Methane emission estimates from enteric fermentation in Indian livestock: Dry matter intake approach

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Methane emission from enteric fermentation of Indian livestock is estimated using dry matter intake approach. Indian livestock emitted about 10.08 Tg methane due to enteric fermentation in the year 1994, in which crossbred cattle, indigenous cattle, buffaloes, goats and sheep and other livestock (mule, yak, camel, donkey, pig, mithun, horse and pony) emitted about 4.6, 48.5, 39, 4.7, 1.8 and 1.4% respectively. Amongst states, methane emission was highest in Uttar Pradesh followed by Madhya Pradesh and Bihar due to their larger livestock population. Average methane emission for lactating animals was about 53.6 g CH_4/kg milk; however, when the methane emission from whole livestock population (productive and non-productive male and female) was considered, the emission value was about 159.9 g CH_4/kg milk. Studies for reducing uncertainty in methane emission estimate and mitigating the same from the livestock may be undertaken as it is a major sources category in the agriculture sector.

LIVESTOCK are essentially integrated with the agricultural and socio-economic system in India. They play an important role in providing employment and nutritional security in spite of large gaps between the demand and supply of feed resources[1]. In spite of poor productivity and deficient feed resources, livestock contribution to national economy can only be visualized by the fact that India is currently the top milk producer in the world. Agriculture sector greenhouse gas (GHG) emission sources include livestock, rice cultivation, residue burning and agricultural soils. Among these, livestock (CH_4 emission from ruminating animals) and manure management practices (CH_4 and N_2O emission) have maximum share in GHG emissions. The major GHG emissions[2] from the agriculture sector are from enteric fermentation (59%), followed by rice paddy cultivation (23%), manure management (5%), burning of agriculture crop residue (1%) and soils (12%). Compared to CH_4 emission of 4.09 Tg from rice cultivation, ruminating livestock contribution is about 8.97 Tg for the year 1994. Fermentation of carbohydrates in ruminal anaerobic environment results in the production of hydrogen. Methanogenic bacteria utilize this excess hydrogen to reduce carbon dioxide into methane. The symbiosis between bacteria that ferment carbohydrates and the methanogens (such as *Methanobrevibacter ruminantium* and *Methanomicrobium mobile*), results in increased digestion and microbial production. Methane production in ruminants depends upon quality and quantity of feed consumed, type of animal and digestibility of forage and feeds. Indian ruminants are capable of subsisting on relatively low quality forages and crop residues. Low intake clubbed with low digestibility of these feed resources contributes substantially to limit their productivity with emission of methane.

Various attempts have been made to estimate the methane emission from Indian livestock as a result of enteric fermentation. The estimated value of methane emission ranged from 7.26 to 10.4 Tg/year[3,4], without conducting actual experiments on animals and considering the amount and quality of available feed resources. On the basis of *in vitro* dry matter digestibility evaluation of feed resources and their combination used for livestock feeding in the different regions of the country and livestock population in the year 1992, methane emission from livestock had been estimated[5] as 9.02 Tg. The present study is an attempt to estimate the total methane emission from different categories of animals fed on different types of feeds under different agro-climatic regions of the country using data from published reports on actual measurement of methane emission from feed intake.

Data requirement

Livestock population

According to Indian Livestock Census 1992, India had 204.58 million cattle, 84.20 million buffaloes, 50.78 million sheep and 115.28 million goats, which constituted about 20% of the world's ruminant livestock population. The increase in livestock population from 1987 to 1992 is reported to be 2.4% in cattle, 10.8% in buffaloes, 11.1% in sheep and 4.6% in goats. This population has been extrapolated for the year 1994 according to the growth rate reported for each sub-category of animal, published by Govern-

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ment of India on the basis of livestock population recorded[6] during 1987 to 1992. Data on livestock census conducted in 1997, has not been published so far.

Only 70% of the total population of young animals of cattle and buffaloes (in the age group of 0–1 year) has been considered for methane emission, as methane is not produced in young calves (0–3 months) due to the non-functioning of rumen. Similarly, kids and lambs (0–2 months old) also do not produce methane. However, total population of other categories of livestock has been taken for methane emission estimation. Body weight and feed intake varies between male and female, age, breed and availability of feeds and feeding practices in different States.

Categorization of livestock and their bodyweight

The livestock are grouped in different categories depending upon their sex, age, type and productivity. Cattle and buffalo have been categorized into dairy and non-dairy. Cattle are further categorized into crossbred and indigenous. Young stocks are categorized as below one year and 1–3 years (Table 1).

Information about body weight of male and female animals of some Indian breeds of cattle and buffaloes is reported[7]. However, majority of Indian cattle population (80%) is non-descript due to the reckless breeding system. Due to the non-availability of data on body weight of

Table 1. Category of livestock and their bodyweight

Category	Body weight	Category	Body weight
Crossbred male		Crossbred female	
Calves <1 year age (70%)	70–88.5	Calves <1 year age (70%)	75–88
Calves 1–3 years age	154–195	Calves 1–3 years age	165–194
Breeding bulls	280–354	Milking cows	300–352
Working bulls	280–354	Dry cows	300–352
Breeding + working bulls	280–354	Heifers	165–194
Others	266–336	Others	200–330
Indigenous cattle male		Indigenous cattle female	
Calves <1 year age (70%)	65–80	Calves <1 year age (70%)	65–75
Calves 1–3 years age	136–157	Calves 1–3 year age	136–157
Breeding bulls	260–320	Milking cows	200–333
Working bulls	260–320	Dry cows	200–363
Breeding + working bulls	260–320	Heifers	200–250
Others	247–285	Others	200–330
Buffalo male		Buffalo female	
Calves <1 year age (70%)	70–80	Calves <1 year age (70%)	80–100
Calves 1–3 years age	160–200	Calves 1–3 years age	176–220
Breeding bulls	475–550	Milking buffaloes	400–516
Working bulls	475–550	Dry buffaloes	400–516
Breeding + working bulls	475–550	Heifers	276–320
Others	450–500	Others	275–416
Goat male		Goat female	
<1 year age (70%)	8.8–21.7	<1 year age (70%)	8.8–21.7
1–2 years age	12–27	1–2 years age	12–25.6
Sheep male		Sheep female	
<1 year age (70%)	14–22	<1 year age (70%)	14–22
1–2 years age	30–40	1–2 years age	25–30
Camel	300		
Pig	70		
Horses and pony			
<3 years	200		
>3 years	300		
Donkey	150		
Mithun	400		
Yak	230–300		
Mule	150		

Table 2. Dry matter intake (kg/100 kg body weight) in different categories of animals

Age	Cattle				
	Male crossbred	Male indigenous	Male buffalo	Male sheep	Male goat
0–1 yr	2.0–2.2	1.8–2.0	1.8	3.0	3.0
1–3 yrs	2.0–2.5	1.8–2.0	1.8	3.0–4.0	3.0–4.0
Breeding	2.0–2.5	1.8–2.0	2.2		
Breeding + working	2.0–2.5	1.8–2.5	2.2		
Others	2.0	1.8	2		
Age	Female crossbred	Female indigenous	Female buffalo	Female sheep	Female goa t
0–1 yr	2.0–2.2	2.0	2.0	3.0	3.0
1–3 yr	2.5–2.8	2.0	2.2	3.0–4.0	3.0–4.0
Milking	3.0	2.2	2.8		
Dry	2.0	2.0	2.5		
Heifers	2.0	2.0	2.5		
Others	1.8	1.8	2.0		

Table 3. Methane conversion factor reported by various workers

Animal category	Type of feed	CH_4 g/kg DMI
Cattle (crossbred)		
0–1 yr	Conc. mix + wheat straw	14–20 (ref. 16)
1 yr	Paddy straw + fodder	19.26 (ref. 17)
	Paddy straw + fodder + conc. mix	18.40 (ref. 17)
1.5 yr Sahiwal	Paddy straw + conc. mix.	18.57 (ref. 17)
	Paddy straw + UMM block	16.02 (ref. 17)
1–3 yr	Conc. mix + wheat straw	19–20 (ref. 5)
Holeisten heifer	Conc. mix + Hay	20.16 (ref. 18)
Holeisten heifer	Hay	23.98 (ref. 18)
Steers	Conc. mix: roughage (97 : 3)	20.0 (ref. 19)
Lactating cows	Conc. mix + straw ad lib	16.04 (ref. 20)
Lactating cows	Conc. mix + straw + UMMB	14.24 (ref. 20)
Lactating cows	Conc. mix + straw + fodder	19–21(ref. 21)
Lactating cows (indigenous)	As in Gujarat villages	16.6 (ref. 22)
Exotic lactating	Alfalfa + pasture	23.28 (ref. 23)
Exotic cows	Alfalfa hay + silage	20.85 (ref. 18)
Buffaloes		
0–1 yr	Green fodder + conc. mix	9–11(unpublished)
1–1.5 yr male	Jowar fodder + conc. mix	10.06 (ref. 24)
1–1.5 yr female	Jowar fodder + conc. mix	9.25 (ref. 24)
Female calves	Maize fodder + conc. mix	15.97 (ref. 25)
Male calves	Maize fodder + conc. mix	18.34 (ref. 25)
2 yr male	Conc. mix: roughage 60 : 40	14.14 (ref. 26)
1–3 yr	Conc. mix + wheat straw	10–16 (ref. 27)
Lactating goats	As in Gujarat villages	18.0 (ref. 22)
	Conc. mix: roughage 30 : 70	28.79 (ref. 28)
	Hay + conc. mix	19.24 (ref. 18)
	Oat hay	22.0 (ref. 29)
	Oat hay + conc. mix I	24.0 (ref. 29)
	Oat hay + conc. mix II	22.0 (ref. 29)
Adult sheep	Hay + conc. mix	18.39 (ref. 18)
Sheep	High roughage diet	13.04 (ref. 30)
Adult sheep	Conc. mix: roughage 80 : 20	8.63 (ref. 19)
Adult sheep	High roughage diet	12.76 (ref. 31)

non-descript breeds, experts from various regions have been consulted to acquire information. Reports on the body weight of selected Indian breeds of goats[8] and sheep[9] formed the basis for the expert judgment on their body weight in different Indian States. The bodyweight of other animals, e.g. camel, mithun, yak, donkey, etc. has been taken from the literature to estimate the dry matter intake (DMI) in the respective animals (Table 1).

Dry matter intake

Dry matter intake (DMI) in ruminants is the function of their body weight. Data on daily DMI of various classes of animals were collected from the published reports. Here, emphasis was given to the availability of feed rather than the requirement of the animals, as methane is produced from the feed consumed during the course of its digestion.

Daily DMI in different categories of cattle and buffalo ranges from 1.8 to 2.8% body weight (Table 2). Goats and sheep are maintained on grazing/browsing and consumption of dry matter in these animals is about 3–4% of the body weight (Table 2). Care has been taken that total feed consumed by the animals should match with availability of feed in each State.

Methane emission factor

Methane emission factor estimation has been done on the basis of actual measurements in India using indigenous animals (cows, buffaloes) maintained on indigenous feeds under local climatic conditions. These studies reveal that the conversion rate of feed intake into methane differs from Intergovernmental Panel on Climate Change (IPCC) values for cattle and buffalo[2]. Methane conversion factor recorded in numerous feeding experiments, conducted in different Indian laboratories, has been reviewed (Table 3). The average value of methane conversion factor (in g CH_4/kg DMI) for a particular category of animal has been utilized for the calculation of total methane emission from that particular category of livestock. The methane emission factors for pig, horse, donkey and other animals are taken from the literature[10].

Methodology

Steps in the methane emission estimation methodology adopted (Figure 1) for Indian livestock are as follow:

- Identification and categorization of livestock species, viz. cattle, buffalo, sheep, goat, horse, camel, pig, donkey, yak and mithun is carried out.
- Feed intake in terms of kg DMI/100 kg livestock body weight/day is estimated.
- Body weights have been taken from published reports. Body weight of non-descript cattle has been taken by expert judgment (i.e. having 20% less body weight than well-described breed in that region of the country).
- Total DMI by each subcategory is worked out as percentage of body weight based on literature survey and expert judgment.
- Methane emission has been calculated taking into account methane conversion factor in gCH_4/kg DMI from published reports and dry matter intake of animals.
- Finally, methane emission factor (kg CH_4/head/year) is worked out.

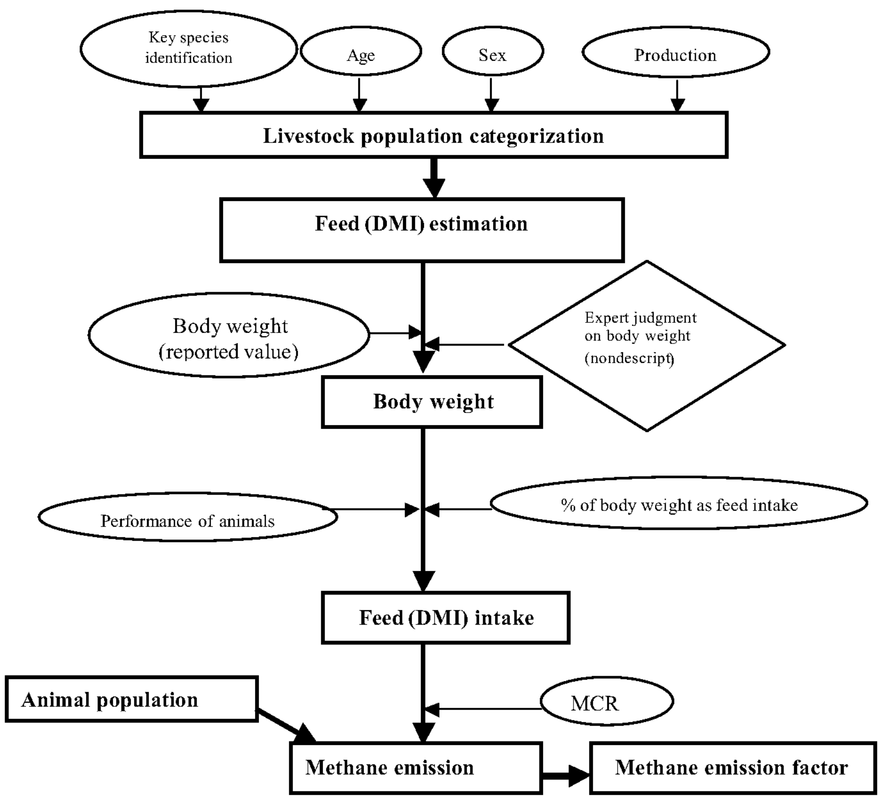

Figure 1. Flow chart of DMI methodology adopted for CH_4 emission estimation from enteric fermentation. Rhomboidal box indicates major uncertainty area and elliptical box represents major input. DMI, Dry matter intake; MCR, Methane conversion rate.

Table 4. Methane emission from different categories of livestock in 1994

Livestock category	Population '000'	DMI (Tg)	CH_4 emission (kg)	CH_4/head/year (kg)	CH_4/day (g)
Cattle–crossbred (male)					
4–12 months	991.33	0.559	8943471	9.02	24.72
1–3 yrs	983.3	1.209	19344038	19.67	53.90
<3 yr breeding	123.89	0.279	4477925	36.14	99.03
Working	2235.684	5.128	81181712	36.31	99.48
Breeding + working	312.92	0.66	10657620	34.05	93.31
Others	97.19	0.158	2534229	26.07	71.44
Total	4744.507	8	127138995		
Cattle–crossbred (female)					
4–12 months	1875.996	1.135	18217593	9.71	26.61
1–3 yrs	2180.956	2.905	46491208	21.31	58.40
Milking	4580.185	11.116	177871162	38.83	106.40
Dry	2061.999	4.963	79417704	38.51	105.52
Heifer	650.099	0.873	13970271	21.49.	58.88
Others	155.88	0.229	3679130	23.60	64.66
Total	11506.12	21.221	339647038		
Cattle–indigenous (male)					
0–12 months	7670.611	3.6455	58328253.67	7.60	20.83
1–3 yrs	14236.15	14.55	232918261	16.36	44.82
< 3 yr breeding	8815.661	15.36	307376342	34.86	95.53
Working	54290.33	111.8	1788846766	32.94	90.27
Breeding + working	8374.85	15.4	246441013	29.42	80.62
Others	759.614	1.15	18517092	24.37	66.79
Total	94147.17	161.93	2652427747		
Cattle–indigenous (female)					
4–12 months	10593.57	4.86	78363677	7.39	20.27
1–3 yrs	19725.51	18.98	303686887	15.39	42.18
Milking	27797.5	62.5	1000076610	35.97	98.57
Dry	24219.72	44.48	711687118	29.38	80.51
Heifer	4270.7	5.98	95765931	22.42	61.44
Others	1804.539	2.71	43489232	24.10	66.03
Total	88411.53	139.53	2233069455		
Buffalo (male)					
0–12 months	4346.92	2.21	22137384	5.09	13.95
1–3 yrs	3843.496	4.37	56828296	14.78	40.51
<3 yr breeding	516.412	1.68	30310620	58.69	160.81
Working	5617.619	16.19	371612268	66.15	181.24
Breeding + working	2165.23	6.52	117536449	54.28	148.72
Others	180.99	0.609	10969866	60.61	166.06
Total	16665.67	31.6	609394884		
Buffalo (female)					
0–1 months	9435.28	5.72	57205289	6.06	16.61
1–3 yrs	11364.05	15.17	197219064	17.35	47.55
Milking	27075.543	115.29	2075332653	76.65	210.00
Dry	15099.35	47.21	849911053	56.28	154.21
Heifer	2953.3	6.04	108732749	36.81	100.87
Others	708.61	1.53	27633712	38.99	106.84
Total	66636.14	190.98	3316034521		
Goat (male)					
<1 yr	13486	1.78	38151826	2.83	7.75
>1 yr	16343.13	3.236	69223209	4.23	11.60
Goat (female)					
<1 yr	17849.76	2.44	52199498	2.92	8.01
>1 yr milking	25271.91	5.89	126107610	4.99	13.67
Dry	38280.91	8.8	188990509	4.93	13.53
Total	111231.9	22.19	474672653		
Sheep	49404.14	14. 21	181309675	3.67	10.05
Others	16363,99	12. 25	141519901	8.64	23.69
Grand total	459111.19	601.95	10075214867		

Results and discussion

Dry matter intake, methane emission and methane emission factor from different categories of livestock have been estimated (Table 4).

Methane emission factor (methane emission/bovine/year)

The weighted average of annual methane emission values for the male working stock (36 kg), was the highest followed by working and breeding stock (35 kg). Young calf (4–12 months age) produced about 7 kg methane/year (Figure 2 *a*). CH_4 emission by a male buffalo in a year is higher than crossbred or indigenous bull, which may be attributed to its larger size and its feeding mainly on crop residues whose fermentation in the digestive tract produces relatively more methane than good quality feeds. Methane emission from lactating crossbred cow was observed to be similar to the dry crossbred cow (Figure 2 *b*), as the owners of crossbred cows feed them optimally even when they are dry, so that the owners can get optimum productivity after their parturition. However, indigenous dairy cow emitted more methane than non-dairy cow, obviously due to less attention on their quality feeding. Dairy crossbred cow, indigenous cow, and buffalo emitted about 39, 36 and 77 kg CH_4/head/year respectively (Table 4). Females (both cattle and buffalo) under the category 'others' emitted on an average 28 kg CH_4/head/year.

Methane emission

Methane emission from enteric fermentation of Indian livestock has been estimated at about 10.08 Tg/year from

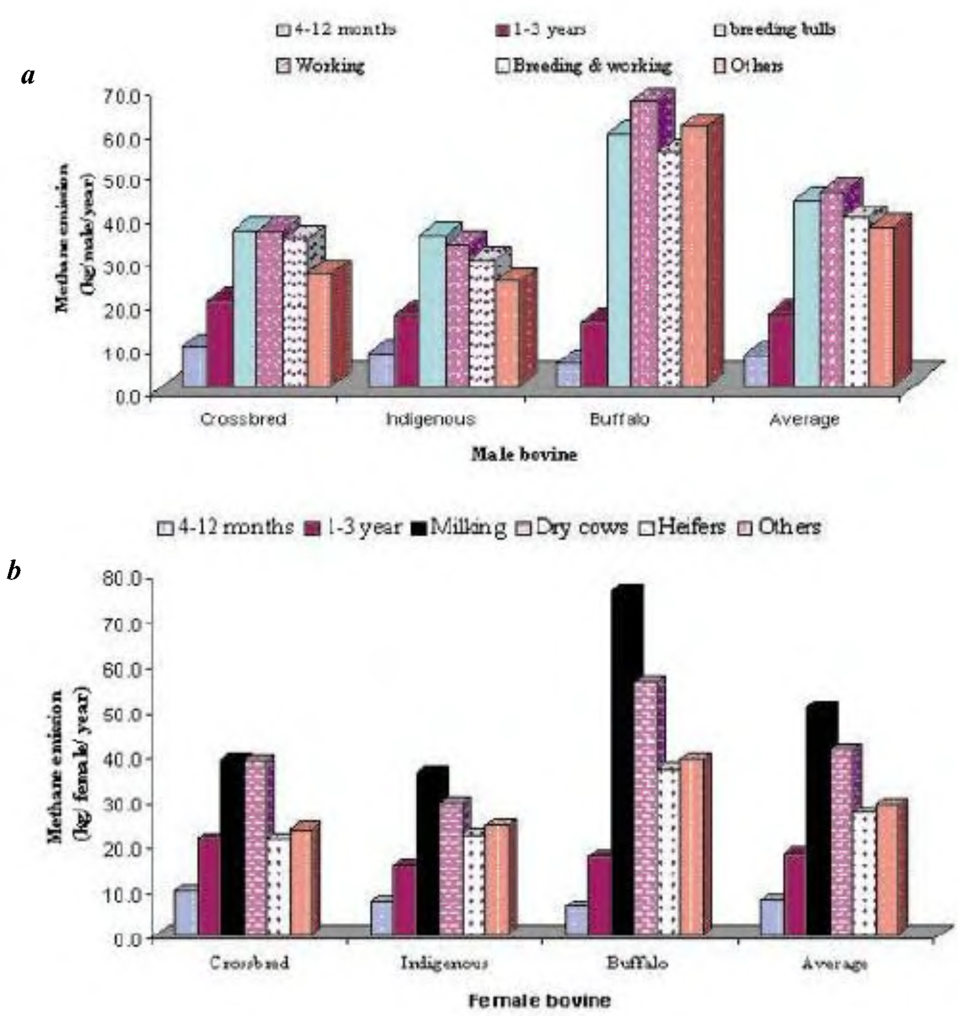

Figure 2. Methane emission factor for male bovine (*a*) and female bovine (*b*).

estimated dry matter intake of 601.95 million tons in 1994 (Table 4). Contribution of crossbred cattle, indigenous cattle, buffalo, goat and sheep in methane emission through enteric fermentation was 4.6, 48.5, 39, 4.7 and 1.8% respectively. The other livestock (mule, yak, camel, donkey, pig, mithun, horse and pony) emitted only 1.4% of total methane emission. Out of total DMI, cattle, buffaloes, goats and sheep consumed about 95.6% of feeds. The estimated total feed consumption of Indian livestock had been similar to the values reported earlier[1,11]. Percentage methane emission contributions of different subcategories, viz. male crossbred cattle, female crossbred cattle, male indigenous cattle, female indigenous cattle, male buffalo and female buffalo are shown in Figure 3 *a–f* respectively. It indicates major methane contributions from working and female (milking) bovines. Methane emission from male cattle and buffalo is 3.39 Tg. Young calves (4–12 months), growing calves, breeding, working, breeding and working stocks and others emitted 3, 9, 10, 66, 11 and 1% of total methane emitted from these animals respectively. Out of total emission of 9.93 Tg from cattle, buffalo, sheep and goat, the contribution from male animals is 34.1% in which working males are the major source of methane emission due to their large population. In the near future, contribution of male working bovines in methane emission is likely to decrease due to mechanization of agriculture and lesser dependence of farmers on them for agricultural and transport operations. However, male buffalo bulls are still preferred in some States for transportation, particularly in sugarcane producing areas. However, their population growth is low due to their utilization as meat, since buffalo meat has good export potential.

Dairy crossbred cows, indigenous cows, and buffaloes emitted about 52.4, 44.8 and 62.5% of total methane emitted by the respective category of female livestock (Figure 3). Lower methane emission from indigenous dairy cows may be attributed to their smaller body size, and less feed intake than crossbred cows and milch buffaloes. On an average, dairy animals emitted 54% of total methane emitted by female livestock as a result of enteric fermentation. Total methane emission from crossbred female cattle (0.34 Tg) was higher than their male counterpart (0.13 Tg) due to their higher population, but the situation was just reverse in case of indigenous female cattle, which produced a total of 2.23 Tg methane. Female buffaloes emitted 3.32 Tg against 0.61 Tg from male buffaloes due to their large population. Male indigenous bulls are preferred over crossbred and buffalo bulls for agricul-

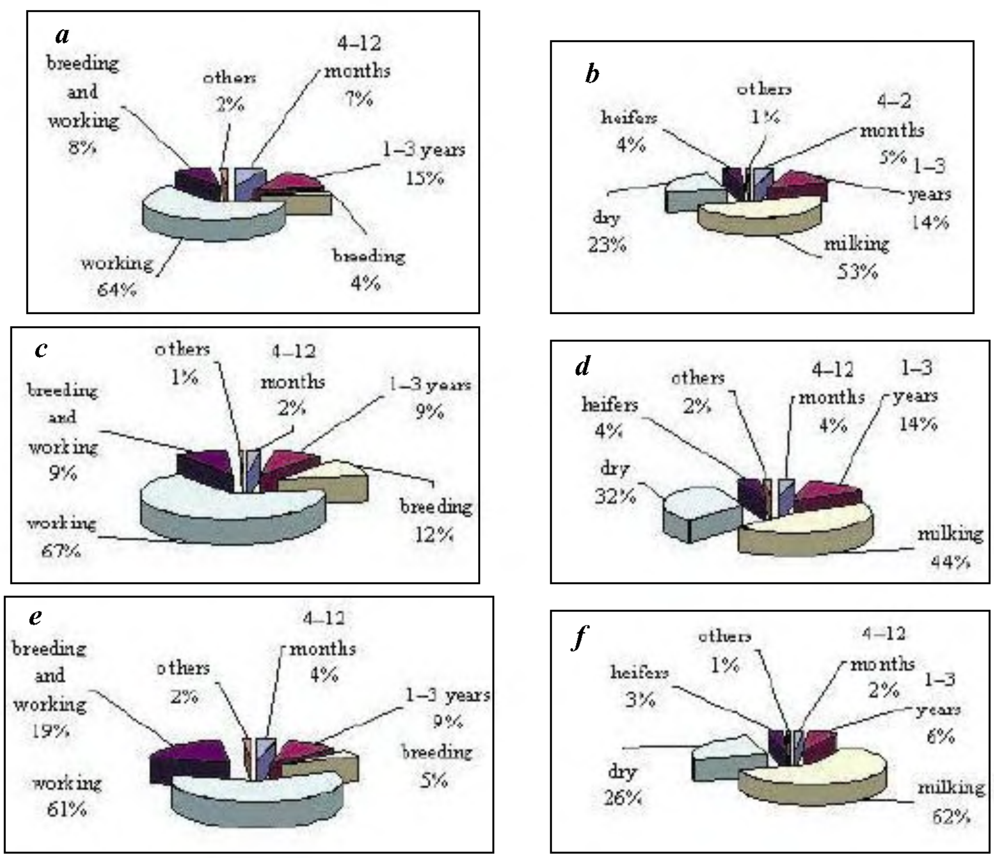

Figure 3. Percentage of methane emission contributions of different subcategories in the respective bovines.

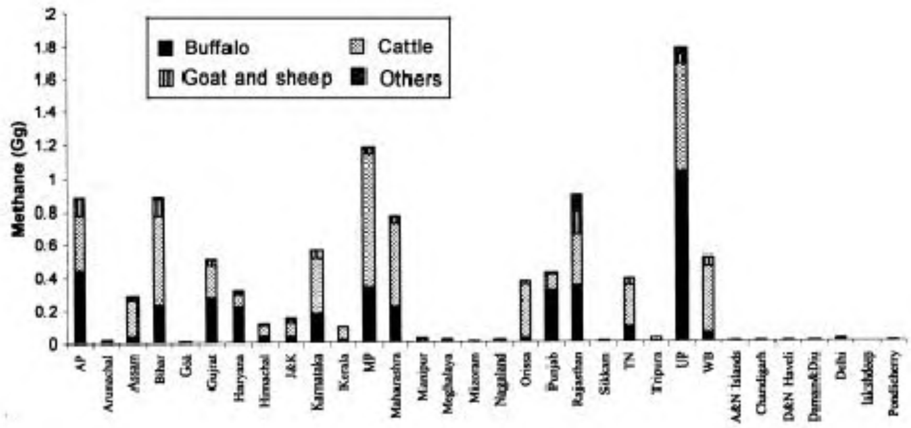

Figure 4. Statewise methane emission (Gg) from Indian livestock in 1994.

tural operations and the latter categories are normally given less attention for feeding and maintenance. Farmers prefer female crossbred cattle and buffaloes to indigenous cows (mainly non-descript) due to higher milk production. Male and female sheep and goat in the subcategories of <1 year and >1 year produced 26.2 and 73.8% of total emitted methane by these animals.

Statewise methane emission from Indian livestock

Statewise and species-wise methane emission from different livestock is presented in Figure 4. Amongst the Indian States, Uttar Pradesh (UP) topped in methane emission followed by Madhya Pradesh (MP), Bihar, Andhra Pradesh (AP) and Rajasthan. This may be attributed to the difference in their livestock population as well as quality and quantity of available feed for the animals. For species-wise methane emission, cattle were the major source of methane in MP and Bihar, whereas buffaloes were the major producers in UP, AP, Punjab and Haryana. Sheep and goats emitted sizable quantity of methane in Rajasthan and AP, as these States have large population of these species.

Methane emission versus milk production

Considering the total methane emission of about 10.08 Tg (Table 4) and total milk yield of 63 million tonnes, estimated[6] in the calendar year 1994, methane emission has been worked out to be about 159.9 g CH_4/kg milk. This appears to be higher than that recorded in the United States and other Western countries[12] due to the higher milk productivity of their animals and feeding of high concentrate-based diets. This fact is also observed in Indian livestock, as methane emission (in g CH_4/kg milk) was less in crossbred cows having higher productivity than in indigenous cows having low productivity. Lactating buffaloes emitted about 61.1 g CH_4/kg milk, which is higher than that for indigenous cows of about 59.2 g CH_4/kg milk. However, buffaloes have higher milk yield with higher energy value due to higher fat content, than indigenous cows. Using methane emission from dairy and non-dairy cattle, buffalo and goat totalling to about 9.75 Tg (Table 4), the value has been worked out to be about 154.8 g CH_4/kg milk. Considering methane emission of about 6.26 Tg from all the female cattle, buffaloes and goats, irrespective of their age and production status, the value for methane emission was estimated to be about 99.3 g CH_4/kg milk; and considering the lactating animals only the value was about 53.6 g CH_4/kg milk. The above values are far lower than that of 240 g CH_4/kg milk for total bovines[13] and a range of 175–210 g CH_4/kg milk reported from Indian female cattle, buffaloes and goats or milch animals[14,15]. These reported values had been derived based on the prediction equations and *in vitro* dry matter digestibility technique-based estimation compared to the present DMI approach that is mainly based on *in vivo* experiments. Due to non-availability of milk production data for crossbred cows from a few union territories and states like Goa, Sikkim and Tripura, the values for methane emission (g CH_4/kg milk) estimated in the present study were higher than that worked out at the national level.

Conclusion

Indian livestock emitted about 10.08 Tg methane from enteric fermentation in the calendar year 1994 and major contribution was from cattle followed by buffalo and other livestock. Majority of emissions come from working male and milking female bovines. Male indigenous cattle emit higher methane than female indigenous cattle. However female crossbred cattle emit more methane than their male counterpart. Amongst the States, methane emission was highest in UP followed by MP and Bihar, due to the larger animal population. Average methane emission in lactating animals has been estimated to be about 53.6 g CH_4/kg milk. However, for Indian livestock the value has been estimated to be about 159.9 g CH_4/kg milk. Methane emission in relation to milk production (g CH_4/kg milk) is lowest in crossbred cattle followed by buffalo and indigenous cattle. *In vivo* methane emission experimental data are more reliable than *in vitro* experimental data. Studies on the mitigation of methane emission from livestock may be undertaken, as it is a major sources category from the agriculture sector. The higher methane emission from the 'others' category of male animals, especially from buffaloes needs to be checked. Increasing the dietary energy level of diets by incorporating cereal grains or molasses (by-product of sugar industry) may be a method to mitigate methane emission as India is emerging as a major producer of cereal grains and sugar.

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