A review on N_2O Emission and its Mitigation Strategies in Livestock

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Abstract : N_2O emissions from livestock indicate that emission intensities from livestock are medium to high in poor countries owing to low animal productivity, low feed quality, lack of knowledge, and limited investments. There are differences among developing countries in animal gas emissions in the same continent or region, indicating that improvements are possible. Mitigation tools to reduce CH_4 and N_2O emissions that are used in industrialized countries are not always applicable to developing countries. Developing countries must use the mitigation tools adaptable to their conditions, considering the costs, knowledge, applicability, and local legislation. In the future, interdisciplinary research should focus on the integration of livestock emissions at country level and sustainable mitigation and adaptation tools that could be applied at local levels.

Key word: GHGs-Greenhouse gases, N_2O- Nitrous Oxide, CO_2- carbon dioxide

Introduction

In developing countries, the numbers of livestock animals are rising to respond to the growing demand for food. Inefficiencies in the livestock systems and low investments in the sector cause the rapid increase of greenhouse gases (GHGs) emitted in the atmosphere (Scholtz *et al.* 2013a). The list of gases that are considered the main sources of global warming includes carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other GHGs. At global level, livestock emits in the atmosphere 18% of the total anthropogenic emissions of GHGs. livestock activities contribute substantially to the emission of N_2O, accounting for almost two thirds of all anthropogenic N_2O emissions and 75 to 80% of agricultural emissions (Steinfeld *et al.* 2006). The production of N_2O vary depending upon the weather, time, species, housing, manure handling system, feed type and management system.

N_2O Emission

In the nitrogen (N) cycle the vast majority, 98% of the earth's nitrogen, is locked away in the lithosphere, 2% is in the atmosphere (the air we breathe is 78% N gas) and only 0.2% in the soil. It is this 0.2% that is the primary driver of the biochemical nitrogen cycle, and it is the movements of nitrogen in the soil that can give rise to N_2O emissions.

The nitrous oxide is formed by nitrifying bacteria in two processes.

1. Nitrification takes place under aerobic conditions, Nitrification progresses under aerobic conditions where ammonium is first oxidised to nitrite, and nitrite is then converted to nitrate with N_2O as a by-product The nitrification process occurrs in animal housing mainly in the surface layer of the manure [Montes *et al.* 2013].
2. Denitrification occurs under anaerobic conditions. Denitrification is a series of microbial reactions during dissimilated NO_2^- reduction when the oxygen (O_2) supply is limited. the formation of N_2O proceeds during incomplete nitrification/denitrification processes that normally convert NH_3 into non-polluting N_2. If conditions are suboptimum and these processes do not run to completion, the air-polluting volatile intermediates N_2O (nitrous oxide) and NO (nitric oxide) are emitted [Groenestein *et al.* 1996, Pahl *et al.* 2001, Wolter *et al.* 2004].

The ratio of denitrification N conversion to N_2O revealed nitrification as the major N_2O producing process at all sites. Predictors of temporal changes in N emissions include nitrate, pH and temperature, indicating the heterogeneity of management The N_2O production during denitrification is promoted by the presence of NO_3^-, N_2O reductase activity, heterotrophic bacteria, reductants such as organic carbon, lack of oxygen and low availability of degradable carbohydrates, while it is also affected by pH, moisture content, soil porosity, amount of solids, under soil and climatic factors [Li *et al.* 2015, McGahan, 2016].

Animal production systems transform animal feed (carbohydrates, protein) into milk, meat and eggs, and into dung and urine. Only a small fraction (5–30%) of the N in animal feed is retained in milk, meat and eggs, depending on animal type and management. The greater part (70–95%) is voided by the animals via urine and dung ie the barns or housing and pasture

Housing

Dairy cattle housing facilities produce twice as much N_2O emissions than piggery facilities (per 500 kg LBW) Sneath *et.* [1997]. Most of these N_2O losses depend on a variety of factors, including surface conditions of open-lot dairy or beef feedlot facilities. Manure management practices on farms vary, but usually pens are cleaned several times a week or after the turnings, which creates conditions for emissions off the pen surface or barn floors [Eckard *et al.* 2003] .Barn floors and hard standings, surfaces which were scraped or flushed frequently, generally release low N_2O emissions (0.03 kg.d-1.yr-1, 0.0004 kg.d-1.yr-1) Owen and Silver [2015]. According to Leytem *et al.* [2010], open lot areas generate the greatest emissions of N_2O, contributing 57%, respectively, to total farm emissions. Higher manure density observed with sawdust may impair the composting process, which normally increases manure temperature and promotes air exchange through the compost heap. Consequently, NH_3 emissions are reduced, which increases the amount of ammonium available for non-thermopilic nitrifying bacteria, with higher N2O emissions released as a consequence [Sommer 2001, Hansen *et al.*2006].

In a deep-litter housing system, animals are kept on a thick layer of a mixture of manure with sawdust, straw or wood shavings. In this system microbial processes are stimulated to enhance composting processes, nitrification (aerobic conditions) of NH_3 and denitrification (anaerobic conditions) of nitrate [Groenestein *et al.* 1996]. Deeplitter bedding is associated with high greenhouse gas production (+125% compared to slatted floor) and slurry composting on straw is associated with high NH_3 emission (+15% compared to slatted floor) [Rigolot *et al.* 2010].

Groenestein *et al*. [1996] showed increasing N_2O emission with decreasing O_2 concentration in the straw bed, indicating that N_2O is mainly produced in the course of nitrification. Also, it appears that deep-litter systems emit more N as NH_3 and that air-polluting nitrogen gases were not reduced with traditional housing systems. This leads to the conclusion that deep-litter systems are not recommended [Groenestein *et al.* 1996]. Chadwick *et al.* [1999] showed that dairy cattle housing with slurry-based systems have significantly lower N2O emissions than dairy housing that used straw bedding.

The relatively large net N_2O flux from liquid manure storage is associated with the predominantly anaerobic conditions typical of unaerated systems. Nitrogen in liquid manure is mostly found in the form of ammonium and organic N, and while anaerobic lagoons are as a rule anaerobic, aerobic conditions which could promote denitrification exist at inlets. Other N_2O formation reactions are also possible, such as denitrification of nitrate (NO_3-) produced through anaerobic NH_4+ oxidation [Maeda *et al.* 2010, Owen and Silver, 2015].

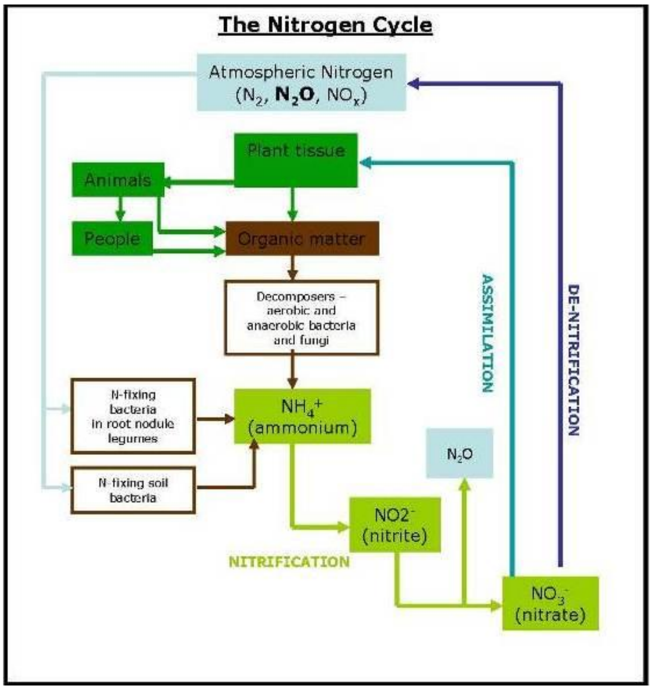
Feed and pasture

Animal feeding operations are an important source of pollutants affecting air quality due to nitrous oxide (N_2O) and nitric oxide (NO) emissions [Li *et al.* 2012]. Dietary lipids also may increase manure emissions either through reduced ration digestibility or increased N contents (if lipids are supplied from oil cakes rich in CP [Hristov *et al.* 2013]. Nitrates can possibly increase N emissions as their addition to the ration may lead to increased urea amounts excreted in urine.

In grazed pasture systems, a major source of N_2O is nitrogen (N) returned to the soil in animal urine [Bhandral *et al.* 2003a]. The N excreted by sheep and cattle onto grazed pastures provides high, localised concentrations of available N and C in soils, and is the main source of anthropogenic N_2O emissions [Saggar *et al.* 2004a,b] along with denitrification [Ball *et al*. 1997].

Denitrification losses increased with temperature in pastures treated with cattle slurry, while N losses from pastures treated with farmyard manure remained unaffected by temperature. Large emissions were detected immediately following cow urine application to pasture.

The management and fate of the animal manure determines the emission of N_2O from animal production systems. Most of the N_2O originates from microbiological transformations of N in the animal excrements urine and dung during storage and management and following application or deposition to land. Nitrifiers and denitrifiers are the principal producers of the gas. Nitrifying microorganisms produce N_2O by nitrification and by nitrifier denitrification. In nitrification, N_2O develops during the oxidation of hydroxylamine (NH_2OH) and In nitrifier denitrification, nitrifiers reduce nitrite (NO_2) via N_2O to dinitrogen (N_2). It is supposed to be similar to denitrification, where nitrate (NO_3) and NO_2 are reduced via nitric oxide (NO) and N_2O to N_2 (It could be a significant source in animal production systems, as animal production systems create lots of opportunities for partial anaerobiosis, which is suggested to favour nitrifier denitrification and denitrification processes. In denitrification, N_2O is an intermediate, which may escape when the rate of N_2O production and the rate of N_2O consumption differ. The amount of N_2O released from denitrification depends on the absence of molecular O_2 and the presence of NO_3 and metabolizable organic carbon.



In addition to these microbiological sources, N_2O can be formed chemically in reactions involving NO_2 (which is first produced biologically) under acidic conditions. This process is also called ‘chemodenitrification’, and some studies have shown this to be a predominant source of N_2O under specific conditions. Because of this multitude of sources and environmental controls, which are only partly manageable, N2O emissions from animal production systems have a highly stochastic nature.

Estimating N2O emissions

The IPCC methodology for estimating N_2O emission from high producing dairy cows in New Zealand, Western Europe and Northern America, milk production ranges between 5000 and 10,000 kg per head per year and the protein content of the animal feed ranges between 15 and 20%. This translates into an annual N excretion of 100– 160 kg per dairy cow, i.e. 3 times as high as the average for developing countries. At similar production levels, variations in protein consumption may cause annual N excretion per head of cattle to vary by a factor of roughly 2. Such large differences indicate that detailed regional differentiation in N excretion according to production level and animal ration will improve the accuracy of global N excretion estimates.

Two-third of the global N excretion by animals is voided in developing countries (Asia, Latin America, Africa and Oceania, excluding Australia and New Zealand,) and one-third in developed countries. Cattle account for almost 60% of the total N excretion. Non-dairy cattle (43%) are the single largest source, followed by dairy cattle (15%), sheep (12%) and pigs (9%). Approximately 40–50% of total N excretion is collected in barns, stables, sheds and corals, while the remainder is voided in pastures.

Nitrous oxide emitted from animal production systems is mainly produced from the N in animal waste. Four direct sources can be distinguished: –

1. Urine and dung from grazing animals in pastures;
2. Dung collected from pastures and paddocks for use as bio fuel;
3. Animal wastes from (temporarily) confined animals during storage and handling;
4. Animal wastes from (temporarily) confined animals following application to land.

In addition, there are indirect sources associated with N lost from animal wastes that enters other systems and is there subject to N_2O producing processes .

Emissions from urine and dung deposited by grazing animals in pastures Between 40 and 60% of the total amount of N excreted is voided in pastures, covering roughly 7% of the Earth's surface, which is twice the area of arable land (3%).

Efficient practices key to reducing emissions.

There is a direct link between GHG emission intensities and the efficiency with which producers use natural resources, i.e. the amount of natural resources engaged in animal production, per unit of edible or non-edible output. For livestock production systems, nitrous oxide, methane and carbon dioxide emissions are losses of nitrogen, energy and organic matter that undermine efficiency and productivity. Possible interventions to reduce emissions are therefore to a large extent based on technologies and practices that improve production efficiency at animal and herd levels.

For ruminants – cows, mainly -- the greatest promise involves improving animal and herd efficiency. This includes using better feeds and feeding techniques, which can reduce methane (CH_4) generated during digestion as well as the amount of CH_4 and nitrous oxide (N_2O) released by decomposing manure.

Improved breeding and animal health interventions to allow herd sizes to shrink (meaning fewer, more productive animals) will also help. And manure management that ensures recovery and recycling of nutrients and energy, plus the use of energy saving devices, also have a role to play.
Additionally, better management of grazing lands could improve productivity and create carbon sinks with the potential to help offset livestock sector emissions.

In monogastric production – primarily poultry and pig farming –"precision feeding," breeding, and better animal health care offer ways to reduce emissions due to feed production and manure management. Switching to feed sources whose production is less energy-intensive, and to more sustainable sources of power would allow additional cuts.

Mitigation Potential

There is currently a wide variability in production practices, even within similar production systems. This results in a large variation of emission intensity within those systems – what FAO calls "an emission intensity gap" between livestock operations that generate high emissions vs. those that put out low emissions per unit of product. FAO's new report estimates that partially reducing this gap within existing production systems could cut emissions by about 30 percent. Grassland carbon sequestration could further contribute to the mitigation effort by, with global estimates of about 0.6 GT CO_2 equ/year.

Key Policy Area for Action

Extension and agricultural support services: This suite of approaches facilitates practice change for mitigation and production enhancement, by providing access to good practices and technologies and building capacity to implement them. . Commonly used approaches include communication, training, demonstration farms and establishing producers' networks for knowledge sharing.
Research and development: R&D is necessary to build the evidence base for mitigation intervention and technologies. It is required to tailor adapted and effective mitigation strategies and plays an important role in refining existing technologies/practices to increase their applicability. R&D is also necessary for increasing the supply of new and improved mitigation technologies/practices.
Financial incentives: These include either 'beneficiary pays' mechanisms (abatement subsidies, carbon credit markets) or 'polluter pays' mechanisms (emissions tax, tradable permits). Economically efficient mechanisms for incentivizing the adoption of mitigation technologies/practices also include support (e.g. soft loans) to initial investments associated to the adoption of most efficient practices.

Market friction instruments: This includes measures that that seek to increase the flow of information about the emissions associated with different livestock commodities (e.g. labeling schemes). This can help consumers and producers to better align their consumption and production preferences with the emission profiles of these commodities.

Advocacy: Raising awareness about livestock's role in tackling climate change, to influence and promote mitigation policy development for the sector.

NAMAs: The development of Nationally Appropriate Mitigation Actions for livestock are national level processes through which countries can develop sectoral mitigation policies that integrate other development objectives, and seek international support towards their implementation.

International agreements: These include commitments, both within and outside the UNFCCC that provide high level incentives to mitigate livestock sector emissions and ensure that mitigation effort is shared between the different sectors of the economy.

Methane and nitrous oxide mitigation strategies from a livestock prospective:

The main aim of N_2O mitigation strategies involves actions that limit the magnitude of negative long-term effects of climate change. Mitigation generally involves reductions in livestock emissions (e.g. respiration and manure) and anthropogenic emissions linked with livestock activities (e.g. fodder production, crop processing, and manure distribution). Mitigation may also be achieved by increasing the capacity of carbon sinks, (e.g. through restoration of degraded soils, and reforestation) and through correct long-term sustainable policies that reduce the risks associated with human-induced global warming. However, mitigation strategies in developed countries are not always feasible and economically sustainable for developing countries. Here are discussed mitigation strategies for the reduction of N_2O emissions in livestock focusing on three areas: selection, feeding, and management.

Selection

In developing countries, measuring N_2O emissions directly from animals is not always feasible owing to high costs and the need for expensive infrastructure such as respiration chambers. In industrialized countries, genomic selection is a reality (Hayes *et al.* 2013), but in developing countries it is not yet disseminated (Scholtz et al., 2010). One of the major issues is the costs associated with the measurement of CH_4 and N_2O emissions and genotyping of a large sample of animals (reference population).

The great advantage of this method is that when the equations that predict genomic breeding values from SNPs (single nucleotide polymorphisms) are estimated on the reference population, they can then be used to predict genomic breeding values (GBV) for selection candidates based on their genotypes alone without the need to collect phenotypic data and with good accuracy of GBV. Alternatively, when direct measures of CH_4 and N_2O cannot feasibly be applied to enough animals to establish a reference population, genomic selection can be based on correlated traits such as dry matter intake and other proxies. While there is evidence that there are correlated and predictor traits for CH_4 and N_2O emissions, the current level of knowledge is insufficient to recommend their use in selection to reduce these gases. In developing countries, where genetic selection is already in place, CH_4 emission from enteric fermentation could be reduced by including in the total merit index (TMI) traits that reduce mortality (such as fertility, longevity, and animal health) and increase the number of productive animals (Meissner *et al*. 2013a). Thus, their feed requirements and gas emissions are diluted over this increased number of offspring. Furthermore, in those countries where protein for human consumption is a priority and productivity of animals is low, selection to increase the quantity of product per animal (e.g. meat, milk, eggs, and wool) should be maintained.

Genetic improvement of indirect traits, such as feed conversion efficiency, plays an important role in the reduction of emissions for all livestock species, and is particularly important in swine and chicken. genetic improvement of feed conversion efficiency reduces the total manure produced and consequently reduces the emissions of CH_4 and N_2O while maintaining productivity (Hristov *et al*. 2013a).

In dairy and beef cattle, In developing countries, where economic resources for selection are insufficient, N_2O emission reduction from enteric and manure fermentation can be achieved with the financial support of international donors (Arakelyan & Moran, 2015) and with the aggregation of countries that have similar selection interests. Aggregation of countries could reduce selection costs per country, increase the number of potential candidates, select for animals that have high performance (i.e., high productivity, low mortality rate, better health), and generate profit with the commercialization of genetic material (i.e. offspring, semen and embryos) of superior animals. Furthermore, the use of local genetic resources in poor countries with extreme environmental conditions (i.e. hot or harsh environments) represents a better solution than importing highly improved animals that cannot perform as expected because of environmental constraints (Boettcher *et al*. 2015). On the opposite side, for developing countries with an environment similar to Europe and North America, the use of exotic breeds (European and American) instead of local genetic resources could represent an efficient economic solution and have a positive effect on reducing GHG emissions. In intermediate climate conditions, such as South Africa, crossbreeding could be a sustainable solution to mitigating gas emission. In this country, 67% of feedlot cattle are crossbreeds from indigenous Sanga and exotic breeds aimed at increasing meat production and adaptability and reducing CH_4 emissions. The use of two-breed and three-breed crosses of indigenous and exotic breeds increases productivity owing to the heterosis effect and reduces the CH4 emission per unit of product (Scholtz *et al*. 2013b). However, it is important to ensure that the indigenous breeds are properly conserved (Boettcher et al., 2015) to guarantee the availability of purebred animals and provide sustainable food for local populations (Meissner *et al*. 2013b), In India and other developing countries, where, for religious reasons, cattle are not slaughtered, if available, the use of sexed semen could be a sustainable solution to reducing the number of unproductive cattle, and this technology could have the positive effect of reducing CH_4 and N_2O emissions (Hristov *et al*. 2013b). In developing countries, where genetically modified animals (GMA) are authorized, the use of environmentally friendly GMA is an option that should be investigated.

Feeding

In developing countries, an important mitigation option for livestock, in particular ruminants, is the utilization of forages of higher digestibility. This aspect is particularly important in those countries where the digestibility of forages in general is limited owing to high amounts of lignin because of incorrect management of agronomical practices. When the digestibility of forages increases, enteric fermentation and manure production are reduced, and consequently the emissions of CH_4 and N_2O decrease. For example, when legume silage replaces grass silage in the diet, because of the lower fibre content and the presence of high digestible organic nitrogen, N_2O emissions are reduced (Hristov *et al*. 2013a).

An effective mitigation strategy is to reduce the number of animals (keeping only the best animals) and provide feed with higher digestibility, reserving the low-quality feed for other purposes (e.g. bedding). This strategy would increase productivity and reduce CH_4 and N_2O emissions. However, this mitigation option is in conflict with the interests of smallholders, who want to have large unproductive herds for social and risk mitigation reasons. Regulatory measures (policy and quota systems), economic incentives (micro credits and loans in kind), and change in social behaviours (social disincentives) could reduce the benefits of keeping unproductive animals and support the intensification of livestock production (Udo *et al*. 2011; Haileslassie *et al*. 2016).

In a study in India, important mitigation measures for livestock are improving feed by adding digesters and CH_4 inhibitors and enhancing the number of crossbred animals that have lower CH_4 emissions per unit of production (Garg *et al*. 2011). In poor economies, urea is used extensively to improve low-quality feed. It is mixed with fodder (e.g. straws and crop residuals) at least one week prior to use. During this period ammonia is formed, which breaks the cell walls and allows the microorganisms in the rumen to metabolize the organic material in the cells, improving feed intake and digestibility. In addition, urea provides N, which improves the feed value (Dawit *et al.* 2015).

A good mitigation option, but less feasible in developing countries, is the use of concentrate feeds in the animal's diet. Concentrates are rich in lipids (oils) and other substances with high levels of energy (e.g. cereal grains). The inclusion of concentrate feeds in the diet of ruminants and nonruminants could reduce CH_4 emission intensity (Herrero *et al*. 2016), but the possibility of using this mitigation tool in poor economies depends on costs and availability.

Correct pasture management, crop rotation and an intensive grazing system could be important mitigation practices that could guarantee more efficient conversion of forage into economic products and result in N_2O emission reduction (Gerber *et al*. 2013a).

Other technical mitigation options (Gerber *et al*. 2013a), such as the use of feed additives (electron receptors, ionophore antibiotics, enzymes and probiotics), vaccines and precision feeding, are not available or only partially available in marginal economies. Their availability and use are limited because of high costs, limited accessibility, policy limitations, lack of technology, and lack of breeders' specific knowledge.

Management of manure

In developing countries, manure and slurry are not always considered valuable resources, and unmanaged accumulation of animal waste represents a source of gas emissions and a health threat for animals and humans. Unmanaged manure and slurry can cause eutrophication and contamination of surface water, leaching of nitrates, degradation of natural resources and GHG in the form of CH_4 and N_2O (direct and indirect emissions), NH_3, and other toxic gases (Hristov *et al*. 2013a). In the extensive rangeland system, manure is not managed, while in the mixed system, manure is applied only partially to grazing land, and in the industrial system it is applied mainly to high-value crops such as coffee, tea, and tobacco (Herrero *et al*. 2013). Furthermore, in both extensive and intensive grazing systems, where N concentrations per hectare are high, large N losses occur through leaching and volatilization from point sources of urine and solid manure (Petersen *et al*. 2013).

Correct management of manure has been extensively demonstrated to be the most important tool that can minimize losses due to N_2O volatilization and runoff (Petersen et al., 2013). Manure from ruminants and non-ruminants can be treated by various methods for improved handling, nutrient use and energy generation. In developing countries, simple techniques such as piling, compacting and covering the manure have positive effects on reducing emissions and nutrient losses. For example, covering solid manure with straw or plastic sheets reduces, in general, both CH_4 and N_2O emissions, whereas covering liquid manure stores is adopted mainly to reduce NH_3 emissions (Petersen *et al*. 2013). N_2O emissions from liquid slurry are minimal during storage, unless a surface crust is present (Vander Zaag *et al.* 2009). In sub-Saharan Africa, the production of compost in pits with a mix of animal faeces, feed and crop residues and domestic waste is extensively prevalent among small households. Householders irrigate the pit, turn the compost, use a cover to limit N losses, and use the compost as natural fertilizer, because it is particularly rich in nutrients (Smith *et al*. 2014). In Vietnam, parts of both liquid and solid manure produced by pig farms are applied to fish ponds and used to feed fish for local consumption (Vu *et al.* 2012). Modern technology, such as manure separation, anaerobic digestion, aeration, use of additives and inhibitors (Petersen *et al*. 2012).

Conclusions

N_2O emissions from livestock and mitigation actions in developing countries indicate that emission intensities from livestock are medium to high in poor countries owing to low animal productivity, low feed quality, lack of knowledge, and limited investments. There are differences among developing countries in animal gas emissions in the same continent or region, indicating that improvements are possible. The countries with lowest livestock gas emissions should be the drivers of improvement of all other countries in the same region or continent. Developing countries should promote production systems with low emission intensity (chicken meat, eggs, cow milk and pork meat) or medium emission intensity (meat and milk from small ruminants), and the international community should support modernizing and improving the efficiency of productions with the higher emission intensity (meat from beef cattle). Mitigation tools to reduce CH_4 and N_2O emissions that are used in industrialized countries are not always applicable to developing countries. Developing countries must use the mitigation tools adaptable to their conditions, considering the costs, knowledge, applicability, and local legislation. In the future, interdisciplinary research should focus on the integration of livestock emissions at country level and sustainable mitigation and adaptation tools that could be applied at local levels.

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