Ruminant grazing feeding and methane production

Alimentación de rumiantes a pastoreo y producción de metano

Alimentação de ruminantes em pastagens e produção de metano

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Abstract

Climate change limits the release of radiation from the earth's atmosphere, a product of the accumulation of greenhouse gases (GHG) such as CO_2, methane, ammonia, among others. Ruminants contribute methane to the atmosphere when fed with low quality forage diets, which in the light of different conservationist organizations, qualifies them as major pollutants. When Venezuela signed the Kyoto Protocol in 2004, it undertook to establish a GHG measurement system, as well as scientific research on the subject; however, there are still no research groups in the country dedicated to the permanent measurement of GHG contributions from these production systems. Grazing pastures and forages of medium to low quality, with high contents of cell wall of low degradability, produce a positive balance towards the generation of methane of enteric origin, which could be mitigated if these feeding schemes are improved, tending to improve the digestibility of basic diets. Methane production by these production systems in the state of Zulia is calculated at 209 Gg, 7.1 % of the total inventoried at the national level; however, the lack of research in this area, as well as of systematic inventories of local herds, prevents obtaining accurate data in this regard.

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Resumen

El cambio climático limita la liberación de radiación de la atmósfera terrestre, producto de acumulación de gases de efecto invernadero (GEI) como el CO_2, metano, amoniaco, entre otros. Los rumiantes aportan metano a la atmósfera al ser alimentados con dietas forrajeras de baja calidad, lo que a la luz de diferentes organizaciones conservacionistas, les califica como grandes contaminantes. Venezuela al suscribir el Protocolo de Kyoto en 2004 se compromete a establecer un sistema de medición de GEI, así como investigación científica al respecto, sin embargo, actualmente aún son inexistentes en el país los grupos de investigación dedicados a la medición permanente de los aportes de GEI por parte de estos sistemas de producción. La alimentación basada en pastos y forrajes de mediana a baja calidad, con altos contenidos de pared celular de baja degradabilidad, producen un balance positivo hacia la generación de metano de origen entérico, lo que podría mitigarse si se mejoran dichos esquemas alimenticios a fin de mejorar la digestibilidad de las dietas básicas. La producción de metano por estos sistemas de producción en el estado Zulia, se calculan en 209 Gg, es decir, 7,1 % del total inventariado a nivel nacional, sin embargo, la carencia de investigación en esta área, así como de inventarios sistemáticos de rebaños locales, impide obtener datos certeros en este sentido.

Palabras clave: cambio climático, Metano, Bovinos Doble Propósito, Pastoreo, Suplementación.

Resumo

A mudança climática limita a liberação de radiação da atmosfera terrestre como resultado do acúmulo de gases de efeito estufa (GEE), como CO_2, metano, amônia, entre outros. Os ruminantes contribuem com metano para a atmosfera ao serem alimentados com dietas de forragem de baixa qualidade, o que, de acordo com várias organizações de conservação, os qualifica como grandes poluentes. Quando a Venezuela assinou o Protocolo de Kyoto em 2004, comprometeu-se a estabelecer um sistema de medição de GEE, bem como pesquisas científicas a esse respeito. No entanto, ainda não existem no país grupos de pesquisa dedicados à medição permanente das contribuições de GEE desses sistemas de produção. As pastagens e forragens de média a baixa qualidade, com alto teor de parede celular e baixa degradabilidade, produzem um saldo positivo na geração de metano de origem entérica, que poderia ser mitigado se esses esquemas de alimentação fossem aprimorados por meio da melhoria da digestibilidade das dietas básicas. A produção de metano por esses sistemas de produção no estado de Zulia é estimada em 209 Gg, 7,1 % do total nacional. No entanto, a falta de pesquisas nessa área, bem como a falta de inventários sistemáticos dos rebanhos locais, nos impede de obter dados precisos a esse respeito.

Palavras-chave: mudanças climáticas, Metano, Gado de dupla finalidade, Pastagem, Suplementação.

Introduction

Despite being one of the most important oil producers in the world, Venezuela is a country that contributes a low level of Greenhouse Gas (GHG) emissions, a similar situation in the case of methane of enteric origin (MARNR, 2005). In 1994, Venezuela ratified the United Nations Framework Convention on Climate Change (UNFCCC) and in 2004 acceded to the Kyoto Protocol through Official Gazette No. 38.081 of December 7, 2004 (Venezuela, 2004, 2010). Venezuela's adherence to this convention imposes a series of commitments to be fulfilled, such as the generation of inventories of GHG emissions by source and their absorption by sinks, updated periodically; development of national and/or regional programs to mitigate climate change and adapt to the potential effects, strengthening scientific and technical research, promoting the development of technologies, practices and processes to control, reduce or prevent anthropogenic GHG emissions.

Reading the document of the First National Communication on Climate Change in Venezuela (MARNR, 2005), the lack of institutions and research groups actively registering GHG emissions scientific data, especially in agricultural production systems, is clearly documented. This leads the discussion to the non-existence of GHG emission estimates in livestock production systems in Venezuela, which places the country in a condition of non-compliance with the commitments acquired with the adhesion to the convention.

On the other hand, ruminant feeding in these systems is based on medium to low quality pasture and forage, which implies a high contribution of methane to the atmosphere (Niggli *et al*., 2009; Vargas *et al*., 2012). However, the supplementation options used by livestock producers are usually commercial concentrate feeds or raw materials with high contents of easily digestible carbohydrates, which favor the digestion of the base diet and consequently, a decrease in emissions (Hristov *et al*., 2013).

At present, the product of a political and economic crisis that has driven the costs of goods and services to a state of hyperinflation, as well as the foreign origin of raw materials for the formulation of concentrated feed, an activity highly dependent on foreign currencies controlled and limited by the state, are factors that have increased the costs of these supplements. This situation has resulted in a decrease in production levels in dual-purpose livestock, but also in an increase in the generation of GHGs such as methane and, consequently, a decrease in the efficiency of dietary energy use (Waghorn and Hegarty, 2011; Vargas *et al*., 2012).

Under a situation like the one described, it is necessary to generate research oriented to the efficient use of pastures and forages as basic feeds in the diet of ruminants, as well as the valuation of supplementary raw materials whose detailed knowledge of chemical composition, digestibility and biological quality in general, will allow a rational use that complements the basic pasture and guarantees an optimal rumen functioning, with minimum emission of GHGs such as methane.

The objective of this review is to analyze the existing information in the literature on ruminant feeding systems and, based on the available regional herd data, to calculate the production of enteric methane by these herds in order to determine if there really is a high contribution of this gas to the pool of GHG produced in the country.

Methods

This review is referred to the calculation of methane production by regional bovine herds, however, the inexistence of specialized national literature on this aspect of digestive physiology in Venezuelan institutions, lead to the use of literature originated in other latitudes, where there is the capacity to carry out measurements of methane production of enteric origin under different experimental conditions. This bibliographic support allowed documenting the physiological and metabolic processes that give rise to methane as a result of the use of different dietary regimes; however, it is pointed out that such information is generated under genetic, productive, climatic and dietary conditions very different from Venezuelan conditions.

Literature was used preferably with a feeding management based on grazing or by the inclusion of vegetable sources for animal feeding, however, for the purpose of contrasting different dietary schemes, articles that used some type of strategic supplementation through concentrated feeds or raw materials were also considered. It is important to point out that predominantly, research on this subject has been carried out in countries with strengths in these measurements. Thus, to document basic principles, classical literature (Church, 1988; Johnson and Johnson, 1995, Kurihara *et al*., 1999), necessary to record the physiological basis of ruminant GIT, as well as the role of the ruminal microbiota in the production of GHG (Hoover and Miller, 1991), was found. Similarly, opinions of environmental organizations such as Greenpeace (2009, 2018) and journalists such as Lombardero (2007) are documented, necessary to discuss the stigmatization and defense of ruminants as GHG generators.

Regional Estimates of Enteric Methane Production

The Intergovernmental Panel on Climate Change (IPCC) generates scientific information on the current state of climate change and potential impacts on the environment and economy (IPCC, 2006, 2019; Smith *et al*., 2014). In the 1996 IPCC Guidelines and Good Practice Guidance (IPCC, 1996), the simplest and most common methodological approach to combine information on the extent to which human activity takes place (called activity data or DA) is performed with coefficients that quantify emissions or removals per unit of activity. These are called Emission Factors (EF). The basic equation is therefore: Emissions = DA × EF.

IPCC methodologies use the concepts of good practices alluding to the care of overestimates and uncertainties; “Tiers” referring to levels of complexity, from the use of values reported in literature to the use of models based on feed quality and productive states of the herd; key categories to refer to the constituent age groups of the regional herds; among other key concepts for the definition of particular regional conditions. In a recently revised version, the IPCC manual (2019) points out the use of Tier 2 or 3 methodologies, for which it is necessary to have gross energy consumption (GEC) figures and methane conversion factors for specific categories of livestock or models based on the consumption of specific nutrients; however, since there is no research of this type in Venezuela, this methodology cannot be used.

On the other hand, in the methodology described in IPCC (2006), it specifies that the main livestock categories and subcategories can be classified according to the guidelines in Table 1, which are adapted to the livestock categories used in dual purpose production systems (DPPS) in the Maracaibo Lake basin.

For the purposes of this review, the Tier 1 methodology was used, which consists of EF derived from the literature, which is multiplied by the number of animals present in a country. These factors have also been suggested by IPCC (2006) according to the type of animal and geographical location, factors similar to those presented by Ungerfeld *et al*. (2018), which correspond to 72 $kg.head^{-1}.year^{-1}$ for dairy cows and 56 $kg.head^{-1}.year^{-1}$ for other types of animals (beef cattle, bulls, calves, heifers). However, IPCC (2019) made changes for these FE, for which it introduces the classification of high (3,400 $kg\ milk.head^{-1}.year^{-1}$) and low production (1,250 $kg\ milk.head^{-1}.year^{-1}$) dairy production systems, the latter classification in which Venezuelan production systems fall. In this sense, IPCC (2019) specifies 78 $kg.head^{-1}.year^{-1}$ for dairy cows and 58 $kg.head^{-1}.year^{-1}$ for other types of animals (beef cattle, bulls, calves, heifers).

Table 1. Representative livestock categories.

Main livestock categories	Livestock subcategories
Mature milking cows or buffaloes	High-producing cows that have calved at least once and are used primarily for milk production. Low-producing cows that have calved at least once and are used primarily for milk production.
Other mature cattle or non-lactating buffaloes	Females Cows used to produce calves for meat Cows used for more than one productive purpose: milk, meat, leather. Males Bulls used primarily for reproductive purposes Steers used mainly for traction
Growing cattle or buffaloes	Preweaned calves Replacement heifers Growing cattle or buffaloes/post-weaning calves Confinement cattle fed diets >90 % concentrates

Source: IPCC (2006, 2019).

The non-existence of national herd inventories available for consultation prevents having official figures for their use in the calculations pursued in this document; however, it was necessary to use indirect sources, such as FAO’s FAOSTAT database (2023), which has an inventory of the Venezuelan herd until the year 2021 of 16,221,020 cattle. On the other hand, the Venezuelan Minister of People’s Power for Productive Agriculture and Lands, in October of this year, referred on the social network Twitter that Venezuela has 17,292,202 animals to date, of which 11,931,619 females and 5,360,583 males, while the state of Zulia has 18.60 % of the herd and is the largest producer (Castro, 2023). The proportions referred by Castro (2023), the only official source of this information, allow calculating a herd of 3,216,350 animals for the state of Zulia. From the ULA-CIAAL (2011) document, a proportion of cows of 35 % can be extracted, which results in 1,125,723 cows and the rest of the age categories in 2,090,627 animals, estimated inventories that were used for the calculation of CH_4 of enteric origin incorporated into the environment.

Discussion

Ruminant feeding

Ruminants have become one of the most important species from the agri-food point of view, due to the production of milk and meat that serve as a source of protein for the human diet, as well as other benefits, such as work and companionship. These animals feed on plant species, predominantly grasses, which in turn serve as substrate for the microorganisms that cohabit the rumen, predominantly bacteria, fungi, protozoa and bacteriophages (Dearing *et al*., 2017; Wang *et al*., 2017; Xia *et al*., 2020).

In the Venezuelan DPPS, crossbred *Bos taurus* × *Bos indicus* animals are fed grazing as a basic diet (Urdaneta, 2009). Peña *et al*. (1997) and Pariacote *et al*. (2012) report that in the Rosario and Machiques de Perijá municipalities of Zulia state, this livestock production system predominates, using Brahman, Holstein and Brown Swiss breeds with different levels of crossbreeding and grazing on grasses with high proportion of cell wall contents (Adesogan *et al*., 2019).

These grasses are fermented by rumen microorganisms producing volatile fatty acids (VFA) that feed the energy metabolism of these animals, taking advantage of their capacity to degrade cellulose (Church, 1988; Reyes Gutiérrez, 2012). Grazing of tropical grasses, incorporating structural carbohydrates in different proportions, produces more methane and promotes a higher acetic acid:propionic acid ratio than fermentation of non-structural carbohydrates (Hyland *et al*., 2016; Valencia-Salazar *et al*., 2022). In these diets, energy losses to form methane are 8 to 12 % of the gross energy (GE) consumed by the animal, but in the case of diets where commercial concentrates (more than 90 % grain and high energy) are incorporated, methane losses can be as low as 2 to 3 % of GE intake (Johnson and Johnson, 1995; Methol, 2005; Hyland *et al*., 2016).

Cattle production systems are the main producers of methane among domestic ruminants, generating 7-9 times more methane than sheep and goats. In cattle and other ruminants, approximately 80 % of methane is generated in the rumen, a product of cellulose digestion by rumen microorganisms, while about 20 % comes from the decomposition of fecal matter (Román and Hernández-Medrano, 2016). At the rumen level, the conversion of CO_2 to CH_4 in microbial fermentative processes confers to the carbon product of this conversion a Global Reheating Power (GRP) 21 times greater than CO_2 (de Blas *et al*., 2008). As a result of these processes, carbohydrates and proteins are cleaved to their simplest chemical elements, such as monosaccharides and amino acids, which are assimilated by microorganisms by specific metabolic pathways and result in volatile fatty acids (VFA), CO_2, CH_4 and heat (McDonald *et al*., 1979; Vargas *et al*., 2012).

When analyzing the phenomenon physiologically, the production of enteric methane in ruminants is carried out by pathways that require important energetic inputs, which are provided by the diet. There are several dietary factors that affect the digestion process of raw materials in the ruminant GIT, among them the relationship between the consumption of pasture, forage and concentrate feeds. Animals with high contents of concentrates are subject to a decrease in the pH of the rumen content due to a high digestibility of this product and a decrease in the buffering power of this medium due to a dilution effect of the forage content. This decreases the populations of cellulolytic flora to the benefit of amylolytic flora, which decreases fiber digestion, leading to a decrease in acetic acid production and an increase in propionic acid, which in turn leads to a decrease in pH by release of protons (H_2) increasing enteric methane production (Oldham *et al*., 1977; Johnson and Johnson, 1995; de Blas *et al*., 2008; Vargas *et al*., 2012).

Dietary factors and enteric methane emission in ruminants

The incorporation of highly digestible diets improves the use of the energy contained in their carbohydrates, which translates into a decrease in methane emissions. There are pasture species that are more efficient in milk production, partly because of their low enteric methane production due to a greater efficiency in protein and energy metabolism. Likewise, as the age of the plant increases, methane production increases due to the effect of the increase in lignocellulosic fractions (Carmona *et al*., 2005).

The non-utilization of energy due to methane gas production is due to many factors: amount and type of feed, manipulation of ruminal fermentation, addition of lipids, type of carbohydrate in the diet and processing of forages (Carmona *et al*., 2005). These factors, if controlled or manipulated, could become efficient alternatives for the control of this type of emissions. Chandramoni *et al*. (2000) evaluated different proportions of forage and concentrate feed incorporation (F:C; 92:8, 50:50 and 30:70) in confinement sheep, recording the production of methane of enteric origin in relation to gross energy and found that in the diet with a high proportion of forages (92:8), methane production was higher (3.93 %) than in 50:50 and 30:70 (3.34 % and 2.98 %, respectively). The findings of these researchers led to the conclusion that less methane is produced in starch-rich diets than in high-fiber diets.

The inclusion of supplements high in easily digestible carbohydrates promotes changes in the ruminal microflora towards an increase in amylolytic populations, which translates into a decrease in the digestion of fibrous fractions, leading to a lower proportion of acetate and a higher proportion of propionate (Oldham *et al*., 1977). This metabolic scenario drives the rumen environment towards a lower methane emission as described by Van Kessell and Russell (1996).

In the Venezuelan DPPS, the use of commercial concentrate feeds, alternative raw materials (produced or not within the production unit) or agro-industrial by-products, traditionally constituted the elements used as feed materials to make up for the deficiencies inherent to the medium to low quality of pastures and forages used as basic diet in ruminants.

In a review by Ungerfeld *et al*. (2018), the processes by which, carbohydrates during glycolysis and oxidative decarboxylation of pyruvate to acetyl-CoA, reduce cofactors that are reoxidized to continue ruminal fermentation are summarized; these cofactors transfer electrons to protons forming H_2, which is transferred from the fermenting organisms to methanogenic *Archaea*, which use it to reduce CO_2 to CH_4 (Carmona *et al*., 2005).

Methane, the main electron sink in the rumen, during propionate formation also incorporates metabolic hydrogen from reduced cofactors. Thus the production of acetate, and to a lesser extent butyrate, from hexoses results in the release of reducing equivalents that will be mostly available for methanogenesis, while propionate production incorporates reducing equivalents competing with CH_4 formation (Bonilla-Sandí *et al*., 2020).

While it is true that there is a direct relationship between the level of dry matter intake and CH_4 production (Hristov *et al*., 2013), it is also true that the nutritional composition of the diet plays an important role in CH_4 production. The presence of insoluble cell wall fiber in the diet favors a higher acetate:propionate ratio and, consequently, higher CH_4 production. In contrast, fermentation of soluble carbohydrates results in lower CH_4 production (Rivas-Martínez *et al*., 2023).

Estimation of methane production in ruminants

Advances in the understanding of ruminal fermentation have allowed the development of mathematical models for the prediction of enteric methane emission in ruminants. Hristov *et al*. (2013) and Ungerfeld *et al*. (2018) have generated prediction equations with different levels of complexity, estimating such emissions by relating different productive stages, chemical composition of the diet, animal products such as milk fat, or with animal behavior such as feed intake or with live weight.

Johnson and Johnson (1995) in a detailed review of different aspects related to CH_4 emissions in ruminants, state that when daily feed intake (DFA) increases, the percentage of dietary GE lost as CH_4 (Y_m) decreases on average 1.6 % per level of intake, however, the linear mathematical model to predict this decrease fails and therefore limits its extrapolation from laboratory to field. When highly available carbohydrates are fed at limited intakes, high fractional CH_4 losses occur, while at high intakes of highly digestible diets, low fractional CH_4 losses occur.

Yan *et al*. (2000) after a meta-analysis similar to the previous one developed CH_4 prediction models based on digestible energy intake (DEC) including silage acid detergent fiber (ADF) (or DMI ratios) and feed intake level. However, in the review by Hristov *et al*. (2013) it is concluded that the validity of Y_m is questionable, since according to Ellis *et al*. (2010), this parameter does not have the ability to differentiate between a change in CH_4 produced due to an increase in DMI and a change in CH_4 due to increases in dietary fat content, to which they propose to express energy losses in CH_4 based on GE (or per unit of animal product), which will more adequately reflect forage quality and other mitigation practices, such as the inclusion of grains or fats in diets.

For growing, grazing-fed lambs, Hegarty *et al*. (2010) proposed the following relationships between feed intake, digestibility (55 to 85 %) and CH_4 production:

- The increase in DMI is associated with a linear increase in average daily weight gain (ADG), with the rate of ADG higher in feeds of higher digestibility.
- The increase in DMI is associated with an increase in CH_4 production. In diets with low to moderate digestibility, such as those in Australian extensive grazing systems, CH_4 release per unit of additional intake is greater than when there is a high intake of highly digestible feeds.
- CH_4 production per unit of metabolizable energy (ME) intake is lower in diets with high energy densities.
- Although an increase in the intake of any diet reduces the intensity of emissions in the growth phase (g $CH_4.kg^{-1}$ LWG), the intensity of emissions at any DMI level is lower in highly digestible feeds than in low digestible feeds.
- Small changes in energy intake result in small changes in CH_4 production, but large changes in the productive performance of the animal.

In the meta-analysis of Hristov *et al*. (2013) a total of 377 observations were analyzed, which allowed to ensure with an R^2 = 0.86 that DMI (specifically digestible OM) is the most important promoter of CH_4 production in ruminants, so that the dietary effect and forage quality on intake is of utmost importance. The authors clarify that, when using such an equation, the prediction error could be higher with increases in DMI, since changing DMI to a narrower range (ie. 10 % increase from approximately 18 to 20 $kg.day^{-1}$) would result in higher variability, making further research necessary to nurture these predictions.

Dry matter intake and DE are the most important determinants of milk and meat production, but the meta-analysis by Hristov *et al*. (2013) did not include increased production or decreased enteric CH_4 relative to production when increasing DMI. CH_4 increases with increasing DMI, but if this phenomenon is viewed from a lens of increased milk and meat production, CH_4 decrease would only be achieved with increased feed efficiency and genetically determined productive potential in herds that would tend to be lower in high-tech production systems.

Enteric methane contributions

Industrial processes and the burning of fossil fuels make a significant contribution of GHGs, which have been estimated and discussed in the workshops of the IPCC, a body established by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) to generate scientific information on the current state of climate change and possible impacts on the environment and the economy (Smith *et al*., 2014).

According to the results of those workshops, agriculture contributes about 14 % of GHGs, while, of these, methane occupies 18 %, and animal agricultural production systems about 20 %, mostly due to enteric fermentation (Smith *et al*., 2014). On the other hand, some environmental conservationist organizations have pointed to cattle as the main species responsible for this phenomenon. Greenpeace (2009) in Brazil, points to the cattle-producing meat activity, not only for the deforestation of 19,368 km^2 per year of the Brazilian Amazon rainforest, but, consequently, for the increase of GHGs resulting from this activity. The subsidiary of this same global organization in Spain, ensures that, in this country, the livestock sector emitted in 2015 more than 86 million tons of CO_{2-eq} originated in the production of fodder and grains for animal feed, followed by methane emissions produced in the digestion of ruminants (Greenpeace, 2018).

In Venezuela, the extinct Ministry of Environment and Renewable Natural Resources (MARNR), in inter-institutional workshops, yielded figures of 2,950 Gg total CH_4, while enteric fermentation registers 757.2 Gg, i.e. 25.7 % of the total produced in the country. For Zulia state, the national herd data referred to by Castro (2023) and the EFs specified by IPCC (2006; 2019) and Ungerfeld *et al*. (2018), allow calculating an estimated 209 Gg of CH_4 contributed by this herd, which represents 7.1 % of the total CH_4 inventoried at the national level and 27.6 % of the CH_4 of enteric origin reported in the MARNR report (2005). Although these calculations place Venezuela in very conservative conditions with respect to GHG emissions to the atmosphere, it is also true that they should be taken with caution, since the data were not produced under the conditions of the productive systems, nor under Venezuelan agro-climatic conditions.

Conclusions

The feeding of grazing ruminants, based on the consumption of high proportions of vegetable cell walls, generates a greater proportion of methane of enteric origin in animal production systems.

The incorporation of supplements that improve the digestibility of basic forage diets helps to reduce the generation of methane of enteric origin in grazing ruminants, which also leads to a more efficient productive performance, being able to achieve a shorter stay of animals within the system, which translates into a lower contribution of methane to the group of GHG that are incorporated into the environment.

According to calculations made on the basis of data generated by governmental institutions, the contribution of methane of enteric origin was about 209 Gg, that is, 7.1 % of the total inventoried in Venezuela, estimates that should be considered with caution, given the foreign origin of the partial data used.

At present, Venezuela does not have scientific work teams with the technological capabilities or research projects that contemplate the permanent monitoring of GHG emissions produced in ruminant production systems. However, there are laboratories in different university or research institutions in the state, which have a minimum installed capacity and the human talent to implement such measurement systems.

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