Chapter 1

GHG Emissions from Livestock: Challenges and Ameliorative Measures to Counter Adversity

Pradeep Kumar Malik, Atul Purushottam Kolte,
Arindam Dhali, Veerasamy Sejian,
Govindasamy Thirumalaisamy, Rajan Gupta and
Raghavendra Bhatta

Additional information is available at the end of the chapter

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Abstract

Livestock and climate change are interlinked through a complex mechanism and serve the role of both contributor as well as sufferer. The livestock sector is primarily accountable for the emission of methane and nitrous oxide. Methane emission takes place from both enteric fermentation and manure management; whilst nitrous oxide emission is purely from manure management. Rumen methanogenesis due to emission intensity and loss of biological energy always remains a priority for the researchers. Greenhouse gas (GHG) emissions from manure are determined by storage conditions and the organic content of the manure waste. Due to large livestock population, India is a major contributor of enteric methane emission, while its contribution to the excrement methane is negligible. In this chapter, information pertaining to enteric methane emission, excrement methane and nitrous oxide emissions and ameliorative/ precautionary measures for reducing the intensity of emissions have been compiled and presented.

Keywords: greenhouse gas, GHG mitigation, livestock, methane, nitrous oxide

1. Introduction

Annual greenhouse gas (GHG) emission in 2005 was about 49 gigatonnes (Gt), wherein China contributed the maximum, followed by the United States of America and the European Union

27 [1]. The contribution of India to the total emission is about 4.25% (**Figure 1**). Worldwide livestock are integral component of agriculture and support the livelihood of billions by fulfilling 13% of energy and 28% of protein requirement. Due to the rapid change in food habits, the global demand for milk, meat and eggs in 2050 with reference to year 1990, is expected to increase 30, 60 and 80%, respectively. This additional demand will be met from livestock either by increasing their number or by intensifying productivity. The bovine and ovine population is expected to grow up at a rate of 2.6 and 2.7%, respectively, during next 35 years.

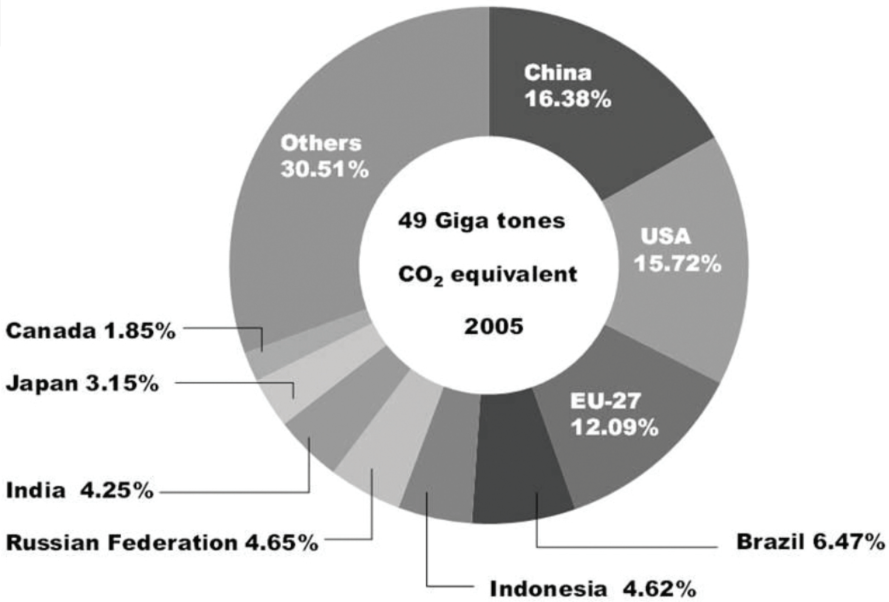

Figure 1. Nation wise greenhouse gas emissions [2] (Reprinted with permission from Takahashi [2]).

Livestock and climate change are inter-hooked in a complex mechanism where adversity of one affects another. Adverse impact of climate change on livestock across the globe will be stratified in accordance with the prevailing agro-climatic conditions. The climatic variation influences livestock in both direct and indirect ways and alterations in ambience (stresses), qualitative and quantitative changes in fodder crops, health are few of them. We can consider the livestock as one of the culprit for climate change and also the sufferer due to negative consequences of changing climate on the productive and reproductive performances of the animal. Elaborating the adverse impact of climate change on livestock production is beyond the scope of chapter and discussed elsewhere in the book. This chapter would focus primarily on the role of livestock in greenhouse gas emissions and ameliorative/precautionary measures for countering the adverse impact.

2. GHG emissions from livestock

Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are three major GHG emissions from livestock into the atmosphere. However, CO_2 being the part of continuous biological

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system cycling is not taken into consideration while calculating total GHG emission from livestock [3]. After power and land use change, agriculture including livestock is the third sector responsible for largest greenhouse gases emission. GHG emissions from different sectors are presented in **Figure 2**. Agriculture as such contributes 14% to the global GHG emissions. Of the total agricultural emissions, 38% is contributed from the soil where N_2O is one of the major GHG. GHG emission from enteric fermentation is also equally large and constitutes 32% of the total GHG emission from agriculture (**Figure 3**). In addition, rice cultivation, biomass burning, and manure management also contribute significantly and make about 30% of the agricultural emissions.

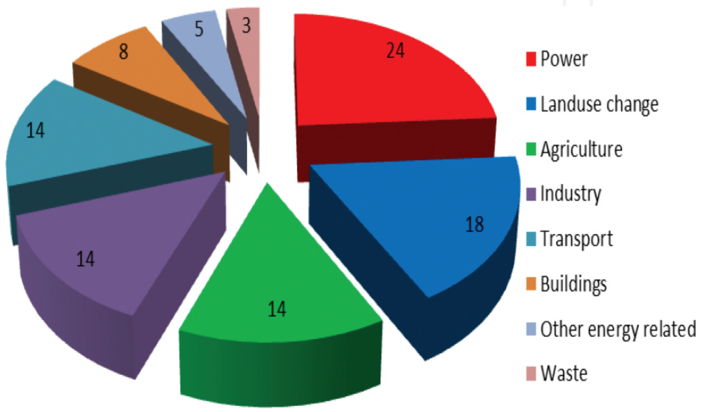

Figure 2. Sector wise GHG emissions.

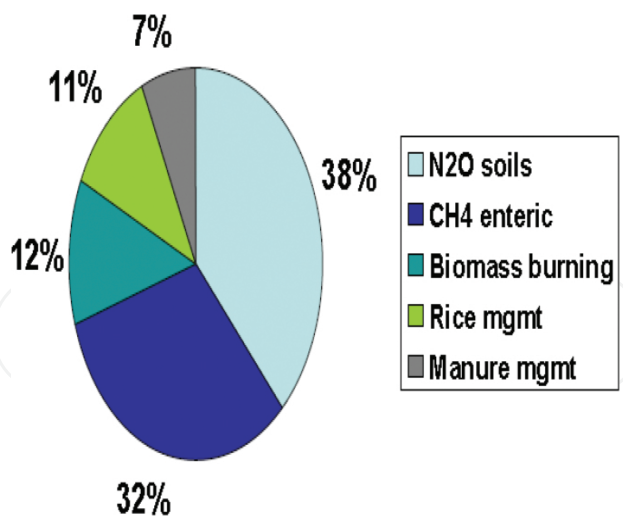

Figure 3. Global agricultural GHG emission.

Livestock emits methane both from enteric fermentation and from manure management; whilst nitrous oxide emission is purely associated with the manure management system. However, methane emission from manure management is far less than the emission from enteric fermentation. Methane emission from excrement is mainly confined to animal management operations where excrement is handled in liquid based systems. N_2O emission from manure management varies significantly between types of management system and also related to indirect emissions from other forms of nitrogen. Of the total anthropogenic methane and nitrous oxide emissions, livestock globally contribute 35 and 65% of the respective GHGs. Latin America occupies first position (23%) in the list of top enteric methane emitting countries (**Figure 4**), while Africa (14%) and China (13%) hold second and third positions. India stands at the fourth position and is accountable for 11% of the worldwide enteric methane emission (**Figure 4**). The contribution from Middle East and Eastern Europe is negligible and contributes only 2.8% of the total emission [4]. The United States' Environmental Protection Agency [5] projected that the enteric methane emission will substantially increase in 2020 and 2030 in comparison to 2010 (**Figure 5A**). Similarly, projections also imply an increase in enteric methane emission from Indian livestock than that was in 2010. However, methane and nitrous oxide emission will almost remain stabilized for the next 10–20 years (**Figure 5**).

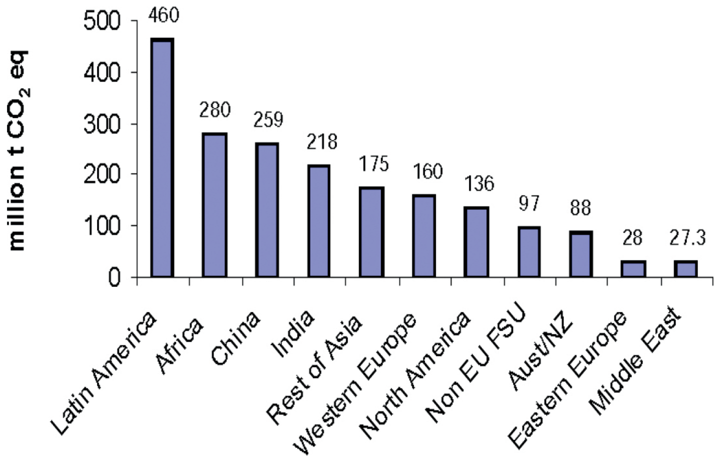

Figure 4. Region wise enteric methane emission [4].

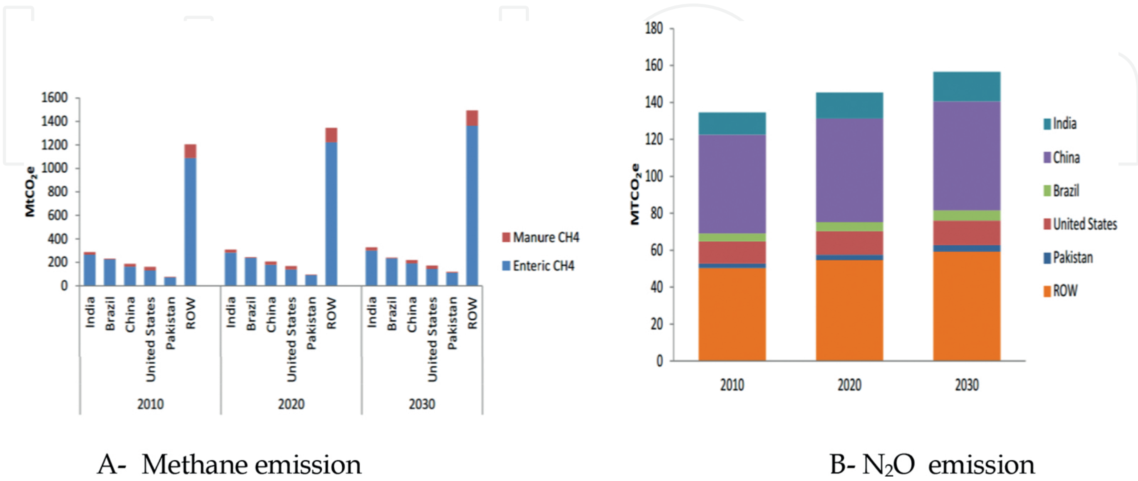

Figure 5. Projections for 2020 and 2030 [5]. (A) Methane emission. (B) N_2O emission.

2.1. Rumen methanogenesis: good and bad associated with it

Rumen harbours a diverse group of microbes that undertake different functions from complex carbohydrate degradation to the removal of end metabolites arise from fermentation. These microbes work in a syntrophic fashion under strict anaerobic conditions and help each other in performing their functions. H_2 is a central metabolite produced in large volume from fermentation and need to be disposed off away from the rumen. Many hydrogenotrophic pathways, such as methanogenesis, reductive acetogenesis, sulfate reduction, and nitrate reduction, have been described as a sink for H_2 in the rumen. Under normal rumen functioning, methanogenesis due to the thermodynamic efficiency is the most prominent hydrogenotrophic pathway. In methanogenesis, H_2 is used for the reduction of CO_2 and conversion into methane which later on eructate from the rumen. Methanogenesis removes unwanted and fatal products of fermentation from the rumen, therefore, it is an essential pathway for the normal rumen functioning, involving the residing microbes and the host animal. The methane energy value is 55.65 MJ/kg [6] and therefore its removal deprives the host animal from a substantial fraction of ingested biological energy. This loss generally lies in the range of 6–12% of the intake [7]. In addition, enteric methane emission due to its high global warming potential (25 times of CO_2) also contributes significantly to the global warming [5]. Due to many intact disadvantages with enteric methane emission, its amelioration up to a desirable extent is much more important than any other GHG. Its relatively shorter half-life offers added opportunity to stabilize global warming in short time and meanwhile other GHG could also be tackled.

2.2. Enteric methane emission: Indian scenario

Various agencies reported quite variable figures for enteric methane emission from Indian livestock. Many have reported annual emission as high as 18 Tg per year, while others have estimated only 7 Tg (**Figure 6**). The average of these estimates comes around 8–10 Tg per year which constitutes about 11% of the global enteric methane emission. India possesses 512 million livestock [8] wherein cattle and buffaloes are the prominent species and make up to 60% of the total livestock in the country.

One of the reasons for high enteric methane emission from India is the larger bovine population which emits more methane than any other livestock species. On an average, cattle and buffaloes aggregately emits more than 90% of the total enteric methane emission of the country. The contribution from small ruminants is relatively small and constitutes only 7.7%. Rest of the methane emissions arise from the species such as yak and mithun, which are scattered to specific states only. Enteric methane emission from crossbred cattle is comparatively much more than the emissions from indigenous cattle (46 versus 25 kg/animal/year). Enteric methane emission from livestock is not uniform across the states and varies considerably according to the livestock numbers, species, type of feed and fodders, etc. The National Institute of Animal Nutrition and Physiology (NIANP), Bangalore has developed an inventory for state wise enteric methane emission from Indian livestock using 19th livestock census report. The NIANP estimates revealed Uttar Pradesh as the largest enteric methane emitting state of the country [9]. Other major methane emitting states in the country are Rajasthan, Madhya Pradesh, Bihar, West Bengal, Maharashtra, Karnataka and Andhra Pradesh (**Figure 7**). These states altogether holds 66% of the livestock population and accountable for 68% enteric methane emissions. Due to large contribution, these states can be considered as hotspots for reducing enteric methane emissions from livestock and are given priority for tackling the emission.

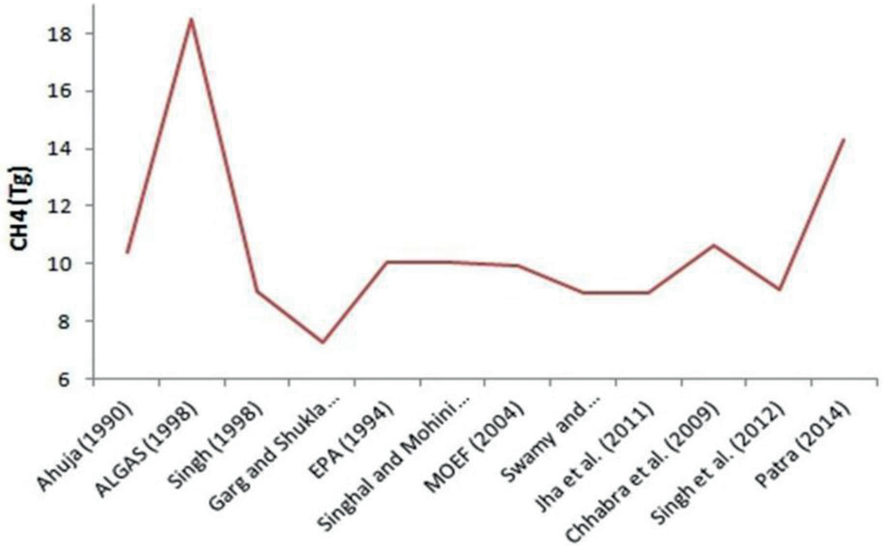

Figure 6. Disparity in enteric methane emission from Indian livestock.

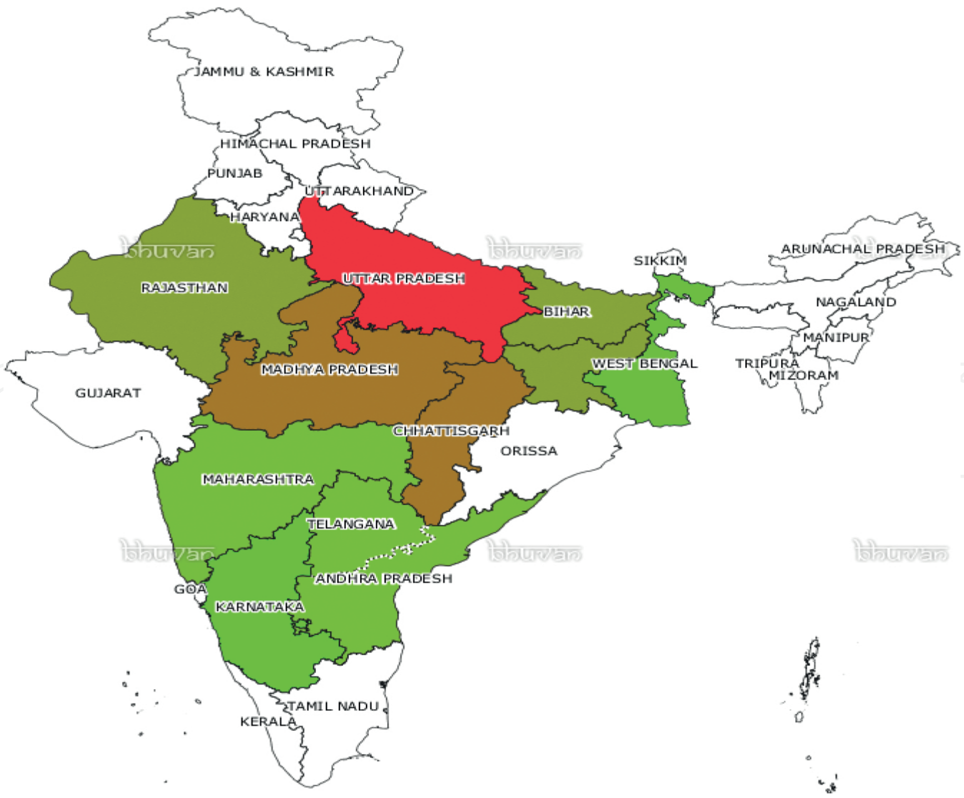

Figure 7. Major enteric methane emitting states in India.

2.3. Enteric methane amelioration: challenges and opportunities

Attempting enteric methane mitigation without understanding necessity, knowing exact emission from country/state, extent and feasibility of reduction, complexity of ruminal microbes and their syntrophic relationship will not serve the effective and sustainable reduction in long term as learnt from past experience in many countries. Archaea in the rumen are methane producing microbes. Earlier methanogens were considered under bacterial domain (prokaryotes), but recent classification by Woese [10] placed them in a distinct domain, which is remarkably different from bacteria. Methanogens archaea are primarily hydrogenotrophic microbes, which utilize H_2 as the main substrate for methanogenesis. Though, they can Use other substrates also for methanogenesis, but H_2 remains a central metabolite and its partial pressure determines the degree of methanogenesis [11]. Due to its main role in maintaining the redox-potential (reducing environment) of rumen, H_2 is referred as *currency of fermentation* [11]. Therefore, deep understanding of rumen archaea, their substrate requirement and role in methanogenesis is pre-requisite for achieving sustainable reduction in methane emission. The latest metagenomic approaches served as potential tool and helped in exploring many more cultured and uncultured rumen methanogens for better understanding. The effectiveness and persistency of the ameliorative approach depends on the extent of methanogens being targeted by the approach under investigation. In spite of initial reduction, enteric methane emission usually gets back to the normal level, which is due to partial targeting of methanogen community in rumen. All possible ameliorative measures for enteric methane mitigation are presented in **Table 1**.

Measures	Opportunities/Limitation	Remarks
Reducing the livestock numbers	Due to high number of low producing or non-producing ruminants methane emission per kg of livestock product is high. Killing of such livestock is not possible due to the ban on cow slaughter in the country.	Low productive animals should be graded up with rigorous selection for improving their productivity and less enteric methane emission.
Feeding of quality fodders, concentrate	Feed interventions are the best option for methane amelioration. The uninterrupted availability is a question mark. Area under pasture and permanent fodder production declining or stagnant since last three decades. Livestock are getting their fodders from 7–8% of the arable area in the country.	Improving quality fodders availability seems unrealistic under ever increasing human population and food-feed-fuel competition scenario.
Ionophore	Selective inhibition of microbes and failure to achieve the reduction in long term are big issues. Animals turn back to normal level of emission after short time. Their use is banned in many European countries.	May be tried in rotation as well in combination for sustaining the reduction in long term.
Ration balancing	Ration balancing with feed resources available at farmer's doorstep will improve the productivity with concurrent methane reduction at a low input level.	Farmers need to be made aware about the importance of ration balancing and monetary advantages from the same.

Measures	Opportunities/Limitation	Remarks
Removal of protozoa	Removal of ciliate protozoa from the rumen results in lower methane production. May witness less fibre digestibility. It is practically impossible to maintain protozoa free ruminants.	In spite of complete removal, partial defaunation may be achieved for enteric methane reduction without affecting the fibre digestion.
Reductive acetogenesis	Thermodynamics favour methanogenesis in the rumen. The affinity of acetogens for H_2 substrate is considerably lower than methanogens. It cannot work until and unless target methanogens are absent in the rumen.	Reductive acetogenesis may be promoted by simultaneously targeting rumen archaea. This will ensure less methane with additional acetate availability for the host animal.
Use of plant secondary metabolites	Under the quality fodders deficit scenario, use of PSM as methane mitigating agents is a good option. Dose optimization and validation of methane migration potential *in vivo* on a large scale is mandatory before recommendation.	Inclusion at a safe level without affecting the feed fermentability may be a viable option for enteric methane amelioration. Studies are warranted for assessing the combined action of PSM on *in vivo* methane emission.
Nitrate/Sulfate	Nitrate and sulfate hold the potential to reduce methane emission to a greater extent. These reductive processes are thermodynamically more favourable than methanogenesis. The end product from this productive process will not have any energetic gain for the animal. Intermediate products are toxic to the host animal.	Probably slow releasing sources for these compounds will reduce the toxicity chances caused by intermediate metabolites. A safe level of inclusion must be decided and tested on large number of animals by considering all the species accountable for methane emission.
Active immunization	This approach hold the potential for substantial methane reduction provided methanogen archaea of rumen is explored to a maximum extent for identifying the target candidate for the inclusion in vaccine.	Information on the species and bio-geographic variation in methanogenic archaeal community should be explored for considering this approach for enteric methane amelioration.
Disabling of surface proteins	It is well established that methanogens adhere to the surface of other microbes for H_2 transfer through surface proteins. Identifying and disabling of these surface proteins will certainly reduce enteric methane emission by cutting the supply of H_2.	This is an unexplored area and need some basic and advance research for exploring the possibility.
Biohydrogentation	Restricting the H_2 supply to methanogens through alternate use in bio-hydrogenation, decrease enteric methane amelioration. Use of fat/lipids at a high level depresses fibre digestion. Of the total, only about 5–7% of H_2 is utilized in this process.	This approach is not practical due to high cost of fat/lipids and fibre depression at a high level of use.

Table 1. Ameliorative measures for enteric methane mitigation.

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2.4. Plant secondary metabolites as ameliorating agent

Plant secondary metabolites (PSMs) are organic compounds that are not directly involved in the growth, development, or reproduction, but play an important role in plant defence against herbivores. Plant secondary metabolites, on the basis of their biosynthetic origins can be grouped into three: flavonoids, and allied phenolic and polyphenolic compounds; terpenoids and nitrogen-containing alkaloids; and sulphur-containing compounds. Among these, tannins are most important for enteric methane amelioration. Chemically, they are polyphenolic compounds with varying molecular weights, and have the ability to bind natural polymers, such as proteins and carbohydrates. Based on their molecular structure, tannins are classified as either hydrolysable tannins (HT; polyesters of gallic acid and various individual sugars) or condensed tannins (CT; polymers of flavonoids), although there are also tannins that represent combinations of these two basic structures. As PSMs are integral components of abundant phyto-sources and are required in very limited quantity for exerting anti-methanogenic action, therefore, using them as an ameliorating agent would cost very little to the stakeholders.

The tannins exert their anti-methanogenic activity through direct inhibition of methanogen archaea or indirectly by interfering with protozoa and restricting the interspecies H_2 transfer [12, 13]. More than 100 phyto-sources have been evaluated in our laboratory (*in vitro)* for determining their methane mitigation potential and to optimize their level of inclusion in the animal diet [14, 15].

Saponin is another group of plant secondary metabolites that possess a carbohydrate moiety attached to an aglycone, usually steroid or triterpenoid. Saponins are widely distributed in the plant kingdom and research revealed the use of saponin as such or as phyto source legumes that contain an appreciable amount of saponins. Malik and Singhal [16] in an *in vitro* study reported 29% reduction in methane production on the addition of 4% commercial grade saponin in wheat straw and concentrate based diet. Further, same authors [17] also reported a reduction of 21% in enteric methane emission in Murrah buffalo calves due to the supplementation of saponin-containing lucerne fodder as 30% of the diet. In an *in vitro* study, Malik et al. [18] observed a significant reduction in methane production due to the supplementation of first cut alfalfa fodder. The addition of saponin or saponin-containing fodder affects methanogenesis primarily through the anti-protozoa action or altering the fermentation pattern and direct inhibition of rumen methanogens [19].

3. GHG emissions from manure management

Livestock manure proved a valuable material that contains required nutrients for plant growth and an excellent soil amendment for improving soil quality and health. Methane is a major greenhouse gas emitted from manure during anaerobic decomposition of the organic matter. Another important greenhouse gas is nitrous oxide, which contrarily emits from aerobic storage of excrement. A pictorial presentation of the possible sources for methane and nitrous oxide emission is provided in **Figure 8**. The thick arrow in **Figure 8** represents the major source for a particular GHG.

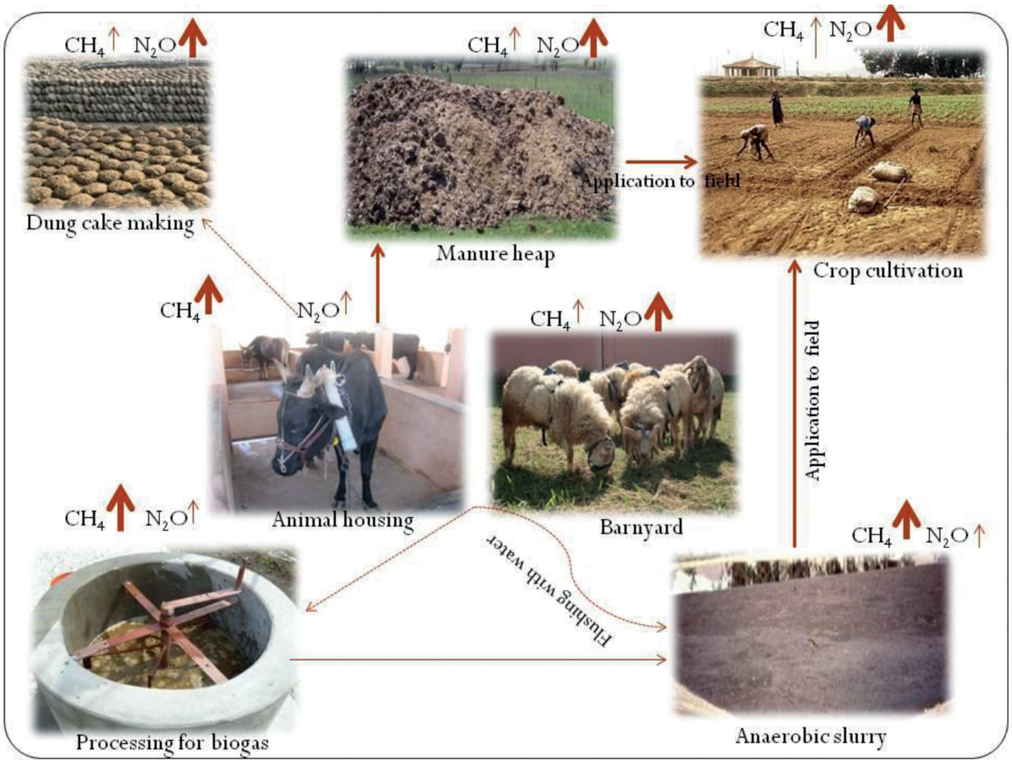

Figure 8. Sources of GHG from livestock excrement.

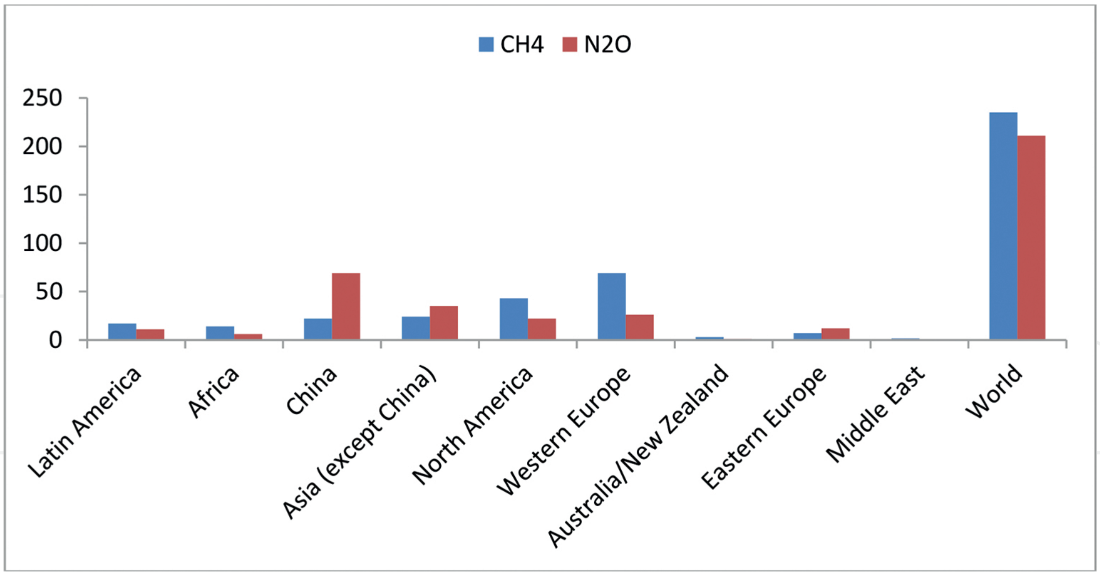

Figure 9. Methane and nitrous oxide emission from manure management in different regions of the world [22] (modified with permission from EPA [3]; O'Mara [21]; UNEP [22]).

The extent of emission of particular greenhouse is determined by the disposal and processing of waste. For example, methane is the primary GHG emit from the excrement, if waste is flushed with water and stored in lagoon; while on the other hand, nitrous oxide is the primary

GHG, if waste is stored as heap in an aerobic environment (**Figure 8**). Methane emission from livestock excrement as such is not a major issue in developing countries, like India. However, excrement is a major source of methane emission in developed world, where excrement is mainly disposed anaerobically. Worldwide production of methane and nitrous oxide annually contribute about 235 and 211 Mt of CO_2-eq, respectively [20, 21]. Regional estimates of manure methane and nitrous oxide are presented in **Figure 9**. Asian countries due to following aerobic storage of excrement contribute about 49% of the total nitrous oxide emissions (**Figure 9**). The aerobic conditions favour nitrous oxide emission from excrement and disfavour methanogenesis. The contribution from America and Africa to total nitrous oxide emission is 15 and 3%, respectively. On the other hand, methane emission from manure is highest in America (22%), which is obviously due to anaerobic processing of animal wastes.

Methane	**Manure Methane (kg x 10^5)**		
	Estimated	**Projected**	
	2010	**2025**	**2050**
World	11,414	12,849	15,046
India	1096	1221	1543
% of total	9.6	9.5	10.2
Methane	**Manure N_2O (kg x 10^5)**		
	Estimated	**Projected**	
	2010	**2025**	**2050**
World	383	445	516
India	15.3	17.5	21.4
% of total	3.9	3.9	4.1

Table 2. Estimate and projected emissions of methane and methane from manure management [23].

Patra [23] has estimated the methane and nitrous oxide emissions from manure management and also made projections for 2025 and 2050 (**Table 2**). He projected a small increase from 9.6 to 10.2% to the manure methane emission in India over a period of 30 years (**Table 2**). Likewise a small increase is also projected for manure nitrous oxide emission from both world and India. He projected an increase of 133 Mt CO_2-eq nitrous oxide from total manure produced in the world; while in India it would be around 6 Mt CO_2-eq between 2010 and 2030.

The type and quantity of diet are deciding factors for the extent of methane emission from a given volume of manure [24]. International Panel on Climate Change (IPCC) proposed a value of 0.24 L methane per gram of volatile solids (VSs) for dairy cattle [25]. Hashimoto et al. [26] evaluated the methane emission from manure of beef cattle fed different quantities of corn silage and corn grain in the following percentage: 92–0%, 40–53% and 7–88%, respectively. The corresponding emission figures were 0.173, 0.232 and 0.290 L per gram of VS, respectively.

Manure management is an essentiality to be considered for minimizing GHG emissions from excrement processing. The decomposition of dung under anaerobic conditions produces methane. Anaerobic conditions usually arise when dung is mainly disposed along with liquid. Total dung produced and the fraction that undergoes anaerobic decomposition influence methane emissions. When manure is stored or treated as a liquid in lagoons, ponds, tanks or pits, it decomposes anaerobically and produces significant methane. The temperature and the retention in storage vat greatly affect the degree of methanogenesis. Handling dung in the solid form (e.g. stacks or heap) or deposition in pasture and rangelands, accelerate the aerobic decomposition and hence, produce very less methane. The methane production from dung depends on its VS content. VS are organic content of dung which contains both biodegradable and non-biodegradable fractions. VS excretion rates may be retrieved from the literature or determined by conducting experiments. Enhanced characterisation methods can be used for estimating the VS content [Equation 1] . The VS content of dung is considered equivalent to the undigested fraction of the diet, which is consumed but not digested and therefore, excreted as faeces. VS excretion rate may be worked out using the equation of Dong et al. [27]

Volatile solid excretion rates [27],

$$\mathrm{VS} = \left[\mathrm{GE}\left(1 - \frac{\mathrm{DE\%}}{100}\right) + (\mathrm{UE\ GE})\right]\left[\left(\frac{1-\mathrm{ASH}}{18.45}\right)\right]. \tag{1}$$

Using the VS excretion rate, the methane emission factor from dung may be determined as per The equation 2 given below [27]:

$$EF_{(T)} = \left(VS_{(T)}\,365\right)\left[B_{o(T)}\;0.67\,kg/m^3 \sum_{S,k} \frac{MCF_{S,k}}{100}\;MS_{(T,S,k)}\right]. \tag{2}$$

Nitrous oxide emissions from manure management directly arise from the nitrification and denitrification process. The extent of nitrous oxide emission from manure during storage depends on nitrogen and carbon contents as well as storage duration. Nitrification, that is, oxidation of ammonia nitrogen to nitrate nitrogen, is a necessary step in the generation of nitrous oxide from animal manures. Nitrification occurs when stored dung has sufficient supply of oxygen. During denitrification, which is an anaerobic process, nitrites and nitrates are converted into nitrous oxide and dinitrogen. Direct nitrous oxide emission from manure management may be estimated using following equation:

Direct nitrous oxide emission from manure management [27]:

$$N_2O_{D(mm)} = \left[\sum_{\mathrm{S}}\left[\sum_{\mathrm{S}}\left(N_{(T)}\;Nex_{(T)}\;MS_{(T,S)}\right)\right]EF_{3(S)}\right]\frac{44}{28}. \tag{3}$$

3.1. Measures for reducing GHG

Precautionary or ameliorative measures to ensure less greenhouse gas emission from manure depend on the storage conditions. Due to contradictory environmental conditions required for methane and nitrous oxide emissions, similar mitigating or precautionary measures cannot tackle both the gases at the same time. Therefore, we should fix the priority before attempting the mitigation and process the excrement accordingly. For mitigating methane and nitrous oxide emissions from manure management, few precautionary/ameliorative measures are furnished in **Table 3**.

GHG	Measures
Methane	• Handling of manure in the solid form or deposition on pasture rather than storing it in a liquid based system. However, this may increase nitrous oxide emission.
	• Capturing methane from manure decomposition for producing renewable energy.
	• Avoid adding straw to manure which serve as a substrate for anaerobic bacteria.
	• Application of manure to soil as early as possible to avoid the anaerobic storage of manure which encourages anaerobic decomposition and favour methanogenesis.
	• Application of manure when soil surface is wet should be avoided as it may lead to increase methane emissions.
	• Improve animal's feed conversion efficiency either by feeding quality feeds or by processing to decrease GHG emissions.
	• Cover lagoons with plastic covers or any other means to capture GHGs.
N_2O	• Manure should apply shortly before crop growth for efficient utilization of available nitrogen by crop.
	• Avoid applying manure in winter as it can lead to high emission.
	• Hot and windy weather should be avoided for applying manure because these conditions can increase nitrous oxide emissions.
	• Follow the ideal practices for improving drainage, avoiding soil compaction, increasing soil aeration, and use nitrification inhibitors.
	• Even application of manure around the pasture.
	• Maintain healthy pastures by implementing beneficial management grazing practices to help increase the quality of forages.
	• Include low protein levels and the proper balance of amino acids in the diet to minimize the amount of nitrogen excreted, particularly in urine. Use phase feeding to match diet to growth and development.
	• Storage underground surface with lower temperatures reduces microbial activities.

Table 3. Precautionary/ameliorative measures for reducing GHG emissions from manure management.

4. Summary

Livestock are the major source for anthropogenic GHG emissions as they tend to emit methane from enteric fermentation and manure management and nitrous oxide from manure management. These GHGs as compared to carbon dioxide have very high global warming potential. Apart from accelerating the global warming, enteric methane emission from livestock also carry off substantial fraction of the energy which is supposed to be used by the host animal. A country like India cannot afford this energy loss, as it demands additional feed resources to compensate the loss. The adoption of mitigation options for enteric methane amelioration should be based on the feasibility of intervention(s) in a specific region. Our focus should be on those approaches which may persist in a long run and lead to 20–25% reduction in enteric methane emission. Methane and nitrous oxide emissions from manure management demands different storage conditions. Due to storage conditions (mainly aerobic), the methane emission from manure in the developing countries is not very alarming and hence, our focus should be on reducing nitrous oxide emission from manure management by developing the interventions which at least ensure that nitrous oxide emission has not gone up while trying to mitigate methane emission from manure management.

Author details

Pradeep Kumar Malik[1*], Atul Purushottam Kolte[1], Arindam Dhali[1], Veerasamy Sejian[1], Govindasamy Thirumalaisamy[1], Rajan Gupta[2] and Raghavendra Bhatta[1]

*Address all correspondence to: malikndri@gmail.com

1 ICAR-National Institute of Animal Nutrition and Physiology, Bangalore, India

2 Indian Council of Agricultural Research, New Delhi, India

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