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Methane and Nitrous Oxide Emissions from Livestock in India: Impact of Land Use Change

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Abstract

Ruminant livestock has been recognized as a major contributor to greenhouse gases. Total methane (CH_4) and nitrous oxide (N_2O) emission from agricultural sector in India is 10214.8 Gg and 0.07 Gg, respectively. Livestock account for about 63% of all emissions from the agricultural sector in India. Methane emission contribution from Indian livestock is the highest as compared to various other subsectors from agriculture, viz. rice cultivation and open burning of crop residue. The largest biogenic sources of CH_4 are enteric fermentation from ruminant animals (16%) and rice production (11%). Greenhouse gas emissions from the agricultural sector that are related to animal production comprise CH4 directly emitted from domestic animals, CH_4 and N_2O emitted from manure and grazed lands, and N_2O emitted from soils. In India, the agriculture sector emitted 334.41 million tons of CO2e in 2007. Enteric fermentation in livestock released 212.10 million tons of CO2e (10.1 million tons of CH_4). Manure management emitted 0.115 million tons of CH_4 and 70 tons of N_2O, annually. Total emissions from livestock in India stands at 214.5325 million tons of CO2e. The multidisciplinary study showed that a strong interaction exists among soil, livestock, vegetation and hydrology which impacts the GHG emissions from the respective systems. Computation of GHG emission from various farming systems showed that maximum emission was from livestock based farming system, followed by agriculture, and shifting cultivation. Livestock was found to be the most important component of GHG emission in a particular farming system, followed by rice cultivation.

Key words: *Methane; Nitrous oxide; Livestock; Farming systems; India*

Introduction

Methane production in the rumen occurs as a consequence of the presence of a group of microorganisms called methanogens that reside in the reticulo-rumen and large intestine of ruminant livestock. These organisms play an important role in converting organic matter to methane. As described in a detailed review by McAllister et al. (1996), proteins, starch and plant cell-wall polymers consumed by the animal are hydrolyzed to amino acids and simple sugars by the bacteria, protozoa and fungi which reside in the rumen. In ruminants, the vast majority of enteric CH_4 production occurs in the reticulo-rumen. Rectal emissions account for about 2 to 3 percent of the total CH_4 emissions in sheep or dairy cows, according to Murray et al. (1976) and Muñoz et al. (2012), respectively. As stated by Van Soest (1994), the basic problem in anaerobic metabolism is the storage of oxygen (as CO_2) and-disposal of hydrogen (H_2) equivalents (as CH_4). A new group of methylotrophic methanogens that does not require hydrogen as an energy source has been described and appears to play a role in CH_4 formation in ruminants (Mosier 1999, Poulsen et al., 2012).

Fourth Assessment Report (Smith et al., 2007) mentions that, approximately 40-50% of the Earth's surface is managed for agricultural purposes and contributes 10-12% of global greenhouse gas (GHG) emissions, around 5.1-6.1 Pg CO_2-eq yr^{-1} in 2005. This is made up of 3.3 Pg CO2e yr^{-1} from methane (CH_4) and 2.8 Pg CO2e yr^{-1} from nitrous oxide (N_2O) emissions. These emissions are produced by the microbial transformation of N in the soil, often originating from applied mineral fertilizers and manure, and can be enhanced when available N exceeds plant requirements, especially under wet conditions (Oenema et al., 2005; Smith and Conen, 2004). Quantifying these emissions in order to accurately assess both their contribution to total GHG emissions and the effectiveness of mitigation strategies is, however, made difficult by the level of variation, both spatially and over time (Mosier et al., 1998). Globally, agriculture accounts for about 60% of nitrous oxide (N_2O) and 50% of methane (CH_4) emission. Agricultural CH_4 and N_2O emissions increased by 17% from 1990 to 2005 (Smith 2007).

Agriculture accounted for an estimated emission of 5.1 to 6.1 Gt CO2e yr^{-1} in 2005. Agriculture releases to the atmosphere significant amounts of CO_2, CH_4, and N_2O (Cole et al., 1997; IPCC, 2001). CO_2 is released largely from microbial decay or burning of plant litter and soil organic matter (Smith 2004, Janzen, 2004). CH_4 is produced when organic materials decompose in oxygen-deprived conditions, notably from fermentative digestion by ruminant livestock, from stored manures, and from rice grown under flooded conditions (Mosier et al. 1998). N2O is generated by the microbial transformation of nitrogen in soils and manures, and is often enhanced where available nitrogen (N) exceeds plant requirements, especially under wet conditions (Oenema et al., 2005; Smith and Conen, 2004). Agricultural greenhouse gas (GHG) fluxes are complex and heterogeneous, but the active management of agricultural systems offers possibilities for mitigation. A study was undertaken to evaluate various farming systems with regard to productivity and GHG emission under various management practices.

Material and Methods

To evolve eco-friendly and sustainable farming systems to replace shifting cultivation and compute GHG emissions from various farming systems, a multidisciplinary, long-term study was undertaken with seven farming systems on micro watersheds viz.; livestock based, forestry, agro-forestry, agriculture, agri-horti-silvi-pastoral, horticulture and shifting cultivation (Table 1). The study was conducted at Umiam, Meghalaya state of India, located at an altitude of 980m above mean sea level. The micro-watershed area varied from 0.9 ha to 1.5 ha. The prevalence of shifting cultivation in northeastern region of India has encouraged deforestation, resulting in decline in forest area as well as caused soil erosion. Whole vegetation, including forest trees and bushes is put on fire, causing substantial emission of GHG and deteriorating the environment quality of the region. This has also disturbed the hydrological set up and water resources. Slope instability has induced major geo-morphological changes due to landslides and their long term effects, increasing sediment load, causing permanent changes in valleys and plains and significant changes in Brahmaputra river flow. To study the socio-economic aspects, old records were scanned as well as benchmark survey was conducted in selected areas.

The meteorological data were collected in the observatory located near the project site. The livestock was kept right in the respective watersheds and the manure was incorporated in the soil. The IPCC tier-II methodology has been adopted for estimating CH_4 emissions from enteric fermentation in livestock and Tier-I methodology for animal manure management. The methodology for enteric fermentation takes into account age distribution and hence the weight of the animals. For ruminants, Tier-II method was adopted for CH_4 emission; however, default IPCC emission factors were used for other animals. N_2O emission from soils was determined with the equation as suggested by Bouwman (1996). Emissions of N_2O and CH_4 from poultry enteric fermentation were investigated using the values as suggested by Wang and Huang (2005). The GHG emission from rice production was calculated as per the method suggested by Pathak et al. (2011). The GHG from residue burning was determined as per the method suggested by Akagi et al. (2011). The CO2e was calculated by multiplying the values by multiplying factor 21 for CH_4 and 310 for N_2O. The CH_4 has 21 times and N_2O 310 times more warming potential than CO_2.

Land use	Crops / trees	Livestock
Livestock based	Maize, rice-bean, oats, pea, guinea grass, tapioca, broom grass	Cows, pigs
Forestry	Alder nepalensis, Albziia lebbeck, Acacia auriculiformis	None
Agro-forestry	Ficus hookerii, Eucalyptus, guava, pine, pineapple, French bean, pulse crops.	Goats, rabbits
Agriculture	Beans, radish, maize, paddy, ginger, turmeric, ground-nut, oats, grasses on risers.	

Agri-horti-silvi-pastoral	Beans, vegetables, guava, Citrus, ginger, Alder nepalensis, Ficus hookeri, grasses	Pigs, goats
Horticulture	Peach, pear, citrus, guava, lemon, vegetables.	None
Shifting cultivation	Mixture of crops	None

Table 1: *Vegetation and livestock in different farming systems.*

Results and Discussion

Livestock population

The livestock form an important constituent of India economy, particularly agriculture sector. The livestock population according to 2012 livestock census of India is; 190.9 million of cattle and 108.7 million of buffaloes. The population of poultry, sheep, goats, pigs, horses and ponies, donkeys and camels in 2012 was 729.2, 65.1, 135.2, 10.3, 0.62, 0.45 and 0.47 million, respectively. A comparative picture of India's position in the world livestock population reveals that India ranks first in cattle and buffaloes, second in goat, third in sheep, fourth in camels and fifth in poultry (FAO, 2003). In production, India ranks first in milk and fifth in poultry egg production. Total livestock (other than poultry) in India was 529.7 million in 2007 and 512.0 million in 2012, registering a decline of 3.34% during this period (Figure 1a). The total cattle, buffalo, sheep, goats and pigs population in India was, 199.1, 105.3, 71.5, 140.5 and 11.1 million in 2007 and, 190.9, 108.7, 65.1, 135.2 and 10.3 million in 2012, respectively (Figure 1b). The per cent growth/decline rate for above livestock, respectively, was, -4.10, +3.19, -9.07, -3.82 and -7.54 during this period. The per cent population of different categories of livestock has been shown in Figure 1c. A sharp increase of 237.4% in the poultry population was registered in India between 1992 and 2012 (Figure 1d).

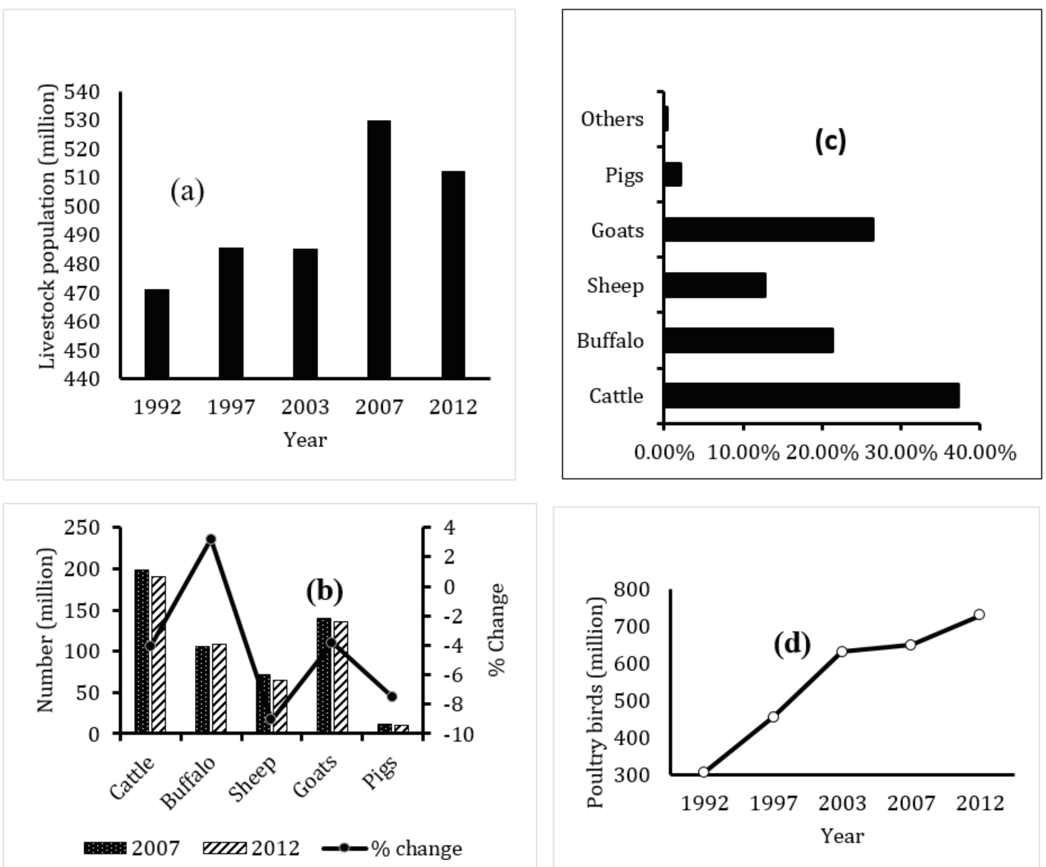

Figure 1: *Showing (a) population of livestock in India from 1992 to 2012; (b), change in population of major livestock species; (c), % of various livestock species and (d) increase in poultry population between 1992 and 2012.*

GHG emission from agriculture sector in India

The emissions of GHG from agriculture sector in India is 212.1, 2.44, 69.87, 43.4 and 6.61 million tonnes of CO2e from livestock, manure management, rice cultivation, soils and burning of crop residues, respectively (Figure 2). The livestock accounted for 63.4% of the GHG emission from the agriculture sector and 11.1% of the total GHG emissions from various sectors in the country. Table 2 gives an estimate of the emissions of CH_4 and N_2O from the agriculture sector. The application of fertilizers, manure, burning of crop residues and indirect additions accounted for 72%, 3%, 11% and 14% towards N^2O emissions (Figure 3). The nitrogenous fertilizers are by far the largest emitter of N_2O and, therefore, need to be managed properly. The GHG emissions from agriculture sector is 17.5% of the total emission from India. One point of significance is that while, GHG emission from India between 1994 and 2007, has increased at an Annual Compound Growth Rate (ACGR) of 4.86%, 3.11% and 7.25% in case of energy production, Industry and waste, respectively; the ACGR for agriculture sector has been -0.233%, indicating decline in GHG emission from this sector (Figure 4).

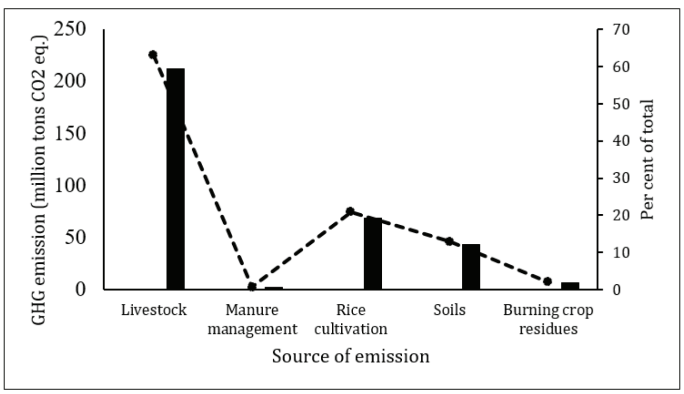

Figure 2: *GHG emission and removal from different land use systems in India (a) and GHG emission from agriculture.*

Source	CH_4	N_20	CO_2 equivalent
Enteric fermentation	10099.8		212095.8
Manure management	115.0	0.07	2436.7
Rice cultivation	3327.0		69867.0
Soils		140.00	43400.0
Burning of crop residues	226.0	6.00	6606.0

Table 2: *Methane and nitrous oxide from agriculture in India in 2007 ('000 tons).*

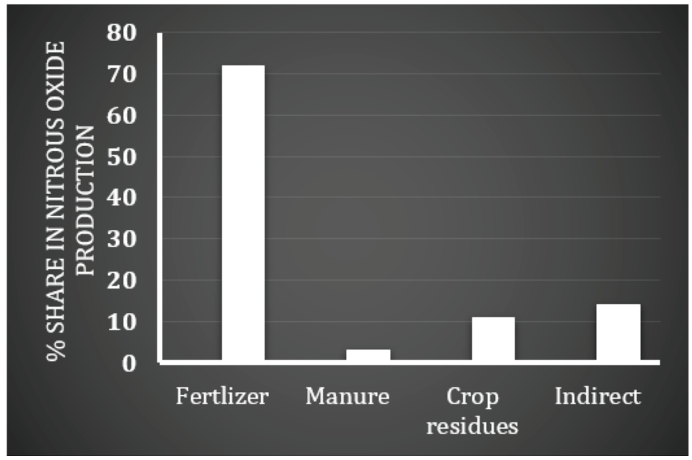

Figure 3: *Showing % share of N_2O emission various sources in agriculture sector.*

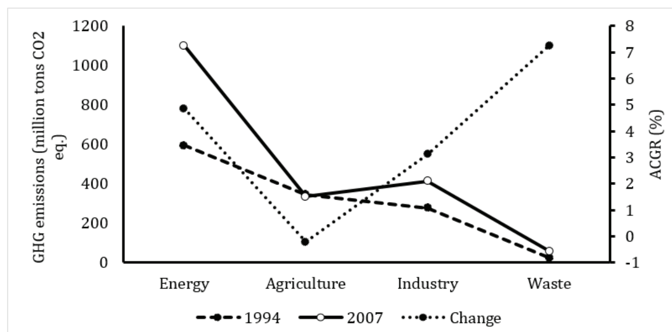

Figure 4: *Change in GHG emission between 1994 and 2007 from various sectors in India.*

GHG emission from livestock

Total emission of methane by livestock in India has been estimated about 9.37 Tg for 2003, of which buffaloes contributed 3.8 Tg (40.0%), indigenous cattle 3.75 Tg (40%), crossbred cattle 0.71 Tg (8.0%) and contribution of sheep and goats was 0.96 Tg (10%) (Upadhyay et al. 2013) (Figure 5). The other livestock with minor population consisting of equines (horses, ponies, mules and donkeys), pigs, yak, mithun and camels contributed only 2% (0.15 Tg) of total emission from livestock sector. The ruminants, both small and large, were the main contributors (98%) to the enteric methane emission in India. Dairy cattle and buffaloes contributed 3.42 Tg methane in 2003. The contribution of milch buffaloes was 59.6%, crossbred cows 11.4% and Indigenous cows 28.9% to the total emissions from dairy livestock. The total emission from draught animals has been estimated 1.2Tg. The contribution of bullocks (indigenous and crossbreds) was 85%, buffalo males 10% and other transport and pack animals contributed about 5% of total methane emission. Total methane emitted due to enteric fermentation and manure management of 485 million heads of livestock has been worked out at 9.37 Tg/annum for the year 2003 (Upadhyay et al. 2007, 2008) on the basis of IPCC methodology.

The relative role of archaea in CH4emissions has yet to be confirmed but this is an important development that may explain the lack of relationship between observed reduction in CH_4 production and abundance of traditional rumen hydrogenotrophic methanogens (Karnati et al., 2009, Lovett et al. 2006; 2009; Tekippe et al., 2011). Valerate, a minorvolatile fatty acid (VFA) resulting from carbohydrate metabolism, can also be a net sink for reducing equivalents(Russell and Wallace, 1997), but owing to its minor nature, this pathway only results in a slight decline in H_2 production. The other two minor VFA in the rumen, isobutyrateand isovalerate, originate from the metabolism of branched-chain amino acid (valine and leucine,respectively), resulting in formation of CO_2 and NH_3 (Van Soest, 1994).Most of the CH_4 emission resulting from manure is produced under anaerobic conditions during storage and very little following land application; manure from grazing ruminants does not produce significant quantities of CH_4 because it remains largely aerobic. The EPA (2005) report pointed out that manure produced little or no CH_4, when handled as a solid or deposited on pasture or rangelands. Similar to enteric fermentation, anaerobic cellulose decomposition in stored manures is typically a source of CH4. Chianese et al. (2009) indicated average CH_4 emissions from covered slurry, uncovered slurry, and stacked manure to be 6.5, 5.4, and 2.3 kg m^{-2} $year^{-1}$. Agricultural soils, with the exception of rice paddies, are generally a sink for atmospheric CH_4 (Chianese et al., 2009). However diffusion of CH_4 from land-applied manures is a shortlived source that disappears within a few days of application to soil (Sherlock et al., 2002). Manure contains most elements necessary for stimulating soil nitrification and denitrification processes that result in N_2O formation. Nitrous oxide is directly produced in manure-amended soils through microbial nitrification under aerobic conditions and partial denitrification under anaerobic conditions, with denitrification generally producing the larger quantity of N_2O (EPA, 2010). Soil temperature, water content, and oxygen concentration each influence rates of both processes, while denitrification rates are also influenced by the quantity of nitrate produced through nitrification (Cavigelli and Parkin, 2012).

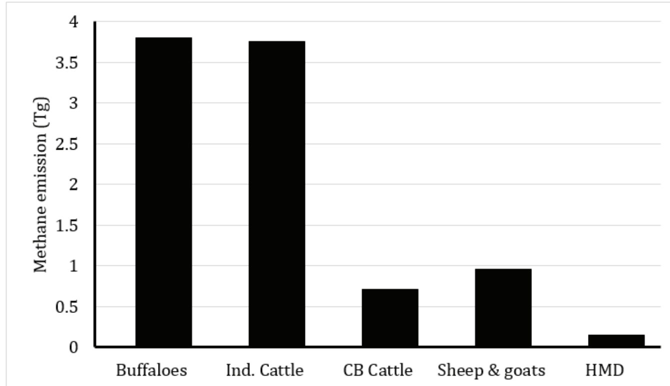

Figure 5: *Methane emission from livestock in India (2003). (Ind., Indigenous; CB, Crossbred).*

Total emissions of GHG from enteric fermentation is about 7186.3 Tg of CO_2e in the world and 214.5 Tg of CO_2e in India, which is 2.98% of global emissions. Out of 7186.3 Tg CO_2e emission in the world, about 84.3 Tg of CO_2e emission was contributed by manure management. The manure management contributed only 2.43 Tg of CO_2e emission in India.

Mitigation of GHG in agriculture

Methane emission from ruminants can be reduced by altering the feed composition, either to reduce the percentage which is converted into methane or to improve the milk and meat yield. Secondary plant metabolites and plant extracts have also been found to reduce methane emission from livestock, therefore are likely to be used in future for methane mitigation in livestock production system. In ruminant animals, methane is produced as a by-product of thedigestion of feed in the rumen under anaerobic condition. Methane emission is related to the composition of animal diet (grass, legume, grain and concentrates) and the proportion of different feeds (e.g. soluble residue, hemicellulose and cellulose content). The most efficient management practice to reduce nitrous oxide emission is site-specific, efficient nutrient management (Pathak 2010). The emission could also be reduced by nitrification inhibitors such as nitrapyrin and dicyandiamide. There are some plant-derived organics such as neem oil, neem cake and karanja seed extract which can also act as nitrification inhibitors. Mitigation of CO_2 emission from agriculture can be achieved by increasing sequestration in soil through manipulation of soil moisture and temperature, setting aside surplus agricultural land, and restoration of soil carbon on degraded lands. It has been estimated that, in 2008, 48% of the global population is dependent on food that would not be produced without N fertilizer inputs (Erisman et al., 2008). Fertilizer use is, however, very inefficient, with a high proportion of applied N being lost to the environment. In 2005, of approximately 100 Tg N used in global agriculture, only 17 Tg N was consumed by humans as crop, dairy or meat products (UNEP, 2007). Agricultural GHG fluxes are produced by complex and heterogeneous mechanisms, but the active management of agricultural systems offers possibilities for mitigation, many using current technologies which could be implemented immediately.

GHG emission from farming systems

The multidisciplinary study showed that a strong interaction exists among soil, livestock, vegetation and hydrology which impacts the GHG emissions from the respective systems. The livestock included cows and their followers, pigs and goats and were kept as per farmer's requirement in different watersheds. Prevalence of shifting cultivation in the region, continuous deforestation and mismanagement of rainwater has affected the biodiversity and ecology of the region. Deforestation and denudation of hill slopes has resulted in water scarcity because the natural water cycle has been upset. Due to deforestation and burning of forest vegetation, the shifting cultivation encourages GHG emission and deteriorates environment quality. Land use change has become inevitable if the existing method of shifting cultivation continues. About 88.3 million tonnes of soil and about 0.5 million tonnes of crop nutrients are lost every year through erosion (Sharma 2009, Sharma & Prasad 1995). Most appropriate measure would be to stop shifting cultivation and introduce new, sustainable and eco- friendly land use systems.

Computation of GHG emission from various land use systems showed that maximum emission was from livestock based farming system (7080.0 kg ha^{-1} CO_2e), followed by agriculture (4249.3 kg ha^{-1} CO_2e), and shifting cultivation (3802.7 kg ha^{-1} CO_2e), (Table 3). The GHG emission wasaffected by the number of livestock kept in a particular farming system and the livestock was found to be the most important component of GHG emission of a particular farming system. In agriculture system, the rice cultivation also enhanced the GHG emission. There was no emission from forestry, while horticulture (fruit trees and vegetable crops) was found to be very safe keeping in view the food security and ecology of the area. However, the agri-horti-silvi-pastoral (forest and pasture on 1/3 top of hill slope, horticulture in 1/3 middle hill slope and, agriculture on 1/3 lower slope or foot-hills) and agro-forestry forming systems were very safe and recommended for the area for enduring food security and environment quality. Since livestock component is important, necessary GHG mitigation measures need to be followed.

Greenhouse gas			Farming	system			
	Livestock based	Forestry	Agro-forestry	Agri-culture	Agri-horti-silvi-pastoral	Horti-culture	Shifting cultivation
Livestock							
CO_2	210	-	30	-	-	-	-
CH_4	324	-	80	128	122	-	-
N_2O	0.052	-	-	0.020	0.014	-	-
Agriculture							
CO_2	-	-	85	219	203	188	76
CH_4	-	-	-	62			
N_2O	0.161	-	0.121	0.110	0.135	0.126	-
Burning							
CO_2	-	-	-	-	-	-	3317.6
CH_4	-	-	-	-	-	-	13.46
N_2O	-	-	-	-		-	0.408
Total GHG emission (CO_2e)	7080.0	0.00	1832.5	4249.3	2811.2	227.0	3802.7

Table 3: *GHG emission from different land use systems (kg ha-1).*

Conclusions

Methane emission contribution from Indian livestock is the highest as compared to various other subsectors from agriculture, viz. rice cultivation and open burning of crop residue. The largest biogenic sources of CH_4 are enteric fermentation from ruminant animals and rice production. Greenhouse gas emissions from the agricultural sector that are related to animal production comprise CH_4 directly emitted from domestic animals, CH_4 and N_2O emitted from manure and grazed lands, and N_2O emitted from soils. There is strong need to reduce GHG emission from livestock in India. Methane emission is related to the composition of animal diet and the proportion of different feeds such as soluble residue, hemicellulose and cellulose content. Mitigation of methane emitted from livestock is approached most effectively by strategies that reduce feed input per unit of product output. Application of fermented manures like biogas slurry in the place of unfermented farmyard manure can help in reducing GHG emissions. Balanced farming systems are required to be introduced for containing greenhouse gas emissions at desired level.

References

1. Akagi SK, Yokelson RJ, Wiedinmyer J, Alvarado MJ, Reid JS, Karl T, Crounse JD, Wennberg PO (2011). Emission factors for open and domestic biomass burning for use in atmospheric models. Atmos Chem Phys., 11: 4039–4072.
2. Bouwman AF (1996). Direct emission of nitrous oxide from agricultural soils. Nutr Cycl Agroecosyst, 46(1): 53-70.
3. Cole CV, Duxbury J, Freney J, Heinemeyer O, Minami K, Mosier A, Paustian K, Rosenberg N, Sampson N, Sauerbeck D, Zhao Q(1997). Global estimates of potential mitigation of greenhouse gas emissions by agriculture. Nutrient Cycling in Agroecosystems, 49, 221-228.
4. Cavigelli MA, Parkin TB (2012). Cropland management contributions to greenhouse gas flux: Central and eastern U.S. In A.J. Franzluebbers & R.F. Follett, eds. Managing Agricultural-Greenhouse Gases: Coordinated Agricultural Research through GRACEnet to Address ourChanging Climate. New York, M.A. Liebig, Academic Press.
5. Chianese DS, Rotz CA, Richard TL (2009). Whole-farm gas emissions: A review with application to a Pennsylvania dairy farm. Applied Engineering in Agriculture, 25: 431–442.
6. EPA (US Environmental Protection Agency). (2005). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2003. EPA 430-R-05-003. Washington, DC, EPA.
7. EPA (US Environmental Protection Agency) (2010). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008. Washington DC.
8. Erisman JW, Sutton MA, Galloway J, Klimont, Z, Winiwarter W. (2008). How a century of ammonia synthesis changed the world. Nature Geoscience 1, 636-639.
9. FAO (2003). Production Year Book, Vol. 57. Rome, Italy.
10. 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, Houghton JT, Ding Y,Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K,Johnson CA (Eds.), Cambridge University Press, 881 pp.
11. Janzen HH. (2004). Carbon cycling in earth systems - a soil science perspective. Agriculture, Ecosystems and Environment, 104.3: 399-417.
12. Karnati SKR, Yu Z, Firkins JL. (2009). Investigating unsaturated fat, monensin or bromoethanesulfonate in continuous cultures retaining ruminal protozoa. II. Interaction of treatment and presence of protozoa on prokaryotic communities. Journal Dairy Science. 92, 3861–3873.
13. Lovett, D.K.; Shalloo, L.; Dillon, P.; O'Mara, F.P. (2006). A systems approach to quantify greenhouse gas fluxes from pastoral dairy production as affected by management regime. Agricultural Systems 88: 156-179.
14. McAllister TA, Okine EK, Mathison GW, Cheng KJ, (1996). Dietary, environmental and microbiological aspects of methane production in ruminants, Canadian Journal of Animal Science, 76.2: 231.
15. Mosier AR, Duxbury JM, Freney JR, Heinemeyer O, Minami K,Jonhson DE, (1998). Assessing and mitigating N2O emissions from agricultural soils. Climatic Change 40: 7-38.
16. Mosier A, Kroeze C, Nevison C, Oenema O, Seitzinger S, Cleemput O van (1999). An overview of the revised 1996 IPCC guidelines for national greenhouse gas inventorymethodology for nitrous oxide from agriculture. Environmental Science and Policy, 2: 325-333.
17. Muñoz C, Yan T, Wills DA, Murray S, Gordon AW. (2012). Comparison of the sulphur hexafluoride tracer and respiration chamber techniques for estimating methane emissions and correction for rectum methane output from dairy cows. Journal Dairy Science 95: 3139–3148.

18. Murray RM, Bryant AM, Leng RA. (1976). Rates of production of methane in the rumenand large intestine of sheep. Br. J. Nutr. 36: 1–14.
19. Oenema O, Wrage N, Velthof GL, van Groenigen JW, Dolfing J, Kuikman P, (2005). Trends in global nitrous oxide emissions from animal production systems. Nutrient Cycling in Agroecosystems, 72, 51-65.
20. Pathak H (2010). Mitigating greenhouse gas and nitrogen loss with improved fertilizermanagement in rice: Quantification and economic assessment. Nutrient Cycling Agroecosystems, 87: 443-454.
21. Pathak H, Saharawat YS, Gathala M, Ladha JK. (2011). Impact of resource-conserving technologies on productivity and greenhouse gas emission in rice-wheat system. Greenh Gas Sci Technol., 1:261-277.
22. Poulsen M, Schwab C, Jensen BB, Engberg RM, Spang A, Canibe N, Hølbetg O, Milinovich G, Fragner L, Schleper C, Weckwerth W, Lund P, Schramm A, UrichT. (2012). Methylotrophic methanogenic Thermoplasmata implicated in reduced methaneemissions from bovine rumen. Nature Communication.
23. Russell JB, Wallace RJ. (1997). Energy-yielding and energy-consuming reactions. Hobson PN Stewart CS, (Eds.)The Rumen Microbial Ecosystem, pp. 246–282. London, U.K., Blackie Academic & Professional.
24. Sharma UC, Vikas Sharma (2009). Plant-animal-soil-hydrology interactions in the northeastern region of India. Biologia, 64 (3): 460-464.
25. Sharma UC, Prasad RN. (1995 Kluwer Academic Press, The Netherlands, pp 689-696.
26. Sherlock RR, Sommer SG, Khan RZ, Wood CW, Guertal EA, Freney JR, Dawson CO, Cameron KC. (2002). Emission of ammonia, methane and nitrous oxide from pigslurry applied to a pasture in New Zealand. Journal Environment Quality 31: 1491–1501.
27. Smith KA, Conen F, (2004). Impacts of land management on fluxes of trace greenhouse gases. Soil Use and Management, 20, pp. 255-263.
28. SmithP (2004) Engineered biological sinks on land. In The Global Carbon Cycle. Integrating humans, climate, and the natural world, Field CB, Raupach MR (Eds.). SCOPE 62, Island Press, Washington D.C.,pp. 479-491.
29. Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B, Sirotenko O, (2007). Agriculture. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (Eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
30. Tekippe JA, Hristov AN, Heyler KS, Cassidy TW, Zheljazkov VD, Ferreira JFS, Karnati SK, Varga GA (2011). Rumen fermentation and production effects of Origanumvulgare L. leaves in lactating dairy cows. Journal Dairy Science 94: 5065–5079.
31. UNEP, (2007). Reactive Nitrogen in the Environment: Too Much or Too Little of a Good Thing. UNEP, WHRC, Paris.
32. Upadhyay RC, Gupta SK, Kumar A, Singh SV, Ashutosh (2007). Uncertaintyreduction in methane emission from Indian livestock: IPCC methodology (Abstract). 2nd International Workshop Uncertainty Reduction on GHG, Austria.
33. Upadhyay RC, Gupta SK, Kumar A, Singh SV, Ashutosh (2008). The contribution of draught animals to methane emission in India. Draught Animal News, 46 (Part-1), 29-36.
34. Van Soest, P.J. 1994. Nutritional Ecology of the Ruminant. Ithaca, N.Y., Cornell University Press.
35. Wang SY, Huang DJ. (2005). Assessment of greenhouse gas emissions from poultry enteric fermentation. Asian-Australas J Anim Sci., 18:873-878.
36. Wassmann R, Pathak H. (2007). Introducing greenhouse gas mitigation as a developmentobjective in rice-based agriculture: II. Cost–benefit assessment for different technologies, regions and scales. Agriculture Systems, 94: 826-840.