Challenges of livestock: climate change, animal welfare and agroforestry

MARÍA G. TORRES[1], RAMON SORIANO[2], JESÚS G. PERALTA[1], JOSÉ I. ALEJOS[3], PAULINO SÁNCHEZ[4], LADISLAO ARIAS[2], RAFAEL G. CAMPOS[1], ISAAC ALMARAZ[1]

[1] Instituto de Ciencias Agrícolas, Universidad Autónoma del Estado de Hidalgo, Tulancingo 43600, Hgo., México

[2] Biología de la Reproducción, Universidad Autónoma Metropolitana-Iztapalapa, Ciudad de México 09340, México

[3] Zootecnia, Universidad Autónoma Chapingo, México 56230, México

[4] Facultad de Medicina Veterinaria y Zootecnia No. 2, Universidad Autónoma de Guerrero. Cuajinicuilapa, Guerrero 41940, México

SUMMARY

Livestock is an activity that generates employment and foods for human consumption. The ruminants are fundamental for the conversion of forage resources into foods and traction due to the symbiotic association with the ruminal microbiota. In this context, this manuscript describes the importance of ruminants as generators of resources, but its adverse effects are also described, specifically the emission of greenhouse effect gases (GHG). The growing trend in the demand for beef and sheep meat, as well as bovine milk, suggests analyzing the current strategies used in their feeding and its effect on animal welfare. These strategies have been implemented to increase the productivity per animal unit and, recently, to reduce the intensity of GHG emissions originated by enteric fermentation. However, most of the techniques used to measure the emission of these gases in ruminants are inaccessible in non-development countries, which suggests proposing interdisciplinary strategies to mitigate their emission. Thus, a brief description of agroforestry and its contribution to carbon fixation was also realized. Currents research about non-fixing and nitrogen-fixing were added due to nitrous oxide emissions from forests and Agroforestry Systems. In this way, the livestock agroecosystem and its environmental benefits that favor the mitigation of GHG and animal welfare, are strategies that encourage environmental sustainability and the systems of animal production.

KEY WORDS

Enteric fermentation, one health, ruminants, shrubby, sustainability.

INTRODUCTION

Globally, livestock contributes to human and nutritional needs. It is a source of fertilizer, traction, quality protein, employment and income-generating activity[1], however, livestock also faces big problems arising from its activity, among them, climate change and biodiversity loss[2]. The Food and Agriculture Organization of the United Nations (FAO) expects that there will be a 73% increase in meat and egg consumption and a 58% in dairy consumption by the year 2050 because of both, increase in the population and per capita consumption[3]. In this context, the Organisation for Economic Cooperation and Development and the Food and Agriculture Organization (OECD-FAO)[4] estimates that meat consumers will increase their food intake towards animal protein more expensive, such as beef and sheep meat. The United States, Argentina, India, Mexico, the Russian Federation and Turkey increased its meat production in 2017, which contributes to these growing demands. However, the land use and food production destroy forest and biodiversity[5], which will impact sectors involved in livestock activities to obtain safe and attainable products[4] and will consequently encourage the greenhouses gas (GHG) emissions.

According to the Environmental Protection Agency (EPA)[6], the primary sources of GHG emissions in the U.S. during 2017 were transportation (29%), electricity production (27.5%), industry (22.2%), commercial and residential (12.2%), land use and forestry (11.1%), and agriculture (9.0%). These activities are entwined because the global population grows, urbanizes and consumes more[5]. Nonetheless, agricultural activities, crop and livestock production for food, contribute to emission of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), where each gas's effect on climate change depends on concentration, abundance and Global Warming Potential[6]. In livestock activities, ruminants (cattle, sheep, and goats) are the primary source of CH_4 emission by enteric fermentation and manure fermentation[7]. The global warming potential of CH_4 is 21 to 25 times that of CO_2[8] and its rate of emission is highly dependent on the management strategies implemented on a farm[9]. Regarding enteric fermentation in ruminants, the GHG emission changes according to the production system, management practices, and implemented strategies into their feeding[3;10].

This double challenge, satisfying the food demand without affecting the environment, has led to bear in mind measures

Corresponding Author:
Isaac Almaraz Buendía (isaac_almaraz9974@uaeh.edu.mx).

and strategies for managing land-use and feeding systems together[5]. Some of these actions have shown that reduce or delete products of animal origin for human consumption might reduce the environmental impact, especially, GHG emissions, use of land and water availability[11;12;13]. Other actions suggest intensifying the animal production, which consists in increasing the quantity of product per unit of input in the production system, for example, reducing the necessary area by animal unity and/or their feeding requirements per each unit of produced animal protein. The intensification of animal production systems has been proved as a way to reduce the environmental impact; however, this intensification is associated with reduced animal welfare. Therefore, the relationship between environmental sustainability and animal welfare should not be interpreted as a paradox, but it must be linked to confront the social and environmental problems, the economic and feeding needs in order to achieve food security without affecting the environment, as was suggested by[15]. In this context, the enteric fermentation in ruminants and GHG emissions are described and discussed in the first section, then the methods for measuring the CH_4 emission into these activities are analyzed for their application in developing countries because according their geographic position these countries has available resources for ruminants feeding. Later, the animal welfare and agroforestry are analyzed together as other strategies available for reducing the climate change and the GHG emissions into livestock. The objective was to elucidate the current challenges of livestock and their relationship with animal welfare including agroforestry.

MATERIAL AND METHODS

The methodology of this study consisted of a literature review. The aim of the review was giving a current perspective of literature in the research fields in developing countries. The literature search was performed in 2018 and 2019 with the science search engines Google Scholar and Primo Exlibris into a digital library. The topic were Foods-Livestock and Animal Welfare, the words used by each topic were livestock-methane, methane, greenhouses gas, agroforestry and agroforestry-livestock. The articles included in the review were the direct relationship through the keywords, published in Spanish or English Language and considering the sustainability of livestock systems. The analyses are presented and discussed in this paper.

RESULTS AND DISCUSSION

Livestock activities and GHG emissions

The Framework Convention on Climate Change (UNFCCC), Article 1, defines climate change as "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods"[15]. The UNFCCC makes a distinction between climate change attributable to human activities, which alters the atmospheric composition, and climatic variability attributable to natural causes.

The anthropogenic emissions of GHG have increased because of population growth and of their economy[6]. This has resulted in a higher concentration of CO_2, CH_4 and N_2O on the atmosphere, such that, the effects of this gasses could be the dominant cause of global warming since half of the 20th century[6]. The GHG emission is carried out from various sectors of the economy (Industry 22%, Agriculture 9%, Transport 28%). Agriculture includes livestock, forestry, and other land uses. Within the livestock, the CH_4 generated by enteric fermentation is the main source of emission and represents around 26% of emitted total[6]. If changes in land use and deforestation (CO_2 emission that represents 10% of the total GHG) were added, these activities must carefully be addressed due to its importance for the production of food, conservation of natural areas and fixation of CO_2.

The contribution to global anthropogenic emissions of GHG are between 7 and 18%, depending on focus and the scope[16,17;18;19;20;21], while the contribution by each continent, of highest to lowest, are Asia, Latin America, Africa, and Europe. The main sources of emission along the agricultural chain are: use and land-use change (forests and natural vegetation replaced by pastures and crops for livestock activities), agricultural activities (fossil fuel used for manufacturing and chemical fertilizers that increase crop yield), animal production (enteric fermentation in ruminants and burning of fossil fuels into farms), and manure management (mainly their storage, application and deposition)[22;23].

The CH_4 and CO_2 are natural by-products produced by enteric fermentation in ruminants from carbohydrates and, to a lesser extent, of the amino acids into the rumen and large intestine of farm animals. The CH_4 is produced in anaerobic conditions by highly specialized methanogenic microorganisms, which are of great interest when some strategies are investigated to reduce their emissions. According to [24] and [25], the highest production of enteric CH_4 in ruminants is carried out into the reticulum-rumen; approximately 13% into the gut and between 2 to 3% in the rectum. The formation of this gas can represent up to 12% of energy consumption in ruminants and is considered an inherent loss in energy metabolism[26].

Thus, to improve the efficiency of energy use in ruminants and reduce GHG emissions, the main strategies to mitigate GHG emissions according to their approach are: 1) to reduce the total emission (inhibit the formation of CH_4 inside of rumen) and 2) to reduce the intensity of emission (decrease the CH_4 emission by each production unity, i.e., without direct methanogenesis)[27]. The first includes chemical inhibitors, electron acceptors (as nitrates), ionophores and lipids within the diet; the second to improve animal health, food digestibility, as well as promoting intensive production systems, reproductive efficiency, and productivity. In summary, strategies that increase the productivity might also reduce carbon footprint generated for livestock. Nevertheless, this will probably be achieved decreasing the animal welfare in intensive systems, although [27] and [28] claims that the supplements used in animal feeding and animal health can also be strategies to reduce the GHG emission and indirectly to improve animal welfare. These strategies encourage environmental sustainability and ethical production by foods.

Uncertainty to measure the CH_4 emission in ruminants

The GHG emission by enteric fermentation in ruminants has been studied by researchers involved in animal nutrition. Their focus has been finding and implementing strategies to reduce GHG emissions in response to current environmental problems and its effect on climate change. The structure and chemical composition of forages and concentrates used in ruminant feeding are fundamental to understand their fermentation and digestibility, which are related to the GHG emission potential. However, the inventory of GHG emission by enteric fermentation in ruminants may be more precise if the methodologies to measure its emission were able to replicate without problems[8]. According to the Department of Agriculture of the United States, the standard method for measuring the CH_4 emission originated by enteric fermentation in ruminants is by calorimetric respiration chambers[29], although they also describe other techniques that have been used for it, for example, cubes where CH_4 is detected when ruminants introduce their head for eating, internal indicators such as hexafluoride (SF6), micrometeorological methods (integrated horizontal flow, gradient flow), dilution of isotopes, polyethylene tunnels and some new techniques not validated. However, when these methodologies are carried out, the dry matter intake by ruminants is frequently reduced and does not reflect their productivity and feed intake in commercial farms, but the animal welfare decreases and uncertainty increases. Based on the above, some models have also been used to estimate the emission of enteric CH_4 in dairy cattle, but the most of models are based on the intake of metabolizable energy (ME), acid detergent fiber (ADF), and starch content in the diet[29], which suggest more studies about it to strengthen and improve their application.

Procedures to estimate the CH_4 emission potential of forages

The technique of *in vitro* gas production has been used to evaluate the effect of additives, metabolic modifiers, changes in the proportion of ingredients and on the fermentation variables, mainly in ruminant feeding as reported by [30] and Macome[31]. The CH_4 is originated because the fermentation inside rumen and it was not a variable of interest many years ago. Currently, the *in vitro* gas production is used to measure CH_4 generated from the fermentation of substrates and can contribute to estimating the emission potential of CH_4 in forages, feedstuffs, and feeding strategies because of approximately 87% of the methanogenesis takes place within the rumen[32]. According to [33], the chemical composition of the forages and feedstuff, as well as its degradability within the rumen, affect the emission of CH_4 due to the proportion of produced volatile fatty acids. In this context, the *in vitro* gas production is a handy option to characterize the emission potential of CH_4 in ruminants[34], similar to anaerobic digestion, which has been widely used to measure the GHG emission potential of substrates using different inoculum, as anaerobic sludge[35] and animal feces[36]. However, the variability into the methods suggests a careful analysis of the results, as described by [35].

The UNFCCC requires countries to provide estimates of all GHG emissions and their uncertainties using the guidelines of the Intergovernmental Panel on Climate Change[37]. In these guidelines, most of the information generated to estimate the emission of CH_4 by enteric fermentation utilize the Tier 1 and Tier 2 methods. The Tier 2 is a more complex method than Tier 1 and is based on an estimated of the total annual energy intake of a representative animal that then multiplies it by a CH_4 conversion factor (Ym) for specific categories of livestock. For Tier 3, it is necessary to consider the chemical composition of the diet and the concentration of products resulting from its fermentation, so the IPCC suggests to countries with large livestock population to generate emission factors for more precise GHG emissions inventories.

For example, the IPCC provides Ym value of 6.5 ± 1% for dairy cows, cattle fed with agricultural waste and low-quality by-products, grazing cattle, and mature sheep; 4.5 ± 1% for lambs; and 3 ± 1% for finishing cattle consuming less than 900 g concentrate kg/DM. These values decrease when 1 to 4% of fat is added to the diet and increase when the grain concentration decrease[8;38]. However, the use of metabolic modifiers and the addition of some components of essential oils in ruminant feeding can affect these values. For example, the *in vitro* production of CH_4 decreased in response to the addition of garlic oil[39] and mixtures of essential oils[40]. This suggests that the accuracy of the IPCC Tier 2 methodology is low because each food has different GHG emission potential that can be altered by the synergy with other foods and/or the addition of metabolic modifiers or essential oils. It is resulting in great uncertainty to estimate emission inventories of GHG, as argued by [41].

Animal welfare into strategies to reduce the enteric CH_4 emission by ruminants

The animal welfare is a criterion of sustainability, since animals that are raised under production systems that allow them a physical, emotional and behavioral balance, show a better state of health and a utilization of resources more efficient, which improve their productivity and decrease carbon footprint by unit of product[27;42;43].

Animal welfare is a current term of global importance: the global bioethics. This term sets goals very important related with global public health (One Health), self-understanding of culture, and following of social welfare, which together returns towards the bioethics where the preservation of the environment and biodiversity are essential. Recently, a new concept with interconnections between animal welfare, human welfare, and the environment has also been recognized and called "One Welfare"[44;45]. Animal welfare brings significant benefits such as reduced veterinary costs, animal performance, and quality products. Furthermore, it also keeps hygienic standards in the production of foods of animal origin. Animal welfare is strongly related to the health and efficiency of the production of farm animals, and currently, its implementation has increased the commercial value of its products due to the growing number of consumers expect that animal foods are obtained and processed with greater respect towards animals[43]. In this context, some strategies reported in the literature that can be used, depending on the context, to reduce emissions of enteric CH_4 are the following:

The composition of the diet. The type of carbohydrates is important for the production of CH_4 because their fermentation into the rumen can modify pH and consequently alter the microbial population[46]. The starch in the diet promotes the formation of propionate through a change to amylolytic bacteria and a reduction in ruminal pH, which leads to a decrease in methanogenesis[38]. The digestion of the cell wall (mainly hemicellulose) looks with favor on the emission of CH_4 because increase the amount of acetate in relation to propionate. The increase in CH_4 production is due to fermentation towards acetate, which provides a methyl group for methanogenesis[38;46;47]. Therefore, a greater proportion of starch in diets for ruminants tends to decrease the formation of CH_4 and the loss of energy[48]. Nonetheless, higher concentration of soluble carbohydrates in diets for ruminants, especially when it is introduced abruptly and an unsuitable strategy is used, could quickly decrease pH into the rumen and cause ruminal and metabolic acidosis, which eventually is related with hoof problems. Both conditions, acidosis and hoof problems, affect the animal health and have economic consequences to long-term because they are associated with gastrointestinal damage and development of liver abscesses, which decrease the dry matter intake and digestibility[27;49]. In addition, the animals feel pain and consequently, they lose their ability to move and get up freely, which is essential to access feeders and drinking fountain and consequently decrease their production and reproduction. The burden produced by pain avoid the normal expression of animal behavior and affect body condition, fertility, and productivity, which leads to premature aging and is due to a negative effect on the five basic needs of animals[49;50].

Lipids. The emission of enteric methane in ruminant decrease when lipids are used in the feed, but their utilization depends on its cost and their effects on dry matter intake, productivity, and welfare[51]. The medium chain fatty acids reduce methanogenesis by several mechanisms, mainly because they reduce the proportion of energy obtained from fermentable carbohydrates and produce changes in microbial population, particularly when the methanogenic microorganisms are inhibited and unsaturated fatty acids that function as hydrogen acceptors are bio-hydrogenated[52]. The combination of these effects decreases between 3.8 and 5.4% the CH_4 formation in response to the addition of 1 and 6% lipids on dry basis, since it has been reported that higher levels may cause dysbiosis that negatively affects rumen function, dry matter intake and digestibility of non-lipidic energetic feed[53;54]. In conclusion, the addition of large amounts of lipid in ruminant feeding affects their gastrointestinal function, nutritional status, well-being, and productive efficiency, as described by [27] and [28].

Chemical inhibitors. Various chemical compounds inhibit methanogenic microorganisms. Bromochloromethane (BCM), 2-bromo-ethane sulfonate (BES), chloroform and cyclodextrin[27;46], and recently the 3-nitrooxypropanol have been evaluated *in vivo* and are among the most successful[55;56]. Some of these inhibitors reduced CH_4 production up to 50% *in vivo* with a slight reduction in dry matter intake, daily weight gain and feed digestibility in sheep, goats[54;57;58] and beef cattle[56]. However, this potential effect must be contrasted with the risk to human health (through the consumption of products of animal origin), animal health and their effect possible on the environment, in this context [23] mentions that there is a potential risk of toxicity when using halomethanes in ruminants feeding to reduce enteric methane emissions. It's possible effects after a long period of use ranging from liver damage to death. So, considering these harmful side effects of halogenated compounds, it is unlikely that they can be used as routine supplements to mitigate the emission of enteric CH_4 as described by [27]. The addition of 3-nitrooxypropanol decreased from 5 to 24% the CH_4 emission in sheep[59] and from 7 to 59% in cattle[60] with a slight decrease on dry matter intake[55], or when the dry matter intake is restricted to maintenance level[56]. It is relevant to mention that these authors have not reported side effects for health attributable to the administration during 3 to 5 weeks of 3-nitrooxypropanol. In this context, the use of this compound to 14 weeks resulted 30% less CH_4 emission without detecting toxic effects[33], so the use of this inhibitor could be an effective and harmless strategy to mitigate the emission of CH_4, however, more studies focusing on the toxic effects possible are needed as is mentioned by[27].

Ionophores (monensin). It is an antibiotic produced by *Streptomyces cinnamonensis* and routinely used in ruminant feeding. It is related to the reduction up to 30% of enteric CH_4 in response to the addition of 32 to 36 mg/kg body weight in beef cattle and 21 mg/kg body weight in dairy cattle[61;62], while the addition of 10 to 40 mg/kg dry matter has improved food efficiency[61;63]. However, effect decreases between 8 and 10% two to four weeks after it has been used due to the adaptation of the ruminal microflora to this antibiotic[62]. According to [46], monensin reduces methanogenesis through an indirect effect since it affects bacteria producing hydrogen ions and thus leads to a reduction of precursors for methanogenesis. The ionophores improve feed efficiency because decreases dry matter intake without decreases the productivity, in other words, the CH_4 emission per unit of product decreases[64]. The ionophores also are associated with the animal health because its utilization in ruminant feeding has reduced morbidity, mortality and the incidence of subclinical acidosis in feedlot[65]. In contrast to these multiple benefits, ionophores can be toxic in larger doses than recommended. In this context, the global increase in resistance to an antimicrobial represents a major threat to human and animal health because it goes against current human and veterinary medicine and affects food security and the environment. Although the use of ionophores in ruminants feeding could contribute for food security and animal welfare, their improper usage associated with the emergence and spread of antimicrobial-resistant microorganisms represents a great risk[66]. In this way, the European Union prohibits the use of antibiotics as growth promoters given the concern for the bacterial resistance they generate, but outside the European Union, ionophores are still used in ruminants feeding.

Compounds present in plants. Several studies have shown that plants contain a wide variety of secondary compounds with antimicrobial activity that, in certain concentrations, improve ruminal fermentation and decrease the CH_4 emission[10;40;67]. These compounds include mainly tannins, saponins, and some essential oils. However, the reported effects are variable and contradictory due to the concentrations different of ingredients, basal diets and lack of direct comparisons *in vivo*[68;69]. Accordingly, more studies on the utilization of these compounds to identify their toxic effects in short and long term and its potential impact on animal welfare are required, as it is argued by [70].

Agroforestry systems as a strategy to mitigate climate change

Agroforestry was naturally originated in Europe by the interaction of different types of livestock with the surrounding landscape (for example, transhumant system or pig fed with the acorn in Spain). In Latin America, the situation was different, inasmuch as this activity was originated with extensive systems of beef cattle grazed on introduced grassland and created from the deforestation of large areas of forest in tropical regions. Agroforestry systems are a form of land use that includes the use and exploitation of trees different kinds (timber, fruit, ornamental, planting) combined with crops and sometimes with animals. These systems provide food, fuelwood, bioenergy, medicine, livestock feed, timber, and construction materials, and their contribution climate change mitigation is according to the permanence of carbon sequestration[71]. From the dawn of mankind, when human beings their sedentary life, the combination of trees, crops and livestock into integrated production systems was carried out in a natural way. According to [72], the Agroforestry in Africa was developed as in Latin American such as it is considered an interdisciplinary practice which consist in using the land for productive activities, for example, the association of woody plant species with non-woody plant species, or woody plant species with non-woody plant species and animal species, both of them with variability in the relationship space-time. However, when all are woody species, at least one should also be managed for agricultural production and/or permanent livestock[73]. For example, farmers of Latin American were the first in using tree branches as fences and have given rise to what we now know as living fences, as well, they leave reman of trees for being used as shady by the animals.

The scattered trees in paddocks and some of the components of the live fences are consumed by the cattle, and according to [71] these trees could have low mitigation benefits due to early harvest of its products. *Leucaena leucocephala, Guazuma ulmifolia*, and *Glyricida sepium*, among others, have used the most used and have captured the interest of researchers from different countries, where this phenomenon has been happening. Subsequent to this and in order to utilize the most of species with high protein contents, such as *leucaena*, the concept of protein bank was born, and with it the livestock agroforestry. These plants belong to *Fabaceae* and can fixing atmospheric nitrogen. The nitrogen-fixing and non-fixing trees sequester CO_2[74], which is used into their photosynthesis and indirectly provide foliage to cattle, such that the interaction between agroforestry and livestock can have offsetting effects on the environment, mainly on climate. However, it is very complex because wastes from one system is raw material of the other. Furthermore, current research refers that Nitrogen-fixing trees (leguminous by example) could exacerbate climate change because elevated soil nitrogen driven by the decomposition of nitrogen-rich plant litter can also drive soil emissions of nitrous oxide (N_2O) as have been reported by [74]. The N_2O is a potent greenhouse gas with 300 times more warming potential than CO_2[6] and its atmospheric concentration is dominated by cumulative emissions over the past two centuries such that the benefits of mitigation take much longer time[75]. So, while the ruminant emits CO_2 from enteric fermentation, also intake foliage from trees, encourage nitrogen recycling and probably decrease nitrogen-rich plant litter. An optimal scenario is when the livestock systems incorporates different types of trees (nitrogen fixing and non fixing trees) in different arrangements that include forage banks of different species, as happen currently with *leucaena*. In this way, livestock agroforestry not only is used to feed livestock[76] but also to generate environmental benefits using agroecological principles.

The carbon capture and efficiency of photosynthesis are higher when three or four layers of vegetation are established. The fixing of nitrogen and nutrient recycling have the purpose of increasing biomass production and the organic matter content on the soil[72]. This is feasible because the inputs of silvopastoral systems come mainly from biological processes and not from fossil fuels or synthetic compounds. The intensive silvopastoral systems, such as protein banks or mixed crops, are a good example of intensified agriculture through the natural way to adapt to climate change. So, the increase in the primary productivity of the livestock agroecosystem is due to the existence of more trees, fodder shrubs, weeds and vigorous pastures[76]. In this sense, livestock agroforestry helps capture carbon (or carbon equivalents when the methane is captured or fixed) through vegetative growth (foliage, fruits and roots), and when the ruminants are fed with quality forages the methane emission is decreased, the ruminal efficiency is improved, and the retention of carbon on the soil and losses of nitrogen towards the atmosphere are diminished because of the recycling of excreta is fast and efficient. According to [75], enhanced mitigation of non-CO_2 gases has quantifiable and significant benefits to reduce GHG emissions. In addition to these benefits, the livestock agroforestry provides other environmental services very important as water retention of rain, erosion reduced and recovery of fragmented habit with the consequent return of wildlife ranging from small insects to mammals of medium size. In order to achieve greater productive and environmental benefits, it is recommended the use of various agroforestry species, and with this increase the sustainability of the silvopastoral agroecosystem.

CONCLUSION AND FINAL CONSIDERATIONS

The emission of greenhouse gases by enteric fermentation in ruminants, mainly methane and carbon dioxide, requires improving and implementing emission factors and strategies to mitigate the climatic change. The methodologies used to measure the concentration and the volume of greenhouse gases generated by the enteric fermentation in ruminants are not uniform, so the results can be inconsistent. This has an impact on the strategies that are implemented in the nutrition and feeding of ruminants and may not conform to the guidelines of the IPCC, therefore generating emission factors of greenhouse gases through simpler universal procedures are priorities. The dangers and potential benefits of strategies to mitigate emission of greenhouse gases from livestock activity should be considered during its implementation and must be a priority those that offer both them, improving the environment and animal welfare. In addition, it is essential to consider holistic synchrony between livestock and agroforestry systems, where the conservation of biodiversity, soil and water quality, contribute to the preservation of the habitat for wildlife. In this regard, agroforestry also is a real tool to mitigate climate change. Based on the foregoing, it should be noted that research in animal production has historically been focused on finding technical solutions for problems related to productive efficiency, while animal welfare and environmental sustainability have been studied in isolation. However, the synergies between animal welfare and environmental sustainability occur when improvements in productive efficiency are concomitant, so they must be addressed jointly in the face of the challenge of food security, safety, and preservation of resources.

References

1. Herrero M., Havlik P., Valin H., Notenbaert A., Rufino M.C., Thornton P.K, Blummel M., Weiss F., Grace D., Obersteiner M. (2013). Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. Proc. Natl. Acad. Sci. U.S. 110: 20888-20893. http://dx.doi.org/10.1073/pnas.1308149110.
2. Gerber P.J., Hristov A.N., Henderson B., Makkar H., Oh J., Lee C., Meinen R., Montes F., Ott T., Firkins J., Rotz A., Dell C., Adesogan A.T., Yang W.Z., Tricarico J.M., Kebreab E., Waghorn G., Dijkstra J., Oosting S. (2013). Technical options for the mitigation of direct methane and nitrous oxide emissions from livestock: a review. Animal 7: 220-234. https://doi.org/10.1017/S1751731113000876.
3. Makkar H.P.S. (2016). Animal nutrition in a 360-degree view a framework for future R&D work: towards sustainable livestock production. Anim. Prod. Sci. 56 (10): 1561-1568.
4. OECD-FAO (2018). Conferencia Regional de la FAO para América Latina y el Caribe: Agricultura sostenible y resiliente al cambio climático. Montego Bay, Jamaica, 5 a 8 de marzo del 2018 (In Spanish). http://www.fao.org/fileadmin/user_upload/bodies/LARC_35/MV865_4/MV865_LARC_18_4_es.pdf.
5. Schmidt-Traub G., Obersteiner M., Mosnier A. (2019). Fix the broken food systems in three steps. Nature, may 9, 569: 182-183.
6. EPA (2019). Sources of greenhouse gas emissions. United States Environmental Protection Agency, USA. https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.
7. Broucek J. (2018). Options to methane production abatement in ruminants: a review. J. Anim. Plant Sci. 28(2): 348-364.
8. National Academies of Sciences, Engineering, and Medicine (2016). Requirements of beef cattle (8th ed.). National Academies Press, Washington, D.C., USA. Doi: 10.17226/19014.
9. Broucek J. (2015). Methane yield from cattle, sheep, and goats housing with emphasis on emission factors: a review. Slovak J. of Anim. Sci. 48: 122-139.
10. Beauchemin K.A., McGinn S.M., Martinez T.F., McAllister T.A. (2007). Use of condensed tannin extract from quebracho trees to reduce methane emissions from cattle. J. Anim. Sci. 85 (8): 1990-1996. https://doi.org/10.2527/jas.2006-686.
11. Stehfest E., Bouwman L., Van Vuuren D.P., Den Elzen M.G.J., Eickhout B., Kabat P. (2009). Climate benefits of changing diet. Climatic Change. 95, 83-102 https://doi.org/10.1007/s10584-008-9534-6.
12. Cassidy E.S., West P.C., Gerber J.S., Foley J.A. (2013). Redefining agricultural yields: from tonnes to people nourished per hectare. Environ. Res. Lett. 8, 034015 (8pp). http://dx.doi.org/10.1088/1748-9326/8/3/034015.
13. Eshel G., Shepon A., Makov T., Milo R. (2014). Land, irrigation water, greenhouse gas, and reactive nitrogen burdens of meat, eggs, and dairy production in the United States. Proc. Natl. Acad. Sci. U.S. 111: 11996-12001. https://doi.org/10.1073/pnas.1402183111.
14. CEPAL (2018). Agenda 2030 y los objetivos de desarrollo sostenible: Una oportunidad para América Latina y el Caribe, Publicación de las Naciones Unidas LC/G.2681/Rev.2/-*, Santiago, Chile (In Spanish).
15. Naciones Unidas (1992). Convención Marco de las Naciones Unidas sobre el cambio climático. Naciones Unidas, FCCC/INFORMAL/84*, GE.05-62301 (S) 220705 220705 (In Spanish).
16. Roy P., Nei D., Orikasa T., Xu Q., Okadome H., Nakamura N., Shiina T. (2009). A review of life cycle assessment (LCA) on some food products. J. Food Eng. 90: 1-10. https://doi.org/10.1016/j.jfoodeng.2008.06.016.
17. Peters G.M., Rowley H.V., Wiedemann S., Tucker R., Short M.D., Schulz M. (2010). Red meat production in Australia: Life cycle assessment and comparison with overseas studies. Environ. Sci. Technol, 44 (4): 1327-1332. https://doi:10.1021/es901131e.
18. FAO (2010). Greenhouse gas emissions from the dairy sector: a life cycle sssessment. Rome, Italy.
19. Beauchemin K.A., Janzen H.H., Little S.M., McAllister T.A., McGinn S.M. (2011). Mitigation of greenhouse gas emissions from beef production in western Canada - Evaluation using farm-based life cycle assessment. Anim. Feed Sci. Technol. 166-167: 663-677. https://doi:10.1016/j.anifeedsci.2011.04.047.
20. Kristensen T., Mogensen L., Knudsen M.T., Hermansen J.E. (2011). Effect of production system and farming strategy on greenhouse gas emissions from commercial dairy farms in a life cycle approach. Livest. Sci. 140 (1-3): 136-148. https://doi.org/10.1016/j.livsci.2011.03.002.
21. Thoma G., Popp J., Nutter D., Shonnard D., Ulrich R., Matlock M., Kim D.S., Neiderman Z., Kemper N., East C., Adom F. (2013). Greenhouse gas emissions from milk production and consumption in the United States: A cradle-to-grave life cycle assessment circa 2008. Int. Dairy J. 31 (Supplement 1): S3-S14. https://doi.org/10.1016/j.idairyj.2012.08.013.
22. Steinfeld H., Gerber P., Wassenaar T., Castel V., Rosales M., De Haan C. (2006). Livestock's Long Shadow: Environmental Issues and Options. Food and Agriculture Organization of the United Nations, Rome. 390 pp. http://www.fao.org/docrep/010/a0701e/a0701e.pdf.
23. Patra A.K. (2012). Enteric methane mitigation technologies for ruminant livestock: a synthesis of current research and future directions. Environ. Monit. Assess 184 (4): 1929-1952. https://doi.org/10.1007/s10661-011-2090-y.
24. Muñoz C., Yan T., Wills D.A., Murray S., Gordon A.W. (2012). Comparison of the sulphur hexafluoride tracer and respiration chamber techniques for estimating methane emissions and correction for rectum methane output from dairy cows. J. Dairy Sci. 95 (6): 3139-3148. https://doi.org/10.3168/jds.2011-4298.
25. Storm I.M.L.D., Hellwing A.L.F., Nielsen N.I., Madsen J. (2012). Methods for measuring and estimating methane emission from ruminants. Animals 2 (2): 160-183. https://doi:10.3390/ani2020160.
26. Morgavi D.P., Forano E., Martin C., Newbold C.J. (2010). Microbial ecosystem and methanogenesis in ruminants. Animal 4: 1024-1036. https://doi.org/10.1017/S1751731110000546.
27. Llonch P., Haskell M.J., Dewhurst R.J., Turner S.P. (2017). Current available strategies to mitigate greenhouse gas emissions in livestock systems: an animal welfare perspective. Animal, 11 (2): 274-284. https://doi:10.1017/S1751731116001440.
28. Guyader J., Janzen H.H., Kroebel R., Beauchemin K.A. (2016). Forage use to improve environmental sustainability of ruminant production. J. Anim. Sci. 94: 3147-3158. https://doi:10.2527/jas.2015-0141.
29. Powers W., Auvermann B., Cole N.A., Gooch C., Grant R., Hatfield J., Hunt P., Johnson K., Leytem A., Liao W., Powell J.M. (2014). Chapter 5: Quantifying greenhouse gas sources and sinks in animal production systems. In: Eve M., Pape D., Flugge M., Steele R., Man D., Riley-Gilbert M., Biggar S. (Eds.), Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory. Technical Bulletin Number 1939, Office of the Chief Economist, U.S. Department of Agriculture, Washington. DC. 606 pp.
30. Hatew B., Cone J.W., Pellikan W.F., Podesta S.C., Hendriks W.H., Dijkstra J. (2015). Relationship between *in vitro* and *in vivo* methane production measured simultaneously with different dietary starch sources levels in dairy cattle. Anim. Feed Sci. Technol. 202: 20-31. https://doi.org/10.1016/j.anifeedsci.2015.01.012.
31. Macome F.M., Pellikaan W.F., Schonewille J.T., Bannink A., van Laar H., Hendriks W.H., Warner D., Cone J.W. (2017). *In vitro* rumen gas and methane production of grass silages differing in plant maturity and nitrogen fertilisation, compared to *in vivo* enteric methane production. Anim. Feed Sci. Technol. 230: 96-102. http://dx.doi.org/10.1016/j.anifeedsci.2017.04.005.
32. Negussie E., Lehtinen J., Mäntysaari P., Bayat A.R., Liinamo A.E., Mäntsaari E.A., Lidauer M.H. (2017). Non-invasive individual methane measurement in dairy cows. Animal 11 (5): 890-899. http://doi:10.1017/S1751731116002718.
33. Hristov A.N., Oh J., Firkins J.L., Dijkstra J., Kebreab E., Waghorn G., Makkar H.P.S., Adesogan A.T., Yang W., Lee C., Gerber P.J., Henderson B., Tricarico J.M. (2013). Mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. J. Anim. Sci. 91: 5045-5069. https://doi.org/10.2527/jas.2013-6583.
34. Campos-Montiel R.G., Del Razo-Rodríguez O.E., Almaraz-Buendía I., Ramírez Bibriesca E., Soriano-Robles R., Salinas-Martínez J.A., Arias-Margarito L., González-Muñoz S.S. (2018). Bioconversión de desperdicios vegetales a biogás a partir de microorganismos ruminales. Rev. Int. Contam. Ambie. 34(1): 149-155. DOI:10.20937/RICA.2018.34.01.13.
35. Yan H., Zhao C., Zhang J., Zhang R., Xue C., Liu G., Chen C. (2017). Study on biomethane production and biodegradability of different leafy vegetables in anaerobic digestion. AMB Express, 7(1): 27. http://doi:10.1186/s13568-017-0325-1.
36. Islas-Espinoza M., de las Heras A., Vázquez-Chagoyan J.C., Salem A.Z.M. (2017). Anaerobic cometabolism of fruit and vegetable wastes using mammalian fecal inoculums: Fast assessment of biomethane production. J. Clean. Prod. 141: 1411-1418. http://dx.doi.org/10.1016/j.jclepro.2016.09.215.
37. IPCC (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry and Land Use, Prepared by the National Greenhouse Gas Inventories Programme. H., Eggleston S., Buendía L., Miwa K., Ngara T., Tanabe K. (Eds.), IGES, Japan.
38. Beauchemin K.A., Kreuzer M., O'Mara F., McAllister T.A. (2008). Nu-

tritional management for enteric methane abatement: a review. Aust. J. Exp. Agr. 48 (1-2): 21-27. https://doi.org/10.1071/EA07199.

39. Benchaar C., Calsamiglia S., Chaves A.V., Fraser G.R., Colombatto D., McAllister T.A., Beauchemin K.A. (2008). A review of plant-derived essential oils in ruminant nutrition and production. Anim. Feed Sci. Technol. 145: 209-228. https://doi:10.1016/j.anifeedsci.2007.04.014.
40. Benchaar C., Greathead H. (2011). Essential oils and opportunities to mitigate enteric methane emissions from ruminants. Anim. Feed Sci. Technol. 166-167: 338-355. https://doi.org/10.1016/j.anifeedsci.2011.04.024.
41. Escobar-Bahamondes P., Oba M., Kröbel R., McAllister T.A., MacDonald D., Beauchemin K.A. (2017). Estimating enteric methane production for beef cattle using empirical prediction models compared with IPCC Tier 2 methodology. Can. J. Anim. Sci. 97: 599-612. https://dx.doi.org/10.1139/cjas-2016-0163.
42. Broom D.M., Galindo F.A., Murgueitio E. (2013). Sustainable, efficient livestock production with high biodiversity and good welfare for animals. Proc. R. Soc. B. 280, 2013-2025. https://doi:10.1136/vr.i5470.
43. Giuseppe P., Francesconi A.H.D, Stefanon B., Sevi A., Calamari L., Lacetera N., Dell'Orto V., Pilla F., Marsan P.A, Mele M., Rossi F., Bertoni G., Crovetto G.M., Ronchi B. (2017). Sustainable ruminant production to help feed the planet. Ital. J. Anim. Sci. 16 (1): 140-171. https://doi.org/10.1080/1828051X.2016.1260500.
44. Nordgren A. (2012). Meat and Global Warming: Impact Models, Mitigation. Approaches and Ethical Aspects. Environ. Value 21: 437-457. https://10.3197/096327112X13466893628067.
45. Pinillos R.G., Appleby M., Manteca X., Scott-Park F., Smith C., Velarde A. (2016). One Welfare-a platform for improving human and animal welfare. Vet. Rec. 179: 412-413. http://dx.doi.org/10.1136/vr.i5470.
46. Sarah E.H., André-Denis G.W., Brian W.M. (2010). Methanogens: methane producers of the rumen and mitigation strategies. Archaea, Volume 2010, Article ID 945785. http://dx.doi.org/10.1155/2010/945785.
47. Zhou M., Hernandez-Sanabria E., Guan L.L. (2010). Characterization of variation in rumen methanogenic communities under different dietary and host feed efficiency conditions, as determined by PCR-denaturing gradient gel electrophoresis analysis. Appl. Environ. Microbiol. 76 (12): 3776-3786. http://10.1128/AEM.00010-10.
48. Sauvant D., Giger-Reverdin S. (2007). Empirical modelling meta-analysis of digestive interactions and CH4 production in ruminants. In: Ortigues-Marty I., Miraux N., Brand-Williams W. (Eds.), Energy and Protein Metabolism and Nutrition, Wageningen Academic, Wageningen, The Netherlands, 561-563, 2007.
49. Abdela N. (2016). Sub-acute ruminal acidosis (SARA) and its consequence in dairy cattle: A review of past and recent research at global prospective. Achiev. Life Sci. 10 (6): 187-196. https://doi.org/10.1016/j.als.2016.11.006.
50. Whay H.R., Shearer J.K. (2017). The Impact of Lameness on Welfare of the Dairy Cow. Vet. Clin. N. Am-Food A. 33 (2): 153-164. http://dx.doi.org/10.1016/j.cvfa.2017.02.008.
51. Grainger C., Beauchemin K.A. (2011). Can enteric methane emissions from ruminants be lowered without lowering their production? Anim. Feed Sci. Technol. 166-167: 308-320. https://doi.org/10.1016/j.anifeedsci.2011.04.021.
52. 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. Livest. Sci. 130 (1-3): 47-56. https://doi.org/10.1016/j.livsci.2010.02.010.
53. Martin C., Morgavi D.P., Doreau M. (2010). Methane mitigation in ruminants: from microbe to the farm scale. Animal 4 (3): 351-365. https://10.1017/S1751731109990620.
54. Hristov A.N., Ott T., Tricarico J., Rotz A., Waghorn G., Adesogan A.T., Dijkstra J., Montes F.R., Oh J., Kebreab E., Oosting S.J., Gerber P.J., Henderson B., Makkar H.P., Firkins J.L. (2013). Mitigation of methane and nitrous oxide emissions from animal operations: III. A review of animal management mitigation options. J. Anim. Sci. 91: 5095-5113. https://doi.org/10.2527/jas.2013-6585.
55. Romero-Pérez A., Okine E.K., McGinn S.M., Guan L.L., Oba M., Duval S.M., Kindermann M., Beauchemin K.A. (2014). The potential of 3-nitrooxypropanol to lower enteric methane emissions from beef cattle. J. Anim. Sci. 92: 4682-4693. http://doi:10.2527/jas2014-7573.
56. Romero-Pérez A., Okine E.K., McGinn S.M., Guan L.L., Oba M., Duval S.M., Kindermann M., Beauchemin K.A. (2015). Sustained reduction in methane production from long-term addition of 3-nitrooxypropanol to a beef cattle diet. J. Anim. Sci. 93 (4): 1780-1791. https://doi.org/10.2527/jas.2014-8726.
57. Mitsumori M., Shinkai T., Takenaka A., Enishi O., Higuchi K., Kobayashi Y., Nonaka I., Asanuma N., Denman S.E., McSweeney C.S. (2012). Responses in digestion, rumen fermentation and microbial populations to inhibition of methane formation by a halogenated methane analogue. Brit. J. Nutr. 108 (3): 482-491. https:// 10.1017/S0007114511005794.
58. Knight T., Ronimus R.S., Dey D., Tootill C., Naylor G., Evans P., Molano G., Smith A., Tavendale M., Pinares-Patiño C.S, Clark H. (2011). Chloroform decreases rumen methanogenesis and methanogen populations without altering rumen function in cattle. Anim. Feed Sci. Technol. 166-167: 101-112. https://doi.org/10.1016/j.anifeedsci.2011.04.059.
59. Martínez-Fernández G., Abecia L., Arco A., Cantalapiedra-Hijar G., Martín-García A., Molina-Alcaide E., Kindermann M., Duval S., Yáñez-Ruiz D.R. (2014). Effects of ethyl-3-nitrooxy propionate and 3-nitrooxypropanol on ruminal fermentation, microbial abundance, and methane emissions in sheep. J. Dairy Sci. 97 (6): 3790-3799. https://doi.org/10.3168/jds.2013-7398.
60. Haisan J., Sun Y., Guan L.L, Beauchemin K.A., Iwaasa A., Duval S., Barreda D.R., Oba M. (2014). The effects of feeding 3-nitrooxypropanol on methane emissions and productivity of Holstein cows in mid lactation. J. Dairy Sci. 97 (5): 3110-3119. http://10.3168/jds.2013-7834.
61. Guan H., Wittenberg K.M., Ominski K.H. (2006). Efficacy of ionophores in cattle diets for mitigation of enteric methane. J. Anim. Sci. 84 (7): 1896-1906. https://10.2527/jas.2005-652.
62. Appuhamy J.A., Strathe A.B., Jayasundara S., Wagner-Riddle C., Dijkstra J., France J., Kebreab E. (2013). Anti-methanogenic effects of monensin in dairy and beef cattle: a meta-analysis. J. Dairy Sci. 96 (8): 5161-5173. https://doi:10.3168/jds.2012-5923.
63. Martineau R., Benchaar C., Petit H.V., Lapierre H., Ouellet D.R., Pellerin D.R., Berthiaume R. (2007). Effects of lasalocid or monensin supplementation on digestion, ruminal fermentation, blood metabolites, and milk production of lactating dairy cows. J. Dairy Sci. 90 (12): 5714-5725. https://10.3168/jds.2007-0368.
64. Duffield T.F., Rabiee A.R., Lean I.J. (2008). A meta-analysis of the impact of monensin in lactating dairy cattle. Part 2. Production effects. J. Dairy Sci., 91 (4): 1347-1360. https://doi.org/10.3168/jds.2007-0608.
65. Mcguffey R.K., Richardson L.F., Wilkinson J.I.D. (2001). Ionophores for dairy cattle: current status and future outlook. J. Dairy Sci. 84: E194-E203. https://doi.org/10.3168/jds.S0022-0302(01)70218-4.
66. FAO (2016). El plan de acción de la FAO sobre la resistencia a los antimicrobianos 2016-2020. Roma, Italia (In Spanish).
67. Grainger C., Clarke T., Auldist M.J, Beauchemin K.A., McGinn S.M., Waghorn G.C, Eckard R.J. (2009). Potential use of *Acacia mearnsii* condensed tannins to reduce methane emissions and nitrogen excretion from grazing dairy cows. Can. J. Anim. Sci. 89 (2): 241-251. https://doi.org/10.4141/CJAS08110.
68. Hart K.J., Martin P.G., Foley P.A., Kenny D.A., Boland T.M. (2009). Effect of sward dry matter digestibility on methane production, ruminal fermentation, and microbial populations of zero-grazed beef cattle. J. Anim. Sci. 87 (10): 3342-3350. https://10.2527/jas.2009-1786.
69. Flachowsky G., Lebzien P. (2012). Effects of phytogenic substances on rumen fermentation and methane emissions: a proposal for a research process. Anim. Feed Sci. Technol. 176 (1-2): 70-77. https://doi.org/10.1016/j.anifeedsci.2012.07.009.
70. Wanapat M., Kang S., Polyorach S. (2013). Development of feeding systems and strategies of supplementation to enhance rumen fermentation and ruminant production in the tropics. J. Anim. Sci. Biotechnol. 4, 32. https://doi.org/10.1186/2049-1891-4-32.
71. De Giusti G., Kristjanson P., Rufino M.C. (2019). Agroforestry as a climate change mitigation practice in smallholder farming: evidence from Kenya. Climate Change, 153 (3): 379-394. https://doi.org/10.1007/s10584-019-02390-0.
72. Mbow C., Noordwijk M.V., Luedeling E., Neufeldt H.P., Minang A., Kowero G. (2014). Agroforestry solutions to address food security and climate change challenges in Africa. Curr. Opin. Environ. Sustainability. 6: 61-67. https://doi.org/10.1016/j.cosust.2013.10.014.
73. Ospina-Ante A. (2006). Agroforestería. Aportes conceptuales, metodológicos y prácticos para el estudio agroforestal. Asociación del Colectivo de Agroecología del Suroccidente Colombiano, Cali, Colombia. 209 pp (In Spanish).
74. Kou-Giesbrecht S., Menge D. (2019). Nitrogen-fixing trees could exacerbate climate change under elevated nitrogen deposition. Nature Communications, 10:1493. https://doi.org/10.1038/s41467-019-09424-2.
75. Reisinger A., Clark H. (2018). How much do direct livestock emissions actually contribute to global warming?. Global Change Biology, 24: 1749-1761. http://doi:10.1111/gcb.13975.
76. Murgueitio E., Chará J.D., Solarte A.J., Uribe F., Zapata C., Rivera J.E. (2013). Agroforestería pecuaria y sistemas silvopastoriles intensivos (SSPI) para la adaptación ganadera al cambio climático con sostenibilidad. Rev. Colomb. Cienc. Pec. 26: 313-316.