American-Eurasian Journal of Scientific Research 11 (6): 411-419, 2016
ISSN 1818-6785

DOI: 10.5829/idosi.aejsr.2016.411.419

A Review on Enteric Methane Emission by Domestic Ruminants: Contribution to Green House Gas and Mitigation Opportunities in Ethiopia

Girma Defar

Madawalabu University, Department of Animal
and Range Sciences. P.O. Box 234. Bale-Robe, Ethiopia

Abstract: Evidence from the Intergovernmental Panel on Climate Change is overwhelmingly convincing climate change is real and it will become worse. Like the other nations of globe, Ethiopia has begun a progressive strengthening collaborative resolve to address the problems associated with global warming. Anthropogenic processes are responsible for global warming. And methane (CH_4) from agricultural sector is released annually into the atmosphere with enteric fermentation has a contribution to emissions in a number of countries. This paper therefore, reviews enteric CH_4 emission from domestic ruminants (cattle, sheep and goats) in Ethiopia, its contribution to greenhouse gas and mitigation opportunities. Though limited research work was done on Ethiopian domestic ruminant, this particular paper considers research results which deal with African condition (particular to east Africa domestic ruminants' enteric CH_4 emissions including Ethiopia). Based on the recent international data from the World Bank, Ethiopia's CH_4 emissions are about 52Mt CO_2-equivalent and the livestock sector contributes 45% of these CH_4 emissions. Report by Global Methane Initiative indicates that the livestock sector has one of the highest potential for CH_4 reduction in Ethiopia and livestock production in Ethiopia experiencing a rapid change in structure and function due to increased demands for livestock products. Some of these changes could lead to increased emissions of CH_4 gas. Methane emissions per tropical livestock unit (TLU, 250kg bodyweight) can vary from 21-40kg per TLU per year, depending on the production system and diet type. But, the average emission factors obtained from literature for this review, 31.1kg CH_4 per TLU per year. Based on this information, domestic ruminants in Ethiopia *viz.,*cattle, sheep and goat emits about 1134.87kg, 112.89kg and 105.43kg respectively, were cattle by far emits more CH_4. Since complexity of livestock production systems and feeding diversity can make estimations of emissions practically complex. Hence, in Ethiopia, different mitigation options of enteric CH_4 emission should be practiced based on the feasibility, sustainability, economic and environmental benefits. Therefore, it is important to identify mitigation measures that are acceptable to implement and cost effective in order to strengthen the capacity of ruminant livestock raisers for the abatement of methane.

Key words: Enteric fermentation · Methane · Ruminant · Ethiopia · Greenhouse gas

INTRODUCTION

Climate change is a great worldwide environmental concern. Similarly, Ethiopia has shown a progressive strengthening of political resolve to address the problems associated with global warming, although agriculture globally and ruminant livestock production in particular, is a contributor to greenhouse gas (GHG) emissions. Ethiopia's agricultural sector is dominated by small-scale, mixed crop-livestockfarming, agro-pastoral and pastoral which is themainstay of livelihood that makes the sector to dominate the economic performance of the country's [1] largest production monetary value [2]. Reported Ethiopia is one of thelargestlivestock populations in Africa that provides incomeand a means of saving for the communities.

Ethiopia, Africa's largest livestock population: with the total of cattle, sheep and goat number estimated to be 52.13, 24.2 and 22.6 million respectively [3, 4]. Reported the country is continent's top livestock producer and

Corresponding Author: Girma Defar, Madawalabu University, Department of Animal and Range Sciences. P.O. Box 234 Bale-Robe, Ethiopia.

exporter with livestock population growing between 1998-2008 and cattle numbers rose by 40%, sheep 85% and goats more than 100%.

Ruminant livestock in different production systems have access to different types and quantities of feeds and therefore have different levels of production, excretion and emission of different quantities of GHGs. [5] noted that the spatial distribution of GHG produced by ruminants were vary considerably depending on their location since the diet varied and depends largely on agro-ecology and type of production system in which the animals kept in. Diet for rangeland based system in an arid region would base on grazing year round and mixed system have a more complex diet consisting of grazing, cut and carry forages, crop residue, roadside weeds and concentrates. These dietary differences are essential for the differences in CH_4 production between livestock production systems [5]. Enteric fermentation is a natural part of the digestive process for many ruminant animals where anaerobic microbes (methanogens) decompose and ferment feed present in the digestive tract producing compounds that absorbed by the host animal. A resulting by-product of this process is CH_4, which has a global warming potential of 25 times that of CO_2as described by [6] and 20-25% by [7]. The same author indicated nations that have agrarian economies with large ruminant populations have much emission levels relatively. Since digestion process is not 100% efficient, some of the feed energy is lost in the form of CH_4 which is estimated to be 7-10% [8], 3.5-7.5% [9] and 2-12% [10]of a ruminant's gross energy intake to be lost to enteric fermentation.

According to [2], Ethiopia's methane emissions have been growing in the last fifteen years. Based on the most recent international data Ethiopia's CH_4 emissions were about 52Mt CO_2-eq, which has been increased by 25% in the last fifteen years from 39Mt CO_2-eq. We know that livestock produce significant amounts of GHG. But how much remains somewhat contentious with the estimated contributions of livestock to global emissions ranging from 10-51%, depending on who is doing the analyses [11]. The reason is that livestock production levels in developed countries are holding steady compared to developing countries particularly in the emerging economies, which are rapidly changing to meet a growing demand for livestock products due to population increase [11]. Therefore, the objective of this paper is to review enteric CH_4 emission from domestic ruminants, contribution to greenhouse gas and mitigation opportunities to Ethiopian context.

Domestic Ruminant Methane Emissions in Ethiopia: Sources of Methane Emissions: Anthropogenic processes were responsible for about 55-70% of CH_4 that released annually into atmosphere with enteric fermentation a major contributor to emissions in a number of countries [7]. Methane released within the agricultural sector from paddy fields, livestock farming and the burning of agricultural wastes. Gastro-enteric fermentation is the main agricultural source of CH_4 with emissions from livestock manure accounting most agricultural CH_4 [12]. This reflects the fact that livestock farming goes together with high CH_4 emissions. The inter-relationship between climate change and livestock sector were important to explore for a reasons of which, the sector has recently blamed for contributing to global climate change than the automobile industry. At the same time, the sector is booming due to a surging global demand, which is closely linked to both economic growth and urbanization. In addition, livestock play a critical role in the livelihoods of many of the country's poor people acting as a source of both credit and savings in rural areas that are remote from financial services, providing food and cash income for the urban as well as the rural poor and for many people offering a route out of poverty [13].

Ethiopia's GHG emissions are dominated by agriculture, which contributes 80% of the total emissions of the country since the dominant position of livestock farming in Ethiopia's economy influences the relative contribution of GHG to the total emissions. These are dominated by CH_4 emissions that accounts for 80% of the warming potential [14]. Biological generation in anaerobic environments (natural and man-made wetlands, enteric fermentation and anaerobic waste processing) were the major sources of CH_4, though losses associated with coal and natural gas industries are also significant in different parts of globe. Methane emissions arising from ruminant livestock is entirely due to man with a continuing expansion of meat and dairy product consumption around the world and the country. Intensive rearing methods developed to provide large amounts of meat and dairy products at low prices and to a wide consumer base have led to high densities of ruminant livestock and local CH_4 sources. An additional, but important source of CH_4 due to ruminant livestock is the waste which is not reviewed in this paper. In general, poor quality feeds (roughages) which accessed easily to livestock producers' leads to higher CH_4 production due to rumen fermentation. However, higher quality feeds were responsible for GHG emissions through manufacturing process and transport [13].

Domestic Ruminants as Source of Methane: Domestic ruminants are the most important anthropogenic source of CH_4 emissions. Currently, about 55-70% of CH_4 emissions result from anthropogenic activities globally [15]; with studies suggesting that ruminant eructation is one of the anthropogenic sources. Their contribution to the CH_4 budget of different countries varies significantly depending on land use patterns, waste management, feed composition and others [16]. Study by [5] found emissions for year 2000 were 7.8 million tons of CH_4, with cattle contributing over 80% of the total emission. In line with this, [16] reported emission from African domestic ruminants is estimated to be 11.6million tons for year 2004 which showed 3.8million tons in four years. They estimated that this equates to a contribution of about 13% to the global CH_4 emissions from enteric fermentation. Different factors that affect CH_4 production in ruminant animals are: the physical and chemical characteristics of the feed, the feeding level and schedule, the use of feed additives to promote production efficiency and the activity and health of the animal. It has been suggested that there may be genetic factors that affect CH_4 production, of which feed characteristics and feeding rate have the most influence for ruminants [17].

Ruminant animals have a unique digestive system, which enables them to eat plant materials and produce CH_4, a potent GHG that contributes to global climate change. Ruminant animals have a "rumen" a large fore-stomach with a complex microbial environment [7] which allows the animals to digest complex carbohydrates that non-ruminant animals cannot digest and a natural component of this process creates CH_4. Ruminants produce much more CH_4 per head than non-ruminant animals, with the rumen being responsible for 90% of the CH_4 from enteric fermentation in a ruminant. Larger ruminants like buffalo and cattle produce greater amounts of CH_4 than smaller ruminants because of their greater feed intake [18]. Typically, more than 80% of the CH_4 is produced in the rumen and the rest in the lower digestive tract [9]. Livestock produce CH_4as a by-product of digestion of structural carbohydrates by the bacteria, fungi and protozoa contained in the rumen [12] where poor quality forage leads to higher CH_4 production. During this digestion, mono-saccharides fermented to Hydrogen, CO_2 and volatile fatty acids. At this stage of ruminant digestion some of the microbes (methanogens) produce CH_4[19]. Methane lost may be up to 15% of the gross energy of feed intake and understanding diet manipulation to reduce CH_4 emissions has been recognized to have economic implications [20].

The loss of CH_4 from ruminant livestock is a problem not only in respect of GHG emissions, but feed converted into and released as CH_4 is a feed not being converted into meat and/or milk. The composition of the animal feed is a crucial factor in controlling the amounts of CH_4 produced. According to [5], the estimated average CH_4 emission factor for African domestic ruminants is 31.1kg CH_4 per year per TLU, which is similar to the value of 32kg CH_4 per yearestimated by [21]. However, they range from 21-40kg CH_4 per year per TLU depending on the type of production system, feed, sex and age of the animal, physiology of the animal and ecological zone. The largest emission factors were found in the more intensive mixed rain-fed systems, especially in the humid and temperate regions where intakes, diet quality, diversity and productions are higher. All rangeland grazing systems and mixed arid systems exhibited lower emission factors [5], which is a result of the lower intakes observed in the dry season due to lack of forage availability.

Contribution of Methane to Greenhouse Gas: The atmospheric concentration of CH_4 has increased dramatically over the last century and continues to increase. The concentration of CH_4, the most abundant organic trace gas in the atmosphere has increased dramatically over the last few centuries more than doubling its concentration. The increasing concentrations of CH_4 are of special concern because of its effects on climate and atmospheric chemistry. On a per molecule basis, additional CH_4 is much more effective as a GHG than additional CO_2[22]. The global average atmospheric concentration of CH_4 were 1750ppbv (parts per billion by volume) which is more than double of its pre-industrial value of 700 ppbv [22]. Theconcentration of CH_4 in the atmosphere is thought to be increasing at a rate of 22Mt per year, due to the imbalance between estimated annual global emissions of 598Mt and removals of 576 Mt. Ruminants were responsible for much larger shares of some GHGs with far higher potential to warm the atmosphere. The sector emits 37% of anthropogenic CH_4 (23 times the global warming potential of CO_2) mostly from enteric fermentation by ruminants. Moreover, CH_4 is the second most important GHG as once emitted remains in the atmosphere for approximately 9-15 years.

The rising concentration of CH_4 correlates with increasing population and currently about 55-70% of CH_4 production arises from anthropogenic sources and the remainder is from natural sources. Since atmospheric CH_4 is increasing at a rate of about 30-40 million tons per year, stabilizing global CH_4 concentrations at current levels would require reductions in CH_4 emissions or increased sinks for CH_4 of approximately the same amount [23]. For African domestic ruminants [5] estimated total CH_4 emissions from cattle, sheep and goats at 7.8 million tons per year for the year 2000; with cattle producing 84% of the total CH_4 which implies that it requires intensive concern for the abatement of its impact on global warming.

Methane Emission and Mitigation Opportunities: Mitigation is a human intervention to reduce the sources or enhance the sinks of GHG. Thus, it is the way to reduce the magnitude of emission in the long term that contributes to global warming. A number of CH_4 emission mitigation strategies have been proposed and ranges from diet manipulation, feed additives inclusion in the diet, rumen micro-flora modifications, changes in market structures of animal products and by-products and others [24]. Here the question is: Can Ethiopia engages in reducing CH_4 emissions from livestock? Yes, the most relevant option for Ethiopian livestock producers seems to be through improvements in the quality of the diet of ruminants that could reduce CH_4 production per unit of intake as mentioned by [25] for African livestock. The magnitudes of these improvements are likely to be modest in relation to the large effects that the increasing livestock populations have on the CH_4 emissions.Reducing CH_4 emissions from ruminant livestock is technically challenging and has to be achieved against a rising demand for animal products. Estimating the contribution of CH_4 emissions from ruminant livestock to total agricultural GHG emissions is problematic due to the diversity of sources and limited data. Successful mitigation of ruminant CH_4emissions is challenging technically [26] but is made even more difficult because of the rising demand for milk and meat. A further challenge is that even if technical solutions are available the solutions need to be practical to implement and viable if they are to be adopted by farmers.

The complexity of different livestock production systems and feed diversity can make estimations of emissions practically complex. To date few studies have been undertaken to determine the importance of production systems and feed management-related differences in CH_4 emissions and in relation to farming system to the continent. It is important to identify mitigation measures that are easy to implement and cost effective in order to strengthen the capacity of local actors to adapt to climate change. Although the Ethiopian livestock sector does not contribute significantly to global climate change, there are options for mitigation of climate change that may provide incentives for improved livestock production where the options include different methods for reducing rumen emissions and improving waste management by rangelands [13]. Therefore, measures to mitigate enteric fermentation not only to reduce emissions, but raise animal productivity through increased digestive efficiency that has better economic implication [8] for livestock producers.

Mitigation Options to Ethiopian Context: Livestock provides a means of producing food on approximately one third of the earth's land surface and perhaps over half of the African land-mass were not feasible for other form of food production [13]. Ruminants transform forages that are useless to other livestock and humans into food for human consumption those living on marginal lands where livestock keeping is the only livelihood option. According to [13], options for mitigating climate change should be linked to local contexts such as eliminating unproductive animals, increasing the overall efficiency of productivity, selection of more productive breeds in line with improving rangelands through improved pasture management, reforestation and tree protection. Increasing feed efficiency and improved digestibility of feed intake were potential ways to reduce CH_4 emissions and maximize production and gross efficiency, as it lowers number of animals raised. Livestock practices such as genetics, nutrition, reproduction, health and dietary supplements and proper feeding could result in improved feed efficiency and needs to be taken into account. The volume of feed intake is related to the volume of CH_4 produced according to the report of [27], the higher the proportion of concentrate in the diet is, the lower the emissions of CH_4 from enteric fermentation. Several studies have formulated abatement strategies to mitigate CH_4 emissions. Mitigations aimed at enteric fermentation may be addressed at three different levels: dietary changes, direct rumen manipulation and systematic changes [28]. The dietary changes involve measures which enhance the efficiency of feed energy use that is an area which has potential implications for forage use in the future to increase productivity.

The concept of increasing animal productivity to reduce CH_4 emissions from ruminants is based on the maintenance of overall production output and as a result, increased production of useful product would mean CH_4 production per unit product would decline. A reduction in total emissions of CH_4 would only result if total outputs (milk or meat) remained constant and livestock numbers were reduced. Affordable possible option [23] to increase productivity of the animal is to determine the type of diet. The forage to concentrate ratio of the ration has an impact on the rumen fermentation and hence the acetate to propionate ratio declines proportionally with forage to concentrate ratio. It would therefore be expected that CH_4 production would be less when high concentrate diets are fed in which passage rates are increased, ruminal pH lowered and certain populations of protozoa, rumen ciliates and methanogenic bacteria may be eliminated or inhibited [29; 30].

Short Term Opportunities: Reducing animal numbers is an obvious way to reduce emissions, although one that may not be acceptable to many smallholders. In addition, increasing productivity per animal will reduce emissions per unit of product due to a smaller proportion of the feed consumed being needed for maintenance. Systematic changes involve identifying animal breeds which result in a reduction of CH_4 output per animal, though so far no clear evidence has been found [31]. Increasing productivity per head or increasing the number of lactations for which the average cow remains economically productive (optimizing the lifetime efficiency of the milking cow) would decrease CH_4 production per unit of milk. In short term mitigation opportunities already identified by researchers have limited applicability for grazing ruminants or they involve actions that may adversely affect profitability of farmers unless high productive animals are available.

Supplementing poor quality forages and chemically upgrading them are good options for increasing productivity and in turn reducing CH_4 emissions per unit product. Reductions of total emissions would only result if livestock numbers are reduced correspondingly [23]. Feeding of ruminants to optimize rumen and animal efficiency become a developing area and the efficient deployment of this information to all livestock producers would benefit the environment in terms of both CH_4 and nitrogen emissions. This would lead to best practice information and would require good technology transfer. Many farmers within the EU have to pay for unbiased nutritional advice. If this advice was freely available, there would likely be an increase in productivity and an improvement in the impact of emissions from livestock into the environment [23]. Early research demonstrates that increasing animal intake of dietary oils helps to curb enteric fermentation and increase yields by limiting energy loss due to fermentation. These oils appear to be a viable option because they can be easily substituted into animal diets. A study by [32] found that increased dietary oils could mitigate emissions from enteric fermentation with a 1% increase in dietary oils, CH_4 emissions decreases by 6%. As part of this study, whole cottonseed was introduced into the diet of dairy cattle and observed to reduce CH_4 emissions by around 12% and increase milk yield by about 15%. Furthermore, study conducted by [33] found that the introduction of sunflower oil abated CH_4 emissions by 22%.

Advanced Mitigation Options of Methane Emission (Medium to Long Term): Methods to mitigate enteric fermentation emissions are still in development and need further research, but early studies looking at potential mitigation options have yielded some promising results. Most research has focused on manipulating animal diet in an effort to inhibit a rumen environment favorable to methanogens. Alternatively, changing type of fermentation taking place by switching ruminants from cellulose to a starch-based diet favors the increases of fermentation while still decreasing levels of CH_4 production [33].

Medium Term Opportunities: Although rumen modifiers are available now a more realistic appraisal is that they hold promise for the future not the present since these products have been developed with productivity increases in mind rather than CH_4 reduction. However, this could change if there is a price on CH_4 which would generate co-benefits for the commercial manufacturers of such products. A reduction in CH_4 production is expected when the residence time of feed in the rumen is reduced since ruminal digestion decreases and methanogenic bacteria are less able to compete in such conditions. Furthermore, a rapid passage rate favors propionate production and the relevant hydrogen use.

According to [34] and [35] a 30% decline in CH_4 production is observed when the ruminal passage rate of liquid and solid phase increased by 54-68%.According to the study by ILRI, livestock-related GHG reduction could be quickly achieved in tropical countries by modifying production practices such as switching to more nutritious pasture grasses, supplementing diets with even small amounts of crop residues or grains, restoring degraded grazing lands, planting trees that trap carbon and produce leaves that to animals and adopting more productive breeds [11]. For example, in Latin America, they note that switching cows from natural grasslands to pastures sown with a more nutritious grass called Brachiaria can increase daily milk production and weight gain by up to three-fold.

Table 1: Total number of ruminant category in terms of Tropical Livestock Unit (TLU) in Ethiopia.

Animal species	Total number (millions)	Conversion factor*	TLU (millions)
Cattle	52.13	0.7	36.491
Sheep	24.2	0.15	3.63
Goat	22.6	0.15	3.39

* = according to [39]

Table 2: Estimated CH_4 emission through enteric fermentation of Ethiopian domestic ruminants

Animal type	TLU	Average CH_4 emission (kg) per TLU per year	Total CH_4 emission per year
Cattle	36.491	31.1kg	1134.87kg
Sheep	3.63	31.1kg	112.89kg
Goat	3.39	31.1kg	105.43kg

Table 3: Main routes for reducing enteric CH_4 emissions from ruminant livestock

Short term	Medium term	Long term
-Reduce animal numbers	-Rumen modifiers	-Targeted manipulation of rumen ecosystem
-Manipulate diet	-Plants with low CH_4 yield	-Breed animals with low CH_4 yield
-Increase production per animal		
-Rumen modifiers		

Source: [26]

They said this increase indicates fewer animals are needed to satisfy demand. In line with ILRI news report by USDA [36] suggested the following: 1) increasing digestibility of forage feed makes feed digestion more efficient, 2) using feed additives to tie up hydrogen in the rumen because hydrogen in the rumen is an important intermediate product to produce CH_4, 3) inhibiting rumen bacteria (methanogens) that produce CH_4, 4) enhancing rumen microbes to produce usable substrate than CH_4 and 5) improving production efficiency of products to reduce animal number.

Long Term Opportunities: The targeted manipulation of the rumen ecosystem provides the best hope for mitigating enteric CH_4 emissions and perhaps the biggest challenge. Developing vaccines which stimulate ruminants to produce antibodies against their rumen methanogens may be feasible in principle [37], but the successful development of a vaccine is still a long way off even in developed nations. Additionally, breeding animals with improved feed conversion efficiency and with low emissions per unit of feed consumed takes time. The best studied and applied CH_4 reduction strategy has been that of altering the feed composition, either to reduce the percentage which is converted into CH_4 or to improve animal product. Improvements in the overall quality of animal feed may allow meat and dairy production to be maintained at the same level with fewer animals and so less total CH_4 emission. Relatively recent ruminant CH_4 reduction strategies have included introduction of CH_4 inhibitors both biological and chemical, with the animal feed to kill or at least reduce the activity of the methanogenic microorganisms in the gut.

Current assumptions introduce other options to combat enteric fermentation like genetic engineering and the use of additives. The use of the antibiotic monensin was examined by [33] but its use did not significantly reduce CH_4 emissions and questions remain about the permanence of these reductions. Studies have also been conducted examining the potential for genetic engineering aimed at increasing the efficiency of feed conversion to biomass which would also reduce enteric fermentation within animals. One recent study laid the groundwork for breeding cattle that would have 25% less CH_4 emissions and require less feed [38]. According to [7] another option is to reduce the consumption of ruminant animals and their products, but this would involve changes in consumer behavior and preferences that are unlikely to take place in the near future.

Generally, CH_4 mitigation strategies in ruminants have focused to obtain economic as well as environmental benefits. Some mitigation options such as chemical inhibitors, defaunation and ionophores inhibit methanogenesis directly or indirectly in the rumen, but they have not confirmed consistent effects for practical use. A variety of nutritional modifications such as increasing the amount of grains, inclusion of leguminous forages containing condensed tannins and ionophore compounds in diets, supplementation of low-quality roughages with readily fermentable carbohydrates and addition of fats show promise for CH_4 mitigation [10].

CONCLUSIONS

As climate change is a subject of worldwide environmental concern, Ethiopia has also shown a progress to address the problems associated with global warming, although globally livestock agriculture is a contributor to GHG emissions. Ruminant livestock in different production systems have access to different types and quantities of feeds which allow them to different levels of GHG emission as of physical and chemical characteristics of the feed, feeding level and schedule, use of feed additives to promote production efficiency and health of the animal. During digestion methanogenic bacteria decompose and ferment feed present in the digestive tract producing CH_4, which has a global warming potential of 23-25 times that of CO_2. Based on the most recent international data Ethiopia's CH_4 emissions are about 52Mt CO_2-eq which has been increased by 25% in the last fifteen years from 39Mt CO_2-eq.

Different researchers reported poor quality roughages feeds which accessed easily to livestock producers' in Ethiopia leads to higher CH_4 production due to rumen fermentation.According to [5], the estimated average CH_4 emission factor for African domestic ruminants is 31.1kg CH_4 per year per TLU. Based on this information, domestic ruminants in Ethiopia mentioned cattle, sheep and goat emits about 1134.87kg, 112.89kg and 105.43kg respectively. The result indicated that cattle were by far more CH_4 emitter compared to sheep and goat which is due to their large body size, more feed intake and large number of population in Ethiopia. Multifaceted of production systems and feed diversity make estimations of emissions complex. However, different mitigation options of CH_4 emission from ruminants which are classified as short, medium and long terms based on the feasibility, sustainability and able to focus on economic as well as environmental benefits.

The concept of increasing animal productivity to reduce CH_4 emissions from ruminants is based on the maintenance of overall production output and as a result, increased production of useful product that declines CH_4 per unit product. The concentrate to roughage ratio of the ration has an impact on the rumen fermentation and hence the acetate to propionate ratio declines inversely with concentrate to roughage ratio increment. Generally, cost-effective and environmentally friendly mitigation options are those which combine practices which deliver reduced GHG emissions with different environmental, animal-welfare and economic or production-related benefits. Therefore, it is important to identify mitigation measures that are acceptable to implement and cost effective in order to strengthen the capacity of local actors to adapt to climate change.

REFERENCES

1. Deressa, T.T., R.M. Hassan and C. Ringler, 2008. Measuring Ethiopian farmers' vulnerability to climate change across regional states, IFPRI Discussion Paper No.806, http://www.ifpri.org/pubs/dp/
2. Global Methane Initiative, 2011. Ethiopia methane emissions from agricultural waste country resource assessment. Prepared by Community Development Research, October 2011.
3. CSA (Central Statistical Authority) 2012. Agricultural sample survey: Livestock and Livestock characteristics, Bulletin 532, Volume II, CSA, Addis Ababa, Ethiopia.
4. Mia, 2010. Climate, Food Security, Welfare and Rights: Ethiopia's Livestock Sector. Africa Animal Welfare Action (AAWA) Conference KBC Leadership Centre, Nairobi, Kenya. www.brightergreen.org
5. Herrero, M., P.K. Thornton, R. Kruska and R.S. Reid, 2008. Systems dynamics and the spatial distribution of methane emissions from African domestic ruminants to 2030. Agriculture, Ecosystems and Environment.126(1-2):122-137.http://mahider.ilri.org/handle/10568/1517
6. Wood, C., 1998. Global Climate Change and Environmental Stewardship by Ruminant Livestock Producers. National Council for Agricultural Education.
7. Thorpe, A., 2009. Enteric fermentation and ruminant eructation: the role and control of methane in the climate change debate. Numbers 3-4, Berlin: Springer Netherlands, Vol. 93.
8. Moss, A.R. and D.R. Givens, 1993. Effect of supplement type and grass silage: concentrate ratio. Proceeding of British Society of Animal Production. Paper, pp: 52.
9. O'Hara, P., J. Freney and M. Ulyatt, 2003. Abatement of agricultural non-carbon dioxide greenhouse gas emissions. A study of research requirements. Ministerial Group on Climate Change, the Minister of Agriculture and the Primary Industries Council. May 2003, New Zealand Ministry of Agriculture and Forestry, Wellington. 171. www.govt.nz/publications.
10. Patra, A., 2012. Enteric methane mitigation technologies for ruminant livestock: a synthesis of current research and future directions. Environmental Monitoring and Assessment, 184 : 4.
11. ILRI News, 2011. Achieving food security in the face of climate change: Summary for policy makers from the commission on sustainable agriculture and climate change.
12. Hokins, A. and A. Del Prado, 2007. Implications of climate change for grassland in Europe: impacts, adaptations and mitigation options: a review. Grass and Forage Science, 62: 118-126.

13. IUCN (International Union for Conservation of Nature), 2010. Building climate change resilience for African livestock in sub-Saharan Africa. World Initiative for Sustainable Pastoralism (WISP): a program of IUCN, Eastern and Southern Africa Regional Office, Nairobi, March 2010.
14. Marius, K., 2009. Climate risks and development projects assessment report for a community-level project in guduru, Oromiya, Ethiopia. Bread for all, November 2009.
15. IPCC, 2001. Climate change 2001: the scientific basis, contribution of working group I to the third assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge.
16. Steinfeld, H., P. Gerber, T. Wassenaar, V. Castel, M. Rosales and C. De Haas, 2006. Livestock's Long Shadow. Environmental Issues and Options. LEAD-FAO (Food and Agriculture Organization), Rome, Italy, pp: 390.
17. State Workbook, 1995. Methodology for Estimating Greenhouse Gas Emissions, EPA 230-B-92-002, US Environmental Protection Agency, Office of Policy, Planning and Evaluation, Washington, DC.
18. Johnson, D.E., 2000. Ruminants and other animals. In: Kahlil (ed) Atmospheric methane: its role in the global environment. Berlin: Springer, 2000.
19. Hopkins, A., 2000. Herbage production in grass: its production and utilization. Oxford: Blackwell Science.
20. Blaxter, K.L. and J.L. Clapperton, 1965. Prediction of the amount of methane produced by ruminants. British Journal of Nutrition, 19: 511-522.
21. IPCC (Intergovernmental Panel on Climate Change), 1996. Climate change: impacts, adaptations and mitigation of climate change: Scientific-Technical Analysis. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Watson, R.T., Zinyowera, M.C. and Noss. Cambridge University Press, Cambridge.
22. Donald, J.W. and H. Katharine, 2002. Atmospheric methane and global change. Elsevier, Earth-Science Reviews, 57(2002): 177-210.
23. Angela, R.M., J. Pierre and N. John, 2000. Methane production by ruminants: its contribution to global warming. ADAS Nutritional Sciences Research Unit, Alcester Road, Stratford Up on Avon, Warwickshire CV37 9RQ, UK.
24. EPA (Environmental Protection Agency), 1999. US methane emissions 1990-2020: Inventories, projections and opportunities for reductions. EPA Publication 430-R-99-013. US EPA Office for Air and Radiation, Washington, DC. http:// www.epa.gov/ methane/projections.html
25. Braatz, B.V., S. Brown, A.O. Isichei, E.O. Odada, R.J. Scholes, Y. Sokona, P. Drichi, G. Gaston, R. Delmas, R. Holmes S. Mous, R.S. Muyungi, A. de Jode and M. Gibbs, 1995. African greenhouse gas emission inventories and mitigation options: forestry, land use change and agriculture. Environ. Monitory Assess, 38: 109-126.
26. Clark, H., 2009. Methane emissions from ruminant livestock; are they important and can we reduce them? Proceedings of the New Zealand Grassland Association, 71: 73-76.
27. IFAD, Livestock and climate change: livestock thematic papers and tools for project design. www.ifad.org/lrkm/index.htm.
28. Jarvis, S.C., 2001. Cost curve analysis of mitigation options in greenhouse emissions from agriculture. Final report to MAFF (UK) on Project CC0229.http:// www2.defra.gov.uk/research/project_data/default.asp
29. Church, D.C., 1988. The ruminant animal: Digestive Physiology and Nutrition. Prentice Hall, Englewood Cliffs, New Jersey, pp: 269-297.
30. Moss, A.R., D.I. Givens and P.C. Garnsworthy, 1995. The effect of supplementing grass silage with barley on digestibility, In-Sacco degradability, rumen fermentation and methane production in sheep at two levels of intake. Animal Feed Science Technology, 55: 9-33.
31. Weiske, A., A. Vabitsch, J.E. Olesen, K. Schelde, J. Michel, R. Friedrich and M. Kaltschmitt, 2006. Mitigation of greenhouse gas emission in European conventional and organic dairy farming. Agriculture, Ecosystems and Environment.
32. Grainger, C., T. Clarke, K.A. Beauchemin, S.M. McGinn and R.J. Eckard, 2008. Effect of whole cottonseed supplementation on energy and nitrogen partitioning and rumen function in dairy cattle on a forage and cereal grain diet. Australian Journal of Experimental Agriculture, 48: 860-865.
33. McGinn, S.M., K.M. Beauchemin, T. Coates and D. Colombatto, 2004. Methane emissions from beef cattle: Effects of monensin, sunflower oil, enzymes, yeast and fumaric acid. Journal of Animal Science. American Society of Animal Science. http://jas.fass.org/cgi/content/full/82/11/3346

34. Kennedy P.M. and L.P. Milligan, 1978. Effects of cold exposure on digestion, microbial synthesis and nitrogen transformation in sheep, British Journal of Nutrition 39 (1978): 105.
35. Okine, E.K., G.W. Mathison and R.T. Hardin, 1989. Effects of changes in frequency of reticular contractions on fluid and particulate passage rates in cattle. Journal of Animal Science, (67): 1989.
36. USDA (US Department of Agriculture), 2004. US agriculture and forestry greenhouse-gas inventory 1990-2001. Global Change Program Office, Office of the Chief Economist. Tech. Bull. No 1907.
37. Wright, A.D., P. Kennedy, C.J. O'Neill, A.F. Toovey, S. Popovski, S.M. Rea, C.L. Pimm and L. Klein, 2004. Reducing methane emission in sheep by immunization against rumen methanogens. Vaccine 22: 3976-3985.
38. Britten, N., 2009. Cows that burp less methane to be bred. UK Telegraph.
39. Jahnke, H.E., 1982. Livestock production systems and livestock development in tropical Africa. Wissenschaftsverlag Vauk, Kiel, Germany.