated that the condensed tannin-containing legumes *Lotus corniculatus* and *Hedysarum coronarium* promoted faster growth rates in young sheep and deer in the presence of internal parasites, and showed reduced CH_4 production relative to forages without tannins (*Chicorium intybus*). They also reported that grazing on *L. corniculatus* with CT was associated with increased reproduction rates in sheep, increased in milk production in both ewes and dairy cows and reduced CH_4 production.

The effect of tannins from different sources (*Lespedeza cuneata*, *Lespedeza striata* and Quebracho) on digestibility, N and energy balance, energy expenditure, CH_4 emission, and ruminal microflora of goats was studied by Animut *et al*., (2008). Results showed that the different tannin sources had different influence on N digestion, but similar effects on ruminal microbial CH_4 emission by goats, possibly by altering activity of ruminal methanogens.

Studies reported in the literature on strategic use of tropical legumes with tannins to reduce CH_4 in ruminants are limited. Hess *et al*., (2006), reported reductions in CH_4 emissions when feeding *Calliandra calothyrsus* high in tannins as compared to *Cratylia argentea* low in tannins. In addition, Tiemann *et al*., (2008) indicated that with some tropical legumes with tannins (i.e. *Calliandra calothyrsus* and *Fleminigia macrophylla*) there low fiber digestibility contributed to reduced in vitro CH_4 production.

In summary, various CT from legume plants could be an alternative to reduce ruminal CH_4 emission. However, more research is needed to better define the mechanisms associated with reduction of CH_4 by CT from different sources since the methanogenic effect produced may not be the same for all CT, but rather depends on the concentration and chemical structure of the CT present in the legume being fed (Min *et al*., 2003).

<u>Feeding plants with saponins to defaunate:</u> The elimination of protozoa from the rumen by dietary or chemical agents was shown to reduce ruminal CH_4 production from 20 to 50% depending on the composition of the diet (Whitelaw *et al*., 1984; Itabashi *et al*., 1994; Van Nevel and Demeyer 1996). The reduced ruminal methanogenesis observed with defaunation can be attributed to a shift of

digestion from the rumen to the lower GI tract (Van Nevel and Demeyer 1996) and to the loss of methanogens associated with protozoa during defaunation (Hegarty, 1999).

Defaunating agents or protozoal inhibitors are not currently available for commercial or practical use as many of the defaunating agents are toxic to the animal. However, it is well documented that secondary compounds known as saponins have antiprotozoal activity, but the level of antiprotozoal activity may vary with the type of saponin (Hess *et al*., 2003). In the rumen, methanogens are associated with protozoa (Lange *et al*., 2005), thus any additive that reduces the protozoa population will inhibit CH_4 production indirectly.

In vitro studies carried out in India using ethanol extracts of *Sapindus mukorossi* (a seed rich in saponins) showed a 52% reduction in protozoa population when the extract was added in the incubation medium and this was associated with inhibition (96%) in CH_4 production by rumen microbes of buffalos (Agarwal *et al*., 2009). In Colombia, Hess *et al*., (2003) evaluated in vitro the fruit of *Sapindus saponaria* and found decreased protozoal count by 54% and daily CH_4 release by 20% relative to the control (grass + legume hay + straw + urea), but without affecting the methanogen count. In this study the effect of *S. saponaria* on CH_4 was greater in defaunated (29%) than in faunated rumen fluid (14%).

In general, the evidence reviewed indicates that saponins from some tropical fruits suppress the protozoa population in the rumen and by doing so reduce methanogenesis, but the effect would not seem to be exclusively due to protozoal count depression. Further work is needed in this area to develop practical means of controlling rumen protozoa in ruminant animals and by doing so reduce CH_4 production.

2.3 CHOICE OF ANIMAL SPECIES IN PRODUCTION SYSTEMS

Production systems with mixed animal species (cattle, sheep and goats) are used in several regions of the world. A good example is the mixed system in the semiarid region of northeast of Brazil which is known as Caatinga (white forest). The production system in the Caatinga is characterized by being extensive (Araujo Filho and Crispim, 2002) and as a result possibly producing high emissions of enteric CH_4 per unit product. In what follows we discuss differences in CH_4 emissions in ruminant species based on differences in anatomy of the GI tract, digestive physiology, and body weight and diet selection.

<u>Animal species</u>**:** Results from few controlled experiments indicate differences in CH_4 production among species. For example**,** in a study in New Zealand daily CH_4 production from cattle (140 g /day) was greater than in deer (31 g /day), which in turn was greater than in sheep (18 g /day). Methane produced per unit of DM intake (DMI) was also greater

in cattle (21 g /kg DMI) than in sheep (18 g /kg DMI) and deer (16 g /kg DMI) (Swaison *et al.*,2008). In another study in New Zealand results showed that Alpacas produced less CH_4 per unit of fermented NDF than sheep (Pinares-Patiño, 2003a).

Rumen fermentation process**:** A different level of production of CH4 per unit of gross energy or DMI in ruminant animal species implies that the fermentation processes varies among species. Theoretically, lower CH_4 emissions can result from reduced degradation of feed associated with increased rate of passage of feed through the digestive tract and from higher proportion of propionate vs. acetate. This was confirmed in studies in New Zealand that showed that CH_4 produced per unit of DMI was lower in animals that exhibited fast rate of passage of feed particles (Pinares-Patiño 2003c). Differences in CH_4 emissions rates among animal species is also related to diet selection as shown by results that indicate that animals that select higher quality diets produce less CH_4 per unit of DMI (Pinares-Patiño *et al.*,2010).

Anatomy of the GI tract and digestive physiology**:** The anatomy of the GI tract and digestive physiology of ruminants could help us understand differences among species in their potential to produce CH_4 when fed similar diets. It has been suggested that the digestive tract of different animal species evolved according to dietary habits (Hofmann, 1993). Based on diet selection habits animal species could be classified in three groups: a) grass / roughage eaters (low selectivity), b) concentrate selectors (high selectivity) and c) intermediate selectors. Based on this classification one can infer that cattle and sheep have lower retention times and produce less CH_4 per unit of DMI than goats given that they are less selective. This conclusion supports the use in the Tier II methodology (IPCC, 2006) of a lower rate of CH_4 emission per unit of energy intake for goats as compared to sheep and cattle.

Results that show lower rates of passage and higher dry matter digestibility in cattle as compared to goats or sheep are well documented. In a review of 82 published papers, Aerts *et al*., (1985) concluded that feed digestibility was higher in cows than in sheep. Other researchers reported that cattle exhibited higher DM digestibility than goats or sheep (Tolkamp and Brouwer, 1993). However, differences between goats and sheep are less clear. For example, Tolkamp e Brouwer (1993) concluded that goats have higher digestibility than sheep, while other studies have indicated higher rates of passage for goats than sheep (García *et al.*, 1995; Huston *et al*., 1986) or have failed to show differences between species (Isac *et al.*,1994; Molina- Alcaide *et al*., 2000). It should be kept in mind however, that higher rates of passage in goats as compared to sheep will only be evident if animals are allowed to select their diet (Molina-Alcaide *et al*., 2000).

The lower rate of passage and higher digestibility in cattle as compared to sheep or goats has also been related to body size and diet selection. Studies by Gordon and Illius (1994) showed that retention time of digesta in the rumen was lower as body size decreased and that smaller ruminant if given the opportunity, selected diets of higher quality than large ruminants. Other researchers observed that the gut capacity of large African herbivores in relation to energy requirements was greater than in small ruminants and as a result they compensated this apparent disadvantage by being more selective and by having higher intakes and higher rates of passage (Demment e Van Soest, 1985).

In general, the literature reviewed indicates that there are differences in rates of passage between large and small ruminants. When fed similar diets small ruminants have higher rates of passage and lower digestibilities than large ruminants and this can result in potentially less CH_4 per unit DMI.

Modelling**:** A more thorough comparison between ruminant animal in their nutritional efficiency requires considering not only total CH_4 production or per unit of feed consumed, but also CH_4 produced per unit of animal product (milk, meat). In order to calculate CH_4 produced by different domesticated ruminants we used the production parameters summarized in Table 1. For the calculations we also used the Tier II equations of the IPCC model (IPCC, 2006), which assume a lower rate of CH_4 emission per unit of energy intake by goats (5%) as compared to sheep and cattle (6%)

Table 1. Production parameters of different domesticated ruminants used to estimate methane production with the IPCC model (2006).

Parameters	Cebu	Holstein	Sheep	Goats
Live weight (kg)	450	600	50	60
Milk production (L/d)	5	18	1	2
Weight gain (kg/d)	0,5	0,6	0,14	0,1
Calvings/year	1	1	1,3	1,3
Offsrings per year	1	1	1,2	1,2
Offspring weight (kg)	30	45	2,5	1,5

The Tier II IPCC model predicted that CH_4 emission by ruminant species was higher in stages of production which demand more energy as well as in breeds with higher genetic potential to produce milk (Table 2). For example, high producing Holstein animals produced on average 39% more CH_4 regardless of stage of production as compared to Cebu animals. The Tier II IPCC model also predicted 24% higher CH_4 emissions in goats than in sheep. However, high producing dairy cattle and goats produce less CH_4 per liter of milk than Cebu cattle or sheep.

Table 2. Gross energy intake and methane production as a function of production stage of different ruminant species estimated using the IPCC model (2006).

Productive stage	Gross Energy Intake	Methane		
	(Mcal/year)	g/Mcal	Kg/year	g/d
Gestation				
Cebu	7866	4,5	35,5	97,2
Holstein	17994	4,5	81,2	222,4
Sheep	1614	4,5	7,3	19,9
Goats	2178	3,8	9,3	25,4
Lactation				
Cebu	11502	4,5	51,9	142,2
Holstein	27780	4,5	125,3	343,3
Sheep	2207	4,5	9,9	27,3
Goats	4005	3,8	15,1	41,2
Growth				
Cebu	15931	4,5	71,8	196,6
Holstein	16199	4,5	73,1	200,1
Sheep	1517	4,5	6,8	18,8
Goats	2178	3,8	8,2	22,4

[1]Kg of offspring, milk or live weight gain for gestation, lactation and growth

Differences in CH_4 production between breeds in different stages of production have been documented in several studies. For example, Odai *et al*. (2010) reported less CH_4 in dry cows than in lactating cows. In another study Primavesi *et al*. (2004) reported that lactating cows of European breeds produced on average 31% more CH_4 when lactating than when dry, while the difference between lactating and dry cows was only 10% for Holstein- Cebu crossbred cattle. These authors concluded that crossbred Cebu cows produce on average 18% less CH_4 than Holstein cows.

Results using the IPCC Tier II model indicate that higher CH_4 emissions by cows with high genetic potential for milk production is compensated by high level of milk yield, which results in less CH_4 per unit of milk (Table 2). The Tier II model also show that CH_4 produced per liter of milk is similar for sheep and Cebu cattle, which on average produce 26% more CH_4 per kg of milk than goats and high producing dairy cows.

In general, predictions obtained using the IPCC model indicate that goats and high producing dairy cattle can potentially produce less CH_4 per unit of milk than Cebu cattle or sheep, while small ruminants (goats and sheep) can produce less CH_4 per unit of LWG (meat) than cattle. The greater environmental efficiency (less CH_4 / unit product) of small ruminants to produce meat as compared to cattle should be verified under control experiments. We predict however, that given that small ruminants have higher weight gain in relation to body weight and are slaughtered at a younger age than cattle, it is highly probable that they produce less CH_4 /unit of LWG (meat) due to lower CH_4 produced for maintenance.

2.4 ANIMAL SELECTION AND BREEDING

Researchers in New Zealand have taken several approaches in an attempt to reduce enteric CH_4 production such as exploiting breed/genotype differences and animal to animal differences. There is evidence that indicates that improving individual animal performance reduces CH_4 produced per unit of product. It is also possible that some animals have intrinsic lower CH_4 emissions per unit of DMI than others at the same level of performance.

In trials with grazing sheep Pinares-Patiño *et al*., (2003b) in New Zealand classified some animals as 'high' and 'low' CH_4 emitters per unit of feed intake. Low emitters were heavier than the high emitters in all experimental periods, but they did not differ in their gross energy intake. In addition, low and high CH_4 emitters consistently maintained throughout the subsequent periods their initial rankings in CH_4 yield (% GEI).The reasons why particular animals emitted less CH_4 per unit of feed intake in these sheep trials is not known, but it does raise the possibility of genetic differences between animals in CH_4 production.

Other researchers have indicated that selection of animals with low potential to produce CH_4 could be based on differences in feed retention time in the rumen, which as discussed earlier has an effect on feed digestibility. For example, Waghorn *et al*. (2006) reported that when compared at the same stages of lactation (60 and 150 days), Holstein cows from the Northern Hemisphere consuming mixed diets produced 15% less CH_4/kg of DMI than cows from New Zealand also consuming mixed diets. However, in a subsequent study Munger and Kreuzer (2008) compared the emission of CH_4 in Jersey and Simmental cattle fed ad libitum in open gas exchange chambers and found no differences in CH_4 production between breeds.

More recently there has been interest in selecting animals with low production of enteric CH_4 based on differences in RFI (residual feed intake = measured intake – predicted intake; animals with a negative RFI are efficient while animals with a positive RFI are less efficient). Few results have shown that RFI is correlated ($r = 0.44$, $P < 0.05$) with daily CH_4 production and energy lost as CH_4 in cattle (Nkrumah *et al.,* 2006). In another study Hegarty *et al*., (2007) also reported a significant ($P=0.01$) positive relationship between CH_4 production and residual feed intake (RFI) in Angus steers.

In summary, large animal-to-animal variation in CH_4 emission is commonly observed, with the variation being larger under grazing conditions (CH_4 measured using theSF6 technique) than indoors (CH_4 measured using gas exchange chambers). Mechanisms responsible for the between animal variation in CH_4 production are unknown. On the other hand, results in the literature suggest that animal breeding could achieve a 10%–20% reduction in CH_4 losses from digestion (Waghorn *et al*., 2006).

In summary, breeding for improved feed conversion efficiency (lower RFI) should be compatible with existing breeding objectives and is likely to reduce both total CH_4 and CH_4 per unit product.

2.5 IMPROVING PRODUCTION SYSTEMS

The introduction of improved high quality forages and the implementation of efficient forage utilization practices (grazing system and stocking rate) can result in most cases in improved animal production in livestock systems, but also in increased daily CH_4 emissions. However, the amount of CH_4 per unit of animal product would most likely decrease with increased animal production associated with improved pastures and management practices.

It has been argued by some authors that enteric CH_4 emissions should be measured on an annual rather than on a short-term basis. For example, results from modeling sheep enterprise indicate that the cost of lamb growth should include the cost of feeding the ewe as well as the lamb. If this approach is followed then CH_4 emissions /Kg of lamb will be reduced if ewes have a long productive live, lamb every year and have multiple lambs (Alcock and Hegarty, 2006). Other authors have argued that enteric CH_4 production should be evaluated from the perspective of the whole farm. In Australia researchers used the GrassGrok ™ model to simulate changes in annual CH_4, meat, wool and gross margin (GM), resulting from sowing improved pasture on a 100 ha cross-bred lamb farm in NSW (Alcock and Hegarty, 2006). Simulations used 45 years of local weather data with stocking rates on unimproved and improved pastures of 3.5 and 9 ewes/ha, respectively. Results showed that by sowing 100% of the farm area to improved pasture, farm CH_4 production and sales of wool and LWG increased by 2.3, 2.7 and 3.1 fold, respectively. These results illustrate that modelling livestock systems is useful to identify relationships between plane of nutrition and animal productivity, economic output and CH_4 emissions of farm enterprises.

In summary, improving pastures can increase forage production, carrying capacity and animal production, which is accompanied by reductions in CH_4 per unit animal product but increases in total CH_4 emission from the farm. However, improved pastures can contribute to livestock enterprise to be more financially secure, produce less CH_4/kg of animal product and have a higher economic profit per unit of CH_4 emitted

3. Conclusion

Ruminant animals produce CH_4 as part of their normal digestive processes that involves microbial fermentation to convert feed into products that can be digested and utilized by the animal. The inhibition of enteric CH_4 emission in ruminant animals is possible through the use of vegetable and animal oils, chemical feed additives like organic acids or antibiotics (ionophores), but high cost and/or short term nature of their effects may limit their use. Therefore, it would seem that priority should be given to the selection of feed ingredients and forage plants containing secondary metabolites (tannins and saponins) that can be used to inhibit methanogenesis selectively, but without adversely affecting feed utilization. Differences between and within species in CH_4 production should also be exploited when designing mixed animal production systems and animal breeding programs in the tropic.

4. References

Aerts, J.V.; De Boever, J.L.; Cottyn, B.G.; De Branebder, D.L.; Buysse, F.X. (1985). Comparative digestibility of feed stuffs by sheep and cows. *Animal Feed Science and Technology*, v.12, p.47-56.

Agarwal, N.; Shekhar, C.; Kumar, R.; Chaudhary, L.C.; Kamra, D.N. (2009). Effect of peppermint (*Mentha piperita*) oil on in vitro methanogenesis and fermentation of feed with buffalo rumen liquor. *Animal Science and Technology*, v. 148, p. 321 - 327.

Alcock D.; Hegarty R.S. (2006). Effects of pasture improvement on productivity, gross margin and methane emissions of a grazing sheep enterprise. *International Congress Series*, v.1293, p.103-106.

Animut, G.; Puchala, R.; Goetsch, A.L.; Patra A.K.; Sahlu, T.; Varel, V.H.; Wells, J. (2008). Methane emission by goats consuming different sources of condensed tannins. *Animal Feed Science and Technology*, v.144, p.228-241.

Araujo Filho J.A.; Crispim S.M.A. (2002). Associated grazing of cattle, sheep and goats at the semi- arid region of Northeast Brazil. Virtual Global Conference on Organic Beef Cattle Production.

Ashes, J.R.; Gulati, S.H.; Scott, T.W. (1997). Potential to alter the content and composition of milk fat through nutrition. *Journal of Dairy Science*. v.80, p.2204-2212.

Beauchemin K, A., Colombatto D., Morgavi, D, P. (2003) Use of exogenous fibrolytic enzymes to improve feed utilization by ruminants. *Journal of Animal Science*, v.81(E. Suppl. 2), E37-E47.

Beauchemin K. A.; McGinn, S. M. (2006). Methane emissions from beef cattle: Effects of fumaric acid, essential oil, and canola oil. *Journal of Animal Science*, v. 84, p. 1489-1496.

Beauchemin K.A.; McGinn S.M.; Petit H. (2007). Methane abatement strategies for cattle: lipid supplementation of diets. *Canadian Journal of Animal Science*, v.87, p.431-440.

Beauchemin, K. A., Kreuzer. M.; O'Mara, F.; McAllister, T. A. (2008). Nutritional management for enteric methane abatement: a review. *Australian Journal of Experimental Agriculture*, v.48, p.21-27.

Blaxter, K.L.; Clapperton, J.L. (1965). Prediction of the amount of methane produced by ruminants. *British Journal of Nutrition*, v. 19, p.511-522.

Boadi D.; Benchaar C.; Chiquette J, Massé, D. (2004). Mitigation strategies to reduce enteric methane emissions from dairy cows: Update review. *Canadian Journal of Animal Science*. v.84, n.3, p.319-335.

Callaway, R.; Martin, S.A.; Wampler, J.L. (1997). Malate Content of Forage Varieties Commonly Fed to Cattle. *Journal of Dairy Science*, v.80, p.1651-1655.

Chen, M.; Wolin, M.J. (1979). Effect of Monensin and Lasalocid-sodium on the growth of methanogenic and rumen saccharolytic bacteria. *Appl. Env. Micro*. v.38, p.72-77.

Demment, M.W.; Van Soets, P.J. (1985). A nutritional explanation for body-size patterns of ruminant and non ruminant herbivores. *The American Naturalist*, v.125, p.641-672.

Dohme, F.; Machmuller, A.; Wasserfallen, A.; Kreuzer, M. (2000). Comparative efficiency of various fats rich in medium chain fatty acids to suppress ruminal methanogenesis as measured with RUSITEC. *Can. J. Anim. Sci*. v.80, p.473-482.

Dong, Y.; Bae, H.D.; McAllister, T.A.; Cheng, K.J. (1997). Lipid-induced depression of methane production and digestibility in the artificial rumen system (RUSITEC). *Can. J. Anim. Sci*. v.77, p. 269-278.

Eckard, R.J.; Grainger, C.; de Klein, C.A.M. (2010). Options for the abatement of methane and nitrous oxide from ruminant production: A review. *Livestock Science*, v.130, p.47-56.

FAO. The genetic improvement of forage grasses and legumes to reduce greenhouse gas emissions.(*www.fao.org/ag/AGP/.../abberton _%20geneticimprovement.pdf*), *2007.*

Garcia, M.A.; Aguilera, J.F; Molina-Alcaide, E. (1995). Voluntary intake and kinetics of degradation and passage of unsupplemented and supplemented pastures from semiarid lands in grazing goats and sheep. *Livestock Production Science.* v. 44, p.245-255.

Gordon, J.J.; Illius, A. (1994). The functional significance of the browser-grazer dichotomy in African ruminants. *Oecologia*. v.98, p.167-175.

Gworgwor, Z. A.; Mbahi, T.F.; Yakubu, B. (2006). Environmental Implications of Methane Production by Ruminants: A Review. *Journal of Sustainable Development in Agriculture and Environment*, v.2, p.1-14.

Hegarty, R. (1999). Reducing rumen methane emissions through elimination of rumen protozoa. *Australian Journal of Agricultural Research*, v. 50, p. 1321-1328.

Hegarty, R.S. (2001). Strategies for mitigating methane emissions from livestock-Australian options and opportunities. In *Proc. 1st International Conference on Greenhouse Gases and Animal Agriculture*. Obihiro, Hokkaido, Japan, p.31-34..

Hegarty R.S.; Goopy, J.P.; Herd, R.M.; McCorkell, B. (2007). Cattle selected for lower residual feed intake have reduced daily methane production. *Journal of Animal Science*, v.85, p. 1479-1486.

Hess, H.D.; Kreuzer, M.; Diaz, T. H.D.; Lascano, C.E.; Carulla, J.E.; Soliva, C.O.; Machmüller, A. (2003). A. Saponin rich tropical fruits affect fermentation and methanogenesis in faunated and defaunated rumen fluid. *Animal Feed Science and Technology*. v.109, p.79-94.

Hess H,D.; Tiemann T,T.; Noto, F. (2006). Strategic use of tannins as means to limiti methane emissions from ruminant livestock. International Congress Series, v.1293, p.164-167.

Hofman, R.R. (1993). Anatomy of the gastro-intestinal tract. In: The ruminant animal:

Digestive Physiology and nutrition. Church, D.C. Ed. Wveland Press, Inc. p.14-43.

Huston, J.E.; Rector, B.S.; Ellis, W.C.; Allen, M.L. (1986). Dynamics of digestion in cattle, sheep, goats and deer. Journal of Animal Science. v.62, p.208-215.

IPCC (Intergovernmental Panel on Climate Change) (2007). Cambio climatico 2007: Informe de síntesis. Contribución de grupos de trabajo I, II y III al cuarto informe de evaluación del grupo intergubernamental de expertos sobre el cambio climático [Equipo de redacción principal: Pachauri R.K. y Reisinger, A. (directores de la publicación)]. IPCC, Ginebra, Suiza, 104 pag.

IPCC (Intergovernmental Panel on Climate Change). (2006). Guidelines for National Greenhouse Inventories. Vol. 4. Agriculture, forestry and other land use. Ch. 10. Emissions from livestock and manure management. p.10.1- 10.87.

Isac, M.D.; Aguilera, J.F.; Molina-Alcaide, E. (1994). Comparative study of nutrient digestibility, kinetics of digestion and passage and rumen fermentation patterns in goats and sheep offered medium quality forages at the maintenance level of feeding. *Archives of Animal Nutrition*, v.46, p.37-50.

Itabashi, H.; Washio, Y.; Takenaka, A., (1994). Effects of a controlled fauna on methanogenesis, fibre digestion and rate of growth in calves. *Proc. Soc. Nutr. Physiol*, v.3, p.179-184.

Johnson, D.E.; Ward, G.W.; Ramsey, J.J. (1996). Livestock methane: Current emissions and mitigation Potential. In*:* E. T. Kornegay, ed. Nutrient management of food animals to enhance and protect the environment. Lewis Publishers, New York, NY. pages 219-234.

Johnson, K.A.; Johnson, D.E. (1995). Methane emissions from cattle. Journal of Animal Science, v.73, p.2483-2492.

Jordan E; Lovett D.K.; Hawkins M. (2006a). The effect of varying levels of coconut oil on intake, digestibility and methane output from continental cross beef heifers. *Animal Science (Penicuik, Scotland)* v.82, 859-865.

Jordan E; Lovett D.K.; Monahan, F.J. (2006b). Effect of refined coconut oil or copra meal on methane output and on intake and performance of beef heifers. *Journal of Animal Science*, v.84, p.162-170.

Kamra, D.N. (2005) Rumen microbial ecosystem. Current Science, v. 89, p.124-135.

Lange, M.; Westermann, P.; Ahring, B.K. (2005). Archea in protozoa and metazoan. *Applied Microbiology and Biotechnology*, v.66, p. 465 – 474.

Lascano Carlos E; Cardenas E. (2010). Alternatives for methane emission mitigation in livestock systems. *Revista Brasileira de Zootecnia*. v.39, p.175-182.

Lassey, K.R.; Marcus, J.; Ulyatt, J. (1997). Methane emissions measured directly from grazing livestock in New Zealand. Atmospheric Environment, v.31, p.2905-2914.

Le-Liboux, S.; Peyraud, J. L. (1999). Effect of forage particle size and feeding frequency on fermentation patterns and sites and extent of digestion in dairy cows fed mixed diets. Anim. Feed Sci. Technol, v.76, p.297-319.

Lockyer, D.R.; Jarvis, S.C. (1995). The measurement of methane losses from grazing animals. *Environmental Pollution*. v.9, p. 383-390.

Lovett, D, K., Lovell, S., Stack, L. (2003). Effect of forage/concentrate ratio and dietary coconut oil level methane output and performance of finishing beef heifers. *Livestock Production Science*, v.84, p.135-146.

Lovett, D.K.; McGilloway, D.; Bortolozzo, A. (2006). In vitro fermentation patterns and methane production as influenced by cultivar and season of harvest of Lolium perenne L. *Grass and forage Science*, v. 61, p.9-21.

Machmüller, A.; Kreuzer, M. (1999). Methane suppression by coconut oil and associated effects on nutrient and energy balance in sheep. *Can. J. Anim. Sci*., v.79, p.65-72.

Machmüller, A.; Soliva, C.R.; Kreuzer, M. (2003). Methane-suppressing effect of myristic acis in sheep as affected by dietary calcium and forage proportion. *British Journal Nutrition*, v.90, p.529-540.

Martin, S.A.; Streeter, M.N. (1995). Effect of malate on in vitro mixed ruminal microorganism fermentation. *Journal of Animal Science*, v. 73, p.2141-2145.

Martin, S.A.; Streeter, M.N.; Nisbet, D.J. (1999). Effects of DL-malate on ruminal metabolism and performance of cattle fed a high-concentrate diet. *Journal of Animal. Science*, v. 77, p.1008-1015.

Mathison, G.W., Okine, E.K., McAllister, T. A. (1998). Reducing methane emissions from ruminant animals. *J. Appl. Anim*. v.14, p.1-28.
May, C.; Payne, A. L.; Stewart, P. L. (1995). A delivery system for agents. International Patent Application No. PCT/AU95/00733.

McCaughey, W. P.; Wittenberg, K.; Corrigan, D. (1997). Methane production by steers on pasture. *Can. J. Anim. Sci*., v.77, p.519-524.

McCrabb G. J.; Berger K. T.; Magner T. (1997). Inhibiting methane production in Brahman cattle by dietary supplementation with a novel compound and the effects on growth. *Australian Journal of Agricultural Research*, v.48, p.323-329.

McCrabb, G.J. (2000). The relationship between methane inhibition, feed digestibility and animal production in ruminants. In: *Methane mitigation. Proceedings of the*

Second International Conference, Novasibirsk, Russia, p.125-131.

McGinn, S.M.; Beauchemin K.A.; Coates T.; Colombatto, D. (2004). Methane emissions from beef cattle: effect of monensin, sunflower oil, enzymes, yeast and fumaric acid. Journal of Animal Science,v.82, p.3346-3356.

Min B.R.; Barry, T.N; Attwood, G.T.; McNabb, W.C. (2003). The effect of condensed tannins on the nutrition and health of ruminants fed fresh temperate forages: A review. *Animal Feed Science and Technology*, v. 106, p.3-19.

Molina Alcaide, E.; Martin Garcia, A.I.; Aguilera, J.F. (2000). A comparative study of nutrient digestibility, kinetics of degradation and passage and rumen fermentation pattern in goats and sheep offered good quality diets. *Livestock Production Science*, v.64, 215-223.

Münger, A.; Kreuzer, M. (2008). Absence of persistent methane emission differences in three breeds of dairy cows. *Australian Journal of Experimental Agriculture*, v.48, p.77-82.

Newbold, C.J.; Wallace, R.J.; Watt, N.D.; Richardson, A.J. (1988). The effect of the novel ionophore tetronasin (ICI 139603) on ruminal microorganisms. *Appl. Environ. Microbiology*, v.54, p.544-547.

Newbold, C.J.; Wallace, R.J.; McIntosh, F. M. (1996). Mode of action of the yeast Sacchararomyces cerevisiae as a feed additive for ruminants. *Br. J. Nutr*, v.76, p.249-261.

Nkrumah, J.D.; Okine, E.K.; G.W. Mathison, G.W.; Schmid, K.; Li, C.; Basarab J.A., Price M.A; Wang, Z.; Moore, S. S. (2006). Relationships of feedlot feed efficiency, performance, and feeding behavior with metabolic rate, methane production, and energy partitioning in beef cattle. *Journal Animal Science*, v.84, p.145-153.

Odai, M.; Nonaka, I.; Sumamal, W., (2010). Estimation of methane production by lactating and dry crossbred Holstein cows in Thailand. *Japan Agricultural Research Quarterly*, v. 44, p.429-434.

Pinares-Patiño C.S.; Ulyatt, M.J.; Waghorn G.C (2003a). Methane emission by alpaca and sheep fed Lucerne hay or grazed on pasture perennial ryegrass/white clover and birdsfood trifoil. *The Journal of Agricultural Science*, v.140, p.215-226.

Pinares-Patiño C. S.; Ulyatt, M. J.; Lassey, K. R. (2003b). Persistence of differences between sheep in methane emission under generous grazing conditions. *The Journal of Agricultural Science*, v.140, p.227-233.

Pinares-Patiño, C.S.; Ulyat, M.J.; Lassey, K.R. (2003c). Rumen function and digestion parameters associated with differences between sheep in methane emission when fed chaffed Lucerne hay. *The Journal of Agricultural Science*, v.140, p.205-214.

Pinares-Patiño, C.S.; Laubach, J.; Molano G. (2010). Methane emissions from cattle stocked at high density and fed at three different feeding levels. Mc Geough and SM McGinn (Eds). Proceedings of the 4th International Conference on Greehouse Gases and Animal Agricultrure, Banff, Canada, October 3-8.

Primavesi, O.; Frighetto, R.T.S.; Pedreira, M.S. (2004). Metano entérico de bovinos leiteiros em condições tropicais brasileiras. *Pesquisa Agropecuaria Brasilera. Brasilia*, v.39, p.277-283.

Ramaswany, V.; Boucher, O.; Haigh, J. (2001). Report of the Intergovernmental Panel on Climate Change. In: Houghton, R. (ed.). Cambridge University Press. Cambridge, UK. p.349-416.

Ramirez-Restrepo; Barry, T. N. (2005). Alternative temperate forages containing secondary compounds for improving sustainable productivity in grazing ruminants. *Animal Feed Science and Technology*, v.120, p.179-201.

Robertson, L.J.; Waghorn, G. C. (2002). Dairy industry perspectives -on methane emissions and production from cattle fed pasture or total mixed rations in New Zealand. *Proc. N. Z. Soc. Anim. Prod*, v.62, p.213-218.

Sauer, F.D.; Fellner, V.; Kinsman, R. (1998). Methane output and lactation response in Holstein cattle with monensin or unsaturated fat added to the diet. *Journal of Animal Science*, v.76, p.906-914.

Shingfield, K.J.; Jaakkola, S.; Huhtanen, P. (2002). Effect of forage conservation method, concentrate level and propylene glycol on diet digestibility, rumen fermentation, blood metabolite concentrations and nutrient utilization of dairy cows. *Anim. Feed Sci. Technol*, v.97, p.1-21.

Solomon, S.; Qin, D.; Manning, M. (2007). Report of the Intergovernmental Panel on Climate Change. In: Solomon *et al.*,(eds.). Cambridge University Press. Cambridge, UK.

Sundstol, F. (1981). Methods for treatment of low quality roughages. In J. A. Kategile, A. N. Sand, and F. Sundstol, eds. Utilization of low quality roughages in Africa. Agricultural University of Norway, Norway. P.61-80.

Swaison N.M; Hoskin S.O.; Clark H. (2008). Comparative methane emissions from cattle, red deer and sheep. Proceedings of the New Zealand. *Society of Animal Production*, v.68, p.59-62.

Tackett, V.L; Bertrand, J.A.; Jenkins, T.C. et al. Interaction of Dietary Fat and Acid Detergent Fiber of lactating dairy cows. Journal of Dairy Science, v.79, p.270-275, 1996.

Tiemann, T.T.; Lascano, C.E.; Kreuzer, M. (2008). The ruminal degradability of fibre explains part of the low nutritional value and reduced methanogenesis in highly tanniniferous tropical legumes. *Journal of the Science of Food and Agriculture*, v.88, p.1794-1803.

Tolkamp, B.J.; Brouwer, B.O. (1993). Statistical review of digestion in goats compared with other ruminants. *Small Ruminant Reaserch*, v.11, p.107-123.

Ulyatt M.J.; Lassey K.R. (2000). Methane Emissions from pastoral systems: the situation in New Zealand. Presentation given at the XVIMetting of the Archivos Latinamericanos de Produccion Animal, Montevideo.

Van Nevel, C.; Demeyer, D. (1996). Control of rumen methanogenesis. *Environment Monitoring Assessment*, v. 42, p. 73-97.

Waghorn, G.C.; Woodward S.L.; Tavendale M. (2006). Inconsistencies in rumen methane production- effects of forage composition and animal genotype. In: *International Congress Series*, v. 1293, p.115 -118.

Whitelaw, F.G.; Eadie, J.M.; Bruce, L.A. (1984). Methane formation in faunated and ciliate-free cattle and its relationship with rumen volatile fatty acid proportions. *Br. J. Nutr.*, v.52, p.261-67.