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Contribution of Livestock Production to Global Greenhouse Gas Emission and Mitigation Strategies

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ABSTRACT

Understanding the interaction of livestock production and climate change is currently the main issue in global warming. This paper reviews the contribution of livestock production in greenhouse gas emission and its mitigation strategies. The potential contribution of individual large ruminants are 200-500 liters of methane per day while small ruminants produces 20-40 liters of methane per day. The major greenhouse gas related to livestock production are methane and nitrous oxide which contribute approximately about 14.5% global GHG emissions. Limiting emissions from livestock, without compromising food security, is an important limit greenhouse gas emissions. The main choices for reducing greenhouse gas emission in livestock production are more related to improving animal production. Mitigating emission of CH₄ by means of improved management of biogas and manure, reducing CH₄ emission from enteric fermentation through improved efficiency and diet, husbandry as well as genetic management are some of strategies used in mitigating enteric emission of methane from livestock. The other one is mitigating emission of nitrous oxide through more efficient use of nitrous fertilizer, proper manure management and by using different feed additives.

1. Introduction

Agricultural production potential has previously grown-up 2.1-2.3 in over the last 40 years as reported by^[1] and this is responsible for 10-12% of the global anthropogenic greenhouse gas emission^[2].

Fossil fuels are the major causes of climate change as first list. Some or the main source of resulted by human related activities as emission of carbon dioxide and some of greenhouse gas are: natural gas, Oil and especially coal. However, the life of animal and animal production as food for human are comprehended that as a main source of greenhouse gases, and this in fact not less than half of

human caused greenhouse gases emission^[3].

According to the report of^[4] there is an expectation of Human population increment from 7.2 - 9.6 billion by the year 2050. This indicates that 33% population increase, but obviously as global living standard increase, the increment in demand for agricultural product will increase by around 70% in the future in the same period estimated by^[1]. Livestock is among one of the fastest growing from agricultural subsectors in developing countries. In these country GDP is around 33% share of the total agricultural GDP and is rapidly increasing. This easily shows that progress is induced by the quickly increasing demand for animal products driven by population growth as well as in-

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creasing income and urbanization in developing countries^[5]. Ruminants are expected to be an important component of global production and there is a growing demand especially for animal protein sources^[6], still keeping their indispensable role in the management and preservation of ecosystems, namely in natural and semi-natural grasslands and rangelands and agrosilvopastoral systems, among others. But, a substantial upsurge in agricultural production will be required to meet these increasing demand for animal originated protein foods^[2]. This is an event that is likely to lead to strengthened production practice and following increases in Greenhouse gas emission.

Livestock system have both negative and positive effect on social equity and economic growth, natural resource and public health^[7]. Livestock produces greenhouse gases in different forms like: in the form of nitrous oxide (N₂O) from the use of nitrogen containing fertilizer, methane (CH₄) from enteric fermentation and N₂O and CH₄ from livestock manure deposition on the pastureland and from different animal manure management. Carbon dioxide is also produced on different livestock farms from different energy usage and fuels^[8].

Currently there is a huge rising interest in understanding the linkage between agricultural production especially livestock production and climate change and it has been motivating a significant amount of research^[9]. Therefore, this paper reviews the livestock sector's contribution to the global climate change and its mitigation strategies.

Objectives

To describe the contribution of livestock sector on climate change

To clarify and summarize mitigation strategies

2. Contribution of Livestock Production Practises to Climate Change

Livestock system plays significant role in climate change^[10]. Livestock production directly and indirectly contributes about soil carbon loss in grazing land, deforestation for grazing land and intensive animal feed production, the amount of energy used in cultivating and harvesting feed and processing, transporting dairy products, meat and meat products, live animals and animal feed, gases from animal manure (especially CH₄) and enteric fermentation and nitrous oxide (N₂O) releases from the use of nitrogen containing synthetic fertilizers^[11]. Greenhouse gases most often associated with animal production are methane, nitrous oxide and carbon dioxide^[12, 13]. Similarly, greenhouse gas emission from agricultural sector that are related to animal production are CH₄ which directly emitted

from livestock stomach and manure, while nitrous oxide (N₂O) emitted from fertilizer applied soil and manure as well as grazed lands as reported by^[14].

Different authors approximate the contribution of livestock production on global greenhouse emission with different figures.^[15] estimate the livestock contribution to global anthropogenic greenhouse gas emission at between 7 - 18% . methane is the most important gas produced in agriculture^[13]. Ruminant livestock approximately can produce 250-500 litter of CH₄ per day. This level of production results in estimation of the contribution large ruminant to global warming that may occur in the next 50-100 yeqrs to be less than 2% about 65 % of the livestock production emissions. With respect to activities, feed processing and production and enteric fermentation from ruminants are the two major sources of emissions, contributing 45 % and 39 % of total emissions respectively. Manure storage and processing forms 10 % and the rest is attributed to transportation and animal processing. On product-basis, milk from cows and beef are responsible for the most emissions, contributing 20 % and 41 % of the sector's total greenhouse gas (GHG)^[16]. Majority of the livestock industry emission are in the form of methane (44%), while 29% and 27% are nitrous oxide and carbon dioxide respectively (figure 1) below^[2,17,18].

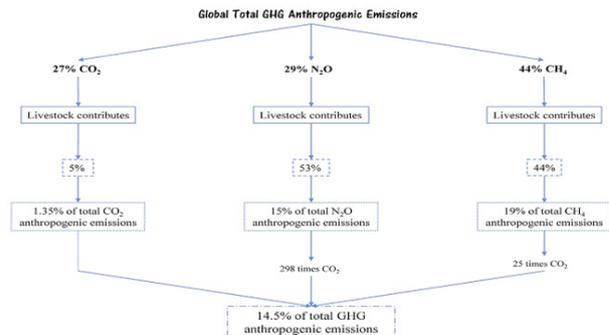


Figure 1. Livestock contribution to global GHG emission^[18]

The green plant used up by the livestock instigates from the conversion of atmospheric carbon dioxide to biomass or organic compound. Hence, under the Kyoto Protocol (2005) it is assumed that the amount of consumed carbon dioxide in negative form are equivalent to those emitted by the animals. Therefore, livestock respiration is not counted as a net source of Carbon dioxide emission since they are part of global biological cycle. On the other hand, the animal is thought to be a carbon sink since a fraction of the Carbon consumed is absorbed in the live tissue of the livestock and livestock products like milk and meat^[19].

Many authors reported that emission from animal production contribute more greenhouse gas emission to the

atmosphere than the entire global transportation sector. Thus, the domestic animal donates indirectly and directly to greenhouse gas emission^[20, 21].

2.1 Direct Contribution of Livestock to Greenhouse Gas Emission

Some of the direct emission from animal source include animal physiology, respiration, enteric fermentation and excretion^[22].

Emission of CH₄ is thought as one of the most significant global issue^[2]. During feed fermentation and digestion in animals, methane gas is produced as by-product of digestion of structural carbohydrate majorly cellulose due to the action of microorganism (fungus, protozoa and bacteria) in the rumen (figure 2). At the time this digestion of monosaccharide are fermented to CO₂, H₂ and VFA such as propionate, butyrate and acetate^[23]. This process releases H₂ while producing VFA and some of the microbial cells comprising energy and essential protein to be made available for the growth of animals in all ruminants, the H₂ is removed through the action a group of microorganism known by methanogenic archaea or methanogens that can gain their energy via combining CO₂ and H₂ to form methane^[24]. Of course, CH₄ is produced by archaeal microorganism known as methanogen which utilizes predominantly carbon dioxide and hydrogen in the rumen to form CH₄ in the animals, thereby maintaining the lower partial pressure of H₂ in the rumen. Actually this CH₄ production from the production from the rumen archaea result in 2-12% loss of metabolizable energy in the rumen^[16,24]. According to the report of^[2] GHG account shows that CH₄ emission from livestock is almost equivalent to the GHG emission from the transportation sector in the case of Australia.

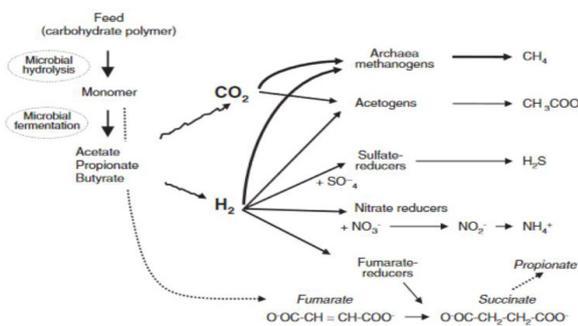


Figure 2. Feed and H₂ reduction in the rumen adopted from^[25]

2.2 Indirect Contribution to Greenhouse Gas Emission

Indirect emission refers to emission resulted from ma-

nure application, manure storage, farm operation, land application chemical fertilizers and manure treatments, feed crop, transportation, animal product processing and land allocation for livestock production (like: desertification, deforestation and carbon release from cultivated land)^[20]. Generally, in the case of livestock production indirect emission play a great role in the release of C₂O to the atmosphere than direct emission^[26].

Greenhouse gas emission from animal production in particular and agriculture in general are expected to grow as food production expands to keep pace with a growing world which is expected to reach 8.3 billion by 2030 and 9.1 bill by 2050 as estimated by^[4].

In developing country especially in Africa, there is an increase in CH₄ emission resulted from increased livestock production. According to the report of^[27] there was an estimation that African cattle, sheep and goat produce about 7.8mil tons of CH₄ in 2000 which are likely to increase to 11.1mil tons by 2030. As^[28] reported that, in case this linear relationship between methane emission and livestock population continue, it could be concluded that global methane emission form animals production may increase 60% by the year 2030. Though, the moderate solution for reducing methane emission from livestock production practices could be changing feeding practices and manure management^[29].

3. Livestock Sector GHG Mitigation Strategies

Reducing greenhouse gas emissions from livestock, without conceding food security is therefore clearly an important portion of any international effort to limit greenhouse gas emission overall and their effect on climate system^[30].

The main alternatives for limiting GHG emission per unit of animal production: firstly, mitigating emission of CH₄ via improved management of biogas and manure; secondly, reducing CH₄ emission from enteric fermentation especially in ruminant animals (mostly cattle, goat and sheep) via improved feed efficiency; thirdly, mitigating emission of NO₂ through more effectual use of inorganic or nitrogenous fertilizers; fourthly, confiscating carbon and mitigating CO₂ emission by reduction and reversal of deforestation due to agricultural intensification and by restoration of organic carbon to cultivated soil and degraded pasture land or rangeland and fifthly, changing the herd structure through increasing the proportion of monogstric animals like pig and chickens as well as vegetarian fish in the flow of animals grown for human consumption^[31].

3.1 Methane Mitigation Strategies

Numerous studies have formulated reduction schemes to

mitigate methane emission. Generally, mitigation can be grouped in to two: basically those targeting manure management and those targeted at enteric fermentation^[23].

3.1.1 Methane Mitigation Strategies Aimed at Enteric Fermentation

Diminishing enteric CH₄ emission from ruminant livestock without changing livestock production is needed both as a strategy to reduce global greenhouse gas emission and as means of improving feed conversion efficiency of the individual animals^[32].

Some of mitigation strategies can be used to reduce greenhouse gas emission such as the use of some specified chemicals and vaccines, genetic selection and the capture of methane have been proposed, yet dietary management is considered the most promising strategy for the diminution of methane from ruminant animal production system^[33].

(1) Genetic Management

Naturally the potential of animals to produce enteric methane is vary. As the first strategy to reduce methane emission per individual animals is the use of selection or selective breeding with an animal's permitting low methane emission per unit of feed consumed 10% with no negative impact on productivity record^[10]. Therefore, selecting animals that shows excellent production performance on low quality feeds is also another way of reducing CH₄ emission per individual animal product.

Another option to reduce methane emission is the potential of changing rumen microorganism. Currently changing the rumen microbial composition in lambs and calves after weaning towards lowering methane emission in the future adult life is being explored and practically available^[10].

(2) Dietary Manipulation

Dietary manipulation is also the second strategy to reduce methane emission per individual animals. Harvesting pasture and forage at early maturity stage improves its nutritional content of some soluble carbohydrate and decrease the level of lignin in the plant cell wall thus increases its digestibility^[34] and also reducing enteric methane emission per unit of digestible dry Matter.

Mechanical processing of feeds like processing via its influence on energy losses, passage rate and digestibility can be an effective enteric methane emission mitigation alternative although it may not be economically feasible in some animal production systems. Providing higher quality forage is also another way of reducing enteric methane emission because it improve digestibility of the feed^[15].

Another strategy of dietary manipulation is concentrate supplementation. Addition of small amount of concentrate

to all roughage (natural pasture or forage) is expected to increase animal productivity and reduce greenhouse emission per individual animals^[15].

Lipid supplementation is the most reliable and technically acceptable nutritional manipulation used to reduce enteric methane emissions. Nevertheless, its diminution potential is ultimately limited by a restriction on dietary inclusion in order to maintain production efficiency^[33]. Similarly,^[15] reported that dietary lipid are effective in reducing enteric methane emission, but the application of this practice will depends on its cost and its effect on feed intake, production and product composition like milk composition. Reductions of 10-25% may be achieved via the supplementation of dietary lipid or oil to the ration of ruminants^[35]. Some of the possible mechanism by which added oil can reduce CH₄ emission include: (1) by increasing the amount of energy used to digest fiber (mostly in long chain fatty acids); (2) dry matter intake lowering (if total dietary lipid exceeds 6-7%); (3) via suppression of methanogens mainly in medium-chain fatty acids; (4) through overpowering of rumen protozoa; and (5) to a) to a restricted extent via bio-hydrogenation^[6, 35]. According to the evidence of some researchers, a 1% increase of dietary fat can reduce enteric methane emission between 4 - 5%^[32, 35].

Grinding grain feed or physical processing of grain feed aimed to improve its digestibility is expected to decrease enteric methane emission intensity^[15]. Improving quality of diet also result in better animal production performance as well as decreasing methane production in the rumen as measured by decrease in methane emission per unit of animal product^[6].

Strategic supplementation of the diet like chemical treatment of low quality feeds or pasture, ration balancing and crop selection for straw quality are effective mitigation strategies, but these technology has been poorly practiced in animal feeding^[15].

Dietary Protein management is also a good strategy to reduce methane emission. An increase of protein content of diet or ration can also improve digestibility and reduce overall methane emission per unit of animal product^[36].

(3) Husbandry Management

Methane emission from a given farm depends on the number of animals and the emission per head^[24]. Increasing an individual animal productivity can be a very effective strategy for decreasing GHG emission per unit of animal product. Reduction of herd size is a good strategy, this would also increase feed availability and productivity of individual animals and the total herd, thus sinking methane emission intensity^[15].

Minimizing disease and environmental stressor via an

effective disease causing agent management strategy will improve productivity of the herd and results in reduction of CH₄ emission per unit of animal product as well as in overall herd of the farm ^[24].

Regarding the age of calves to reach slaughter weight and the number of days the cattle remained on feed in the feedlot to finish weight has effect on the rate of methane emission per animals. To resolve these problem improving animal nutrition and genetics can have a significant impact on GHG emission in beef and other meat animal production system ^[15]. In case of dairy farming, extending lactation period is the main strategy to reduce methane emission because it reduces herd energy demand and replacement rate ^[12].

(4) Chemical Additives

Some chemicals are used in animal feed for the sake of improving feed digestibility. Recently it is known that some chemical agents such as ionophores (monensin), unsaturated fatty acid, sulphate, nitrate, fumarate and halogenated methane analogues (Bromochloromethane (BCM)) are able to reduce methane production from ruminant animals ^[16,25,37].

Adding nitrate to the ration result in reduced amount of CH₄ emission because it is converted to ammonium (NH₄⁺) which leaves less H₂ available for methane production. This method may have applicability in place such as Australia and Brazil where nitrate could replace the urea which is added to low quality ration to nutritive value ^[10].

Bromochromomethane (BCM) is one of the most effective inhibitors and apparently reduce CH₄ production by interfering with the Cobamide dependent methyl transferase step of methanogenesis ^[38]. Bromochromomethane (BCM) complexed in cyclodextrin CD; BCM-CD) results in the stained inhibition of CH₄ production when fed to ruminants ^[39]. Moreover, an in vitro continuous fermentation system simulating rumen fermentation demonstrated that BCM significantly reduced methane production by (85-90%) and eliminated most methanogens, whereas there was no effect on total production, true digestibility of feed and of feed efficiency of microbial protein synthesis ^[40].

(5) Probiotic Supplements

There are some microbial feed additives that have been developed to improve productivity by directly influencing rumen fermentation ^[41]. Probiotics or direct fed microbial are used in the diet of ruminants to improve the health status, rumen fermentation and ultimately the animal per formance that could also reduce methane emission ^{[42], [43]} Reported the use of probiotics in mitigation of methane from ruminants. Probiotics improved productivity by 7 to 8 percent resulting in reduced CH₄ per unit of product in

cattle.

3.1.2 Methane Mitigation Targeting Manure Management

The most mitigation alternatives for greenhouse gas emission from stored manure, such as reducing the time of aeration, manure storage and stacking are generally aimed at reducing the time of allowed for microbial fermentation process to occur before land application. This kind of mitigation practices are more effective, but their economic feasibility is uncertain ^[15].

Table 1. Methane mitigation strategy from manure.

Slurry manur storage	Solid Manure Storage
Storage temperature	Prevent CH ₄ formation
Manure acidification	Prevent anaerobic conditions
Reduced storage time	Reduced storage time
Prevent and repair leakage	Composting
Improve anaerobic digestion	Reduce manure moisture
Collect and combust methane	Storage temperature
Cover manure storage	Manure acidification

Source: ^[15]

3.2 Mitigating Emissions of Nitrous Oxide

Some of the strategies used for increasing the efficiency of N-Cycle in livestock production system and soil aeration should also lead to reduced N₂O emission ^[4].

Diminishing total ration protein contain and supplementing the ration with synthetic amino acid is an effective means of ammonia and N₂O mitigation strategies for non-ruminants. Ammonia emission from liquid animal waste or slurry receiving the tannin supplemented diet was 8-49% lower than the control slurry. Tannin also lower ammonia emission by 20% when directly applied to the barn floor and 27% after a tannin excreta was applied to the soil ^[44]. In contrary to the economic value of the manure, tannin use can reduce N-release rate from manure and thus affect manure -N availability for plant growth ^[15].

Salt similarly has some mitigation effect of methane in animal production. Adding salt increase water intake in ruminants, this may force the animals both decreasing urinary nitrogen concentration and encouraging more frequent urination events thus spreading urine more evenly across grazing pasture ^[6].

Another mitigation strategy is by use of chemicals that inhibit the oxidation of ammonium to nitrate in soil and thereby reducing N₂O emission from urine ^[15]. Some of Nitrification inhibitors like (Dicyandiamide or 3,4-dimethylpyrazole phosphate) applied with slurry under simulat-

ed Portuguese condition were very efficient in reducing nitrous oxide emission ^[45].

4. Conclusion

The livestock sector contribute indirectly and directly to greenhouse gas emission. Indirect emission include emission resulting from feed crops, farm operation, manure application, transportation, animal product processing and land use allocation for animal production while direct emission from livestock sources refers to enteric fermentation, excretions and respiration. Greenhouse gases most often associated with animal production are methane, nitrous oxide and carbon dioxide. Around 44% of animal emission are in the form of CH₄ while N₂O represent 29% and CO₂ represent 27%. Livestock contribute to global GHG emission approximately 14.5%. Limiting emissions from livestock, without cooperating food security is an important effort to GHG emission. The main option for reducing GHG emission per unit of livestock production include: mitigating emissions of CH₄ through reducing methane emission from enteric fermentation through improved feed efficiency of individual animal, husbandry as well as genetic management and improved management of biogas and manure. The other one is mitigation emission of N₂O via more efficient use of nitrogenous fertilizer, proper manure feed management and by using different feed additives.

References

- [1] FAO 2009. The state of food and agriculture. Livestock in the Balance (Rome: Food and Agriculture Organization of the United Nations), 2009.
- [2] IPCC 2007. Agriculture. In B. Metz, O. R. P. Davidson, R. Bosch, R. Dave, & L. A. Meyer (eds.) Climate Change 2007: Mitigation (Cambridge, New York: Cambridge University Press), Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007: 497+540.
- [3] Robert Goodland, Jeff Anhang, 200669. Livestock and Climate Change. UNEP (United Nations Environment Programme). Global environment outlook, 2012 5: Chapter 5.
http://www.unep.org/geo/pdfs/geo5/GEO5_report_C5.pdf
- [4] UN, 2008. World Population Prospects: The 2008 Revision. New York, NY, USA.
www.esa.un.org/unpp
- [5] Delgado, C. Rising demand for meat and milk in developing countries: implications for grasslands-based livestock production. In Grassland: a global resource (ed. D. A. McGilloway) The Netherlands: Wageningen Academic Publishers, 2005: 29-39.
- [6] Henry, Beverley, Richard Eckard. Greenhouse Gas Emissions in Livestock Production Systems. Tropical Grasslands, 2009, 43:232-38.
- [7] World Bank. Minding the stock: bringing public policy to bear on livestock sector development. Report no. 44010-GLB. Washington, DC, 2009.
- [8] F.P. O'Mara. The significance of livestock as a contributor to global greenhouse gas emissions today and in the near future. Animal Feed Science and Technology, 2011, 166-167: 7-15.
- [9] Aydinalp, C., Cresser, M.S.. The effects of climate change on agriculture. Agric. Environ. Sci. 5, 672-676.
- [10] SAI. 2014. Reducing Greenhouse Gas Emissions from Livestock : Best Practice and Emerging Options. SAI Platform, 2008.
- [11] US EPA. Global anthropogenic non-CO₂ greenhouse gas emissions: 1990-2020. Washington DC: US Environmental Protection Agency, Office of Atmospheric Programs, 2006.
- [12] Smith, p., martino, d., cai, z., gwary, d., janzen, h., kumar, p., mccarl, b., ogle, s., o'mara, f., rice, c., scholes, b., sirotenko, o. Agriculture. In: b. Metz, o.r. davidson, p.r. bosch, r. Dave and l.a. meyer (eds) climate change 2007: mitigation. Contribution of working group iii to the fourth assessment report of the intergovernmental panel on climate change. (cambridge university press: cambridge, united kingdom and new york, usa), 2007.
- [13] Sarkwa, F. O., E. C. Timpung-Jones, N. Assuming-Bediako, S. Aikins, and T. Adogla-Bessa. The Contribution of Livestock Production to Climate Change: A Review. Livestock Research for Rural Development, 2016.
- [14] Kebreab, E, K Clark, C Wagner-Riddle, J France. Methane and Nitrous Oxide Emissions from Canadian Animal Agriculture: A Review. 2006.
- [15] Hristov, Alexander N., Joonpyo Oh, Chanhee Lee, Robert Meinen, Felipe Montes, Troy Ott, Jeff Firkins. Mitigation of Greenhouse Gas Emissions in Livestock Production- A Review of Technical Options for Non-CO₂ Emissions. FAO Animal Production and Health, 2013, Paper No. 177.
<https://doi.org/10.1016/j.agee.2005.08.009>
- [16] Johnson, K A, D E Johnson. Methane Emissions from Cattle. Journal of Animal Science, 1995, 73: 2483-92.
<https://doi.org/10.2527/1995.7382483x>
- [17] Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., Tempio, G.

- Tackling Climate Change Through Livestock: A Global Assessment of Emissions and Mitigation Opportunities. FAO, Rome, 2013.
- [18] Rojas-Downing, M. Melissa, A. Pouyan Nejadhashemi, Timothy Harrigan, Sean A. Woznicki. Climate Change and Livestock: Impacts, Adaptation, and Mitigation. *Climate Risk Management* 16. The Authors, 2017: 145-63.
<https://doi.org/10.1016/j.crm.2017.02.001>
- [19] United Nations Framework Convention on Climate Change (UNFCCC). Kyoto Protocol reference manual on accounting of emissions and assigned amount. Climate Change Secretariat (UNFCCC), Martin-Luther-King-Strasse 8, 53175 Bonn, Germany, 1998.
- [20] Havlik, P., H. Valin, M. Herrero, M. Obersteiner, E. Schmid, M. C. Rufino, A. Mosnier, et al. Climate Change Mitigation through Livestock System Transitions. *Proceedings of the National Academy of Sciences*, 2014, 111 (10): 3709-14.
<https://doi.org/10.1073/pnas.1308044111>
- [21] Casey, Kenneth D, José R Bicudo, David R Schmidt, Anshu Singh, Susan W Gay. *Air Quality and Emissions from Livestock and Poultry Production/Waste Management Systems*, 2006.
- [22] Jungbluth, T., Hartung, E., Brose, G.. Greenhouse gas emissions from animal houses and manure stores. *Nutr. Cycl. Agroecosyst*, 2001, 60: 133-145.
- [23] Hopkins, A., A. Del Prado. Implications of Climate Change for Grassland: Impacts, Adaptations and Mitigation Options. *Grass and Forage Science*, 2007, 62: 118-26.
<https://doi.org/10.1111/j.1365-2494.2007.00575.x>
- [24] Henry, B, R Eckard.. Greenhouse Gas Emissions in Livestock Production Systems. *Tropical Grasslands*, 2009, 43: 232-38.
- [25] Morgavi, D P, E Forano, C Martin, C J Newbold. Microbial Ecosystem and Methanogenesis in Ruminants. *The Animal Consortium*, 2010, 4 (7): 1024-36.
<https://doi.org/10.1017/S1751731110000546>
- [26] Steinfeld, H., Wassenaar, T., Jutzi, S.. Livestock production systems in developing countries: status, drivers, trends. *Rev. Sci. Tech. Off. Int. Epiz.*, , 2006, 25(2): 505-516.
- [27] Herrero, M., Thornton, P.K., Kruska, R., Reid, R.S.. Systems dynamics and the spatial distribution of methane emissions from African domestic ruminants to 2030. *Agric. Ecosyst. Environ.*, 2008, 126: 122-137.
- [28] Bruinsma, J.. *World Agriculture: Towards 2015/2030: An FAO Perspective*. Earthscan, London, 2003.
- [29] Thornton, P.K., Herrero, M., 2010. The Inter-linkages between rapid growth in livestock production, climate change, and the impacts on water resources, [30] NZAGRC. The Impact of Livestock Agriculture on of Climate Change The Impact Livestock Agriculture on Climate Change, 2012: 1-7.
- [31] McMichael, Anthony J., John W. Powles, Colin D. Butler, Ricardo Uauy. Food, Livestock Production, Energy, Climate Change, and Health. *Lancet*, 2007, 370 (9594): 1253-63.
[https://doi.org/10.1016/S0140-6736\(07\)61256-2](https://doi.org/10.1016/S0140-6736(07)61256-2)
- [32] Martin, C., D. P. Morgavi, M. Doreau. Methane Mitigation in Ruminants: From Microbe to the Farm Scale. *Animal*, 2010, 4(3): 351-65.
<https://doi.org/10.1017/S1751731109990620>
- [33] Meale, S. J., T. A. McAllister, K. A. Beauchemin, O. M. Harstad, A. V. Chaves. Strategies to Reduce Greenhouse Gases from Ruminant Livestock. *Acta Agriculturae Scandinavica A: Animal Sciences*, 2012, 62 (4): 199-211.
<https://doi.org/10.1080/09064702>
- [34] VAN SOEST, P.J.. *Nutritional ecology of the ruminant*. 2.ed. New York: Cornell University Press, 1994: 476.
- [35] Beauchemin KA, Kreuzer M, O'Mara F, McAllister TA. Nutritional management for enteric methane abatement: a review. *Australian Journal of Experimental Agriculture*, 2008, 48: 21-27.
- [36] ICF International. Greenhouse gas mitigation options and costs for agricultural land and animal production within the United States, 2013.
http://www.usda.gov/oce/climatechange/mitigationtechnologies/GHG_Mitigation_Options.pdf
- [37] Itabashi H.. Reducing ruminal methane production by chemical and biological manipulation. In *Greenhouse Gases and Animal Agriculture*, 2002: 139-144 [J Takahasi and BA Young, editors]. Amsterdam: Elsevier Science.
- [38] Wood JM, Kennedy FS, Wolfe RS. The reaction of multi-halogenated hydrocarbons with free and bound reduced vitamin B12. *Biochemistry*, 1968, 7: 1707-1713.
- [39] Tomkins N., Hunter R.. Methane reduction in beef cattle using a novel antimethanogen. *Anim Prod Aust*, 2004, 25: 329.
- [40] Goel, Gunjan, Harinder P S Makkar, Klaus Becker. Inhibition of Methanogens by Bromochloromethane: Effects on Microbial Communities and Rumen Fermentation Using Batch and Continuous Fermentations, 2009.
<https://doi.org/10.1017/S0007114508076198>
- [41] Lascano, Carlos E., Edgar Cárdenas. Alternatives for Mitigation of Methane Emission in Livestock Systems. *Brazilian Journal of Animal Science*, 2010, 39

- (SUPPL. 1): 175-82. (in Portuguese)
<https://doi.org/10.1590/S1516-35982010001300020>
- [42] Kumar, Anil, Puniya Guru, Angad Dev.. Controlling Methane Emissions from Ruminants Employing Bacteriocin Controlling Methane Emissions from Ruminants, no. December, 2013: 140-53.
<https://doi.org/10.13140/RG.2.1.3520.2401>
- [43] Klieve, A.V., Joblin, K.. Comparison in hydrogen utilisation of ruminal and marsupial reductive acetogens. In R. Kennedy, (eds) 5 Year Research Progress Report 2002 - 2007, The Pastoral Greenhouse Gas Research Consortium, Wellington, New Zealand, 2007: 34 - 35.
- [44] Powell, J. M., M. J. Aguerre, M. A. Wattiaux. Dietary crude protein and tannin impact dairy manure chemistry and ammonia emissions from incubated soils. *J. Environ. Qual.* 2011a, 40: 1767-1774.
- [45] Hatch, D., H. Trindade, L. Cardenas, J. Carneiro, J. Hawkins, D. Scholefield, D. Chadwick. Laboratory Study of the Effects of Two Nitrification Inhibitors on Greenhouse Gas Emissions from a Slurry-Treated Arable Soil: Impact of Diurnal Temperature Cycle. *Biology and Fertility of Soils*, 2005, 41(4): 225-32.
<https://doi.org/10.1007/s00374-005-0836-9>