Assessment of enteric methane emission of Indian livestock in different agro-ecological regions

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In the present study an estimation of livestock enteric CH_4 emission has been made from feeding systems (diets) for different animal functions (maintenance, production and growth) prevailing in different agro-ecological regions (AERs) of India using livestock population 2003. Estimations comprised of dietary intake, digestibility and CH_4 emission factors for ruminant species of different age groups determined from feeding systems/diets. Methane production (ml g^{-1}) from production diets in animal species tended to be more than growth and maintenance diets. Methane production (g kg digestible dry matter (DDM^{-1})) and percentage energy loss as CH_4 varied significantly amongst diets, animal species and AER. Indian livestock emitted 9.10 T CH_4 from enteric fermentation. Contribution of female animal stock was more than males, except indigenous cattle, where males contributed more (53.60%) than females (46.40%). Wide variability recorded in the study for intake, digestibility, CH_4 production and CH_4 emission factors in the animal species for prevailing feeding systems/diets presents ample scope to abate the livestock resource CH_4 production through appropriate nutritional interventions.

Keywords: Agro-ecological region, feeding system, livestock enteric fermentation, methane emission factors.

LIVESTOCK and crop husbandry are supplementary and complementary constituents of the Indian agricultural system. India is endowed by nature with diverse plant and animal biodiversity. In India, animals utilize primarily crop by-products/residues and other industry processing by-products as their basal diet and add value to them by conversion into animal products (mainly milk, meat and fibre) for human consumption. The process of digestion and metabolism referred to as enteric fermentation causes 2–12% loss of dietary energy as methane (CH_4) in ruminants[1]. Diet composition (chemical and physical quality) and its intake level (quantity consumed) influence CH_4 production due to their effect on the rate of digestion and rate of passage[2]. The agriculture sector constitutes 14.17 Tg of the total 18.10 Tg CH_4 emission in India. Enteric CH_4 emissions of livestock constitute nearly 50% of the total CH_4 emission of the nation[3].

Animal physiological stage also contributes to the variation in CH_4 production within and between the different species of ruminants. The type of diet/substrate is a major source of variations in CH_4 production with respect to fermentation and production of total gas. Relative concentration of CH_4 produced as a result of particular feed/fodder fermentation relies mainly on its quantity and nature of chemical entities. CH_4 inhibition prevents feed energy loss as CH_4 and makes dietary energy available to the system. In a reduced state of CH_4 production from different feeding systems/diets, the availability of nutrients, particularly energy, will be different for different diets in relation to the existing feeding standards. Measurement of CH_4 emission and emission factor for a particular feeding system/diet will help in ranking the feeding systems/diets for a relative CH_4 production in a particular locality for a specific category of livestock. In view of the global concern for environmental safety, it seems to be the appropriate time and opportunity to tap this valuable energy of CH_4 for livestock productivity. Thus it is the need of the hour to reduce the share of CH_4 from ruminants to environment pollution and utilize this energy of food for the benefit of the host ruminant.

Many estimates of enteric CH_4 emission of Indian livestock have been made in the last 25 years, varying from 7.26 to 18.48 Tg based on different approaches[3–11]. CH_4 estimate of 10.08 Tg from enteric fermentation of Indian livestock was made using dry matter intake (DMI) approach[12], which includes CH_4 measurement of animal species on different diets made by various workers. Efforts have been made by the Ministry of Environment and Forests (MoEF), Government of India (GoI), to reduce the uncertainties in CH_4 emission estimates from different sources, including enteric CH_4 emissions to

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Table 1. Proportion of ingredients in different concentrate mixtures

Ingredient	CM_1	CM_2	CM_3	CM_4	CM_5	CM_6	CM_7	CM_8	CM_9
Mustard seed cake	35	40	–	–	–	–	40	45	–
Wheat bran	25	–	25	–	25	–	–	–	–
Maize grain	40	–	–	60	–	–	20	–	40
Barley grain	–	60	–	–	40	–	–	–	–
Cotton seed cake	–	–	35	40	–	–	–	–	–
Oat grain	–	–	40	–	–	60	–	–	–
Groundnut cake	–	–	–	–	35	40	–	–	–
Coconut cake	–	–	–	–		–	–	–	45
Rice bran							40	55	15
Gram chunni									

CM, Concentrate mixture.

prepare more precise and accurate inventories for the country. With this view the present study was undertaken to estimate CH_4 production from *in vitro* fermentation of the prevailing feeding systems/diets in inoculums of different livestock species for subsequent use in livestock enteric CH_4 production estimates in different agro-ecological regions (AERs) of the country.

Methodology

Feeding systems/diets

According to the Planning Commission nomenclature, there are 15 agro-climatic regions in the country. However, some zones with similar feed resources and feeding systems have been clubbed together and according to type-2 classification there are 10 AERs.

Local feed ingredients availability and their use in feeding livestock in different AERs were taken into account for formulation of concentrate mixtures for different AERs of the country. The protein and energy sources and their proportions used in the preparation of the concentrate mixture for different regions are given in Table 1.

Nutritional requirement of livestock can be classified into three categories based on animal functional need, viz. maintenance (non-producing/dry), growth and production (lactation/milking/breeding/working). Accordingly, three types of diets/feeding systems were formulated from available feed resources in each agro-climatic region by mixing various roughages (dry and green) and concentrate mixtures in different ratios (Table 2).

Animal population and their categories

India had livestock wealth of 185.18 million cattle, 97.92 million buffaloes, 61.47 million sheep, 124.36 million goats and 15.82 million others, including pig, donkey, mule, camel, horse, yak and mithun, which constitute about 20% of the world's ruminant population[13]. The Indian livestock population has been divided into different AERs. Classification of species into different categories, viz. calves below 1 year, between 1 and 1.5 years, heifers, working, lactating, breeding, breeding-plus-working and others has been taken from the Livestock Census 2003 of India[13]. Average weight of animal categories used in DMI estimation was worked out from an earlier report[14]. Diets were prepared for maintenance, growth and production of animals in different AERs based on the feed and fodder availability in a particular region. Growing diets were used for calves and heifers. For breeding, working, milking and breeding-plus-working animals production diets were used, whereas for dry and other animals maintenance diets were used.

For calculation of CH_4 production only 70% of the total population of young animals (< 1 year) of the cattle and buffaloes was considered, as CH_4 is not produced in young calves (0–3 months) due to the non-functioning of rumen. Similarly, lambs and kids (0–2 months) also do not produce CH_4.

Laboratory techniques and procedures

Total gas production from incubation/fermentation of diets/feeding systems in inocula of buffalo, sheep and goat was carried out using the pressure transducer technique[15] by incubating 1 g representative sample of individual diet into the digestion medium and rumen inoculums from buffalo/sheep/goats for 24 h. CH_4 in the total gas was measured using a gas chromatograph with methanizer (Nucon 5765 microprocessor-controlled GC) having stainless steel column packed with Porapak-Q of dimension of 2 m × 3.15 mm od × 2 mm id and flame ionization detector (FID). The gas chromatograph was calibrated with standard CH_4 (99.995%) and CO_2 (14.52%). Running oven, detector, injector and methanizer temperatures were 100°C, 150°C, 120°C and 320°C respectively. Nitrogen was used as the carrier gas with air and H_2 gas. CH_4 was also measured from the bottles kept as blank during the different fermentation periods and used for correction. CH_4 concentration (%) measured in the samples was utilized with total gas to estimate CH_4 production in ml/g. CH_4 gas volume was converted to energy

Table 2. Feed resources and feeding systems/diets in different agro-ecological regions (AERs) of the country

AER	States/region	Feeding systems/ diets	Dietary components	Ratio
Western Himalayan region	Jammu and Kashmir, hilly areas of Punjab, Himachal Pradesh and Uttarakhand	Maintenance	Grass : GL	65 : 35
		Growth	SST : L : CM_2	60 : 30 : 10
		Production	WS : B : CM_2	30 : 40 : 30
Eastern Himalayan region	Assam, Darjeeling (West Bengal; WB), Sikkim, Andhra Pradesh (AP), Manipur, Mizoram, Tripura, Nagaland, Meghalaya	Maintenance	Grass : LL	75 : 25
		Growth	PS : LL : CM_1	50 : 35 : 15
		Production	Grass : LL : CM_1	35 : 40 : 25
Eastern plateau and plains region	WB, Jharkhand, Odisha	Maintenance	PS : green maize	20 : 80
		Growth	PS : Napier : CM_7	30 : 50 : 20
		Production	MST : Napier : CM_7	20 : 45 : 35
Middle Gangetic plain	Bihar and eastern part of Uttar Pradesh (UP)	Maintenance	WS : green maize	50 : 50
		Growth	PS : B	40 : 60
		Production	MST : CM_7	60 : 40
Trans and Upper Gangetic plain	Western UP, Punjab, Haryana, Delhi, Chandigarh and Ganganagar District (Rajasthan)	Maintenance	WS : B	70 : 30
		Growth	SST : B : CM_2	60 : 25 : 15
		Production	WS : B : CM_3	30 : 40 : 30
Central plateau and hills	Southern part of UP, southeast Rajasthan, northern Madhya Pradesh (MP) and Chhattisgarh	Maintenance	MS	100
		Growth	GS : CM_2	80 : 20
		Production	MS : CM_5	60 : 40
Western plateau and hills	Interior part of Maharashtra, southwestern part of MP and Gujarat	Maintenance	WS : green sorghum	50 : 50
		Growth	SST : L/B	55 : 45
		Production	WS : B : CM_4	35 : 35 : 30
Southern plateau and hills region	Interior parts of AP, Karnataka and Tamil Nadu	Maintenance	PS : LL	65 : 35
		Growth	SST : ST : CM_7	40 : 40 : 20
		Production	SST : CM_8	60 : 40
Western dry zone	Desert part of Rajasthan and northern part of Gujarat	Maintenance	BST : LL	75 : 25
		Growth	BST : LL : CM_2	55 : 30 : 15
		Production	BS : CM_2	60 : 40
Coastal and island region	Kerala, Andaman and Nicobar Islands, Lakshadweep	Maintenance	PS : L	65 : 35
		Growth	PS : LL : CM_9	45 : 40 : 15
		Production	PS : LL : CM_9	30 : 35 : 35

PS, Paddy straw; SST, Sorghum stover; CM, Concentrate mixture; MS, Masoor straw; GS, Gram straw; BST, Bajra stover; ST, Sugarcane tops; MST, Maize stover; WS, Wheat straw; LL, Leucaena leaves; GL, Grewia leaves; L, Lucerne; B, Berseem.

and mass values using 9.45 kcal/l and 0.716 mg/ml factors respectively.

CH_4 produced (24 h) from fermentation of different diets (maintenance, growth and production) in buffalo, sheep and goat inocula was used for CH_4 estimation from buffalo, sheep and goat population respectively, and for calculating CH_4 emissions from cattle stock buffalo CH_4 emission was used.

In vitro dry matter digestibility (IVDMD) was determined using the standard method[16] by incubating 0.5 g sample in 50 ml digestion solution (40 ml of CO_2 saturated phosphate carbonate buffer and 10 ml strained buffalo/sheep/goat rumen liquor). DMI of diets determined using their chemical constituents[17] was used to estimate animal intake with respect to a particular diet. Gross energy (GE) of roughages was estimated using a bomb calorimeter (Toshniwal Brothers CLOI/M2), with benzoic acid as standard.

Results and discussion

Dry matter intake and dry matter digestibility

DMI calculated based on chemical constituents of maintenance, growth and production diets varied from 1.68% to 2.23%, 1.74% to 2.43% and 1.89% to 2.65% respectively. These were within the range of DMI values for different classes of cattle and buffalo used for CH_4 estimation earlier[12]. On the other hand, DMI values reported for sheep and goat were higher than those reported in the present study. DMI values of buffalo calves on roughage : concentrate diets (wheat straw-berseem : concentrate

Table 3. Dry matter intake (DMI) and digestibility of diets/feeding systems in different livestock species*

AER	Dietary components	Diets/feeding systems	DMI (% body weight)	Buffalo	Sheep	Goat
AER1	Grass : GL	M	1.86 ± 0.01	42.19	45.86	39.13
	SST : L : CM_2	G	1.97 ± 0.01	45.03	42.08	43.59
	WS : B : CM_2	P	2.44 ± 0.03	62.14	64.32	58.79
AER2	Grass : LL	M	1.77 ± 0.03	40.15	43.36	46.62
	PS : LL : CM_1	G	2.28 ± 0.02	49.64	54.14	60.05
	Grass : LL : CM_1	P	2.24 ± 0.01	60.54	55.27	52.91
AER3	MST : CM8	M	1.80 ± 0.02	48.17	55.85	53.98
	PS : Napier : CM_7	G	1.78 ± 0.02	53.51	58.77	47.98
	MST : Napier : CM_7	P	1.90 ± 0.02	59.98	62.94	50.37
AER4	WS : Oat	M	1.84 ± 0.01	48.30	53.90	59.72
	PS : B	G	1.94 ± 0.01	62.79	62.82	42.56
	MST : CM_7	P	2.04 ± 0.01	52.27	58.97	53.86
AER5	WS : B	M	2.10 ± 0.01	47.09	50.32	51.58
	SST : B : CM_2	G	1.97 ± 0.01	46.55	52.37	47.88
	WS : B : CM_3	P	2.27 ± 0.02	51.95	57.72	61.27
AER6	MS	M	2.23 ± 0.01	55.20	52.59	49.99
	GS : CM_2	G	2.20 ± 0.05	52.96	52.88	53.55
	MS : CM_5	P	2.65 ± 0.02	56.34	60.73	63.44
AER7	WS : green sorghum	M	1.68 ± 0.00	42.74	49.85	51.64
	SST/L/B	G	2.05 ± 0.02	40.89	43.23	51.54
	WS : B : CM_4	P	2.19 ± 0.02	49.54	55.46	65.84
AER8	PS : LL	M	2.03 ± 0.01	36.47	41.72	54.89
	SST : ST : CM_7	G	1.74 ± 0.01	37.20	38.94	46.01
	SST : CM8	P	1.89 ± 0.01	39.13	41.22	43.81
AER9	BST : LL	M	2.20 ± 0.01	47.35	48.34	53.93
	BST : LL : CM_2	G	2.43 ± 0.01	46.86	49.30	58.01
	BJS : CM_2	P	2.23 ± 0.07	53.39	56.67	54.13
AER10	PS : LL	M	2.09 ± 0.01	39.38	47.55	55.18
	PS : LL : CM_9	G	2.35 ± 0.03	40.84	42.47	55.32
	PS : LL : CM_9	P	2.36 ± 0.04	53.28	57.72	71.66

M, Maintenance; G, Growth; P, Production; *Each value is a mean of four observations.

70 : 30 and 60 : 40) and jowar–concentrate diet reported earlier[18,19] agree with to the present results.

DMI values were more for production diets than maintenance diets across the AERs (Table 3). Diets/feeding systems of AER9 (desert part of Rajasthan and northern part of Gujarat), AER6 (southern part of Uttar Pradesh, southeast Rajasthan, northern Madhya Pradesh and Chhattisgarh) and AER10 (Kerala, Andaman and Nicobar Islands, Lakshadweep) had higher DMI than the diets of AER1 (Jammu and Kashmir, hilly areas of Punjab, Himachal Pradesh and Uttarakhand) and AER8 (interior parts of Andhra Pradesh, Karnataka, Tamil Nadu). IVDMD of diets/feeding systems varied significantly among livestock species and AER. Dry matter digestibility (DMD) of production diets tended to be more in livestock species inocula across all AERs. Pattern of DMD of different diets was similar, but its extent was inconsistent with respect to livestock species. DMD of diets in different AERs varied from 36.47% to 62.79%, 38.96% to 64.32% and 39.13% to 71.6% in buffalo, sheep and goat inocula respectively. This may be attributed to the differences in cell wall and cell contents of diets as well as manifestations in digestive physiology and rumen microbial activity of animal species[20,21].

CH_4 production and CH_4% of gross energy

Daily CH_4 production from diets/feeding systems of different AERs varied from 14.26 to 32.33, 17.80 to 30.44 and 12.10 to 26.64 ml g^{-1} on fermentation in inocula of sheep, goat and buffaloes respectively (Table 4). These values of CH_4 production (ml g^{-1}) from incubation of diets in sheep, goat and buffalo inocula lie within the range of values reported earlier[12,22,23] for animals of different categories on different diets. *In vitro* CH_4 production (ml/g) from wheat straw–concentrate diets supplemented with different levels of lucerne (12.95–13.50) was

Table 4. CH_4 production (ml g^{-1}) from fermentation of diets/feeding systems in buffalo, sheep and goat rumen inocula at 24 h of fermentation*

AER	Dietary components	Feeding systems/diets	Sheep	Goat	Buffalo
AER1	Grass : GL	M	18.07	22.44	15.6
	SST : L : CM_2	G	20.75	22.5	18.51
	WS : B : CM_2	P	24.8	28.11	26.59
AER2	Grass : LL	M	15.29	17.8	12.13
	PS : LL : CM_1	G	19.36	23.88	18.33
	Grass : LL : CM_1	P	20.8	23.45	20.08
AER3	MST : CM8	M	19.85	25.77	23.48
	PS : Napier : CM_7	G	23.01	26.51	21.12
	MST : Napier : CM_7	P	25.55	26.94	22.03
AER4	WS : Oat	M	23.77	22.71	23.75
	PS : B	G	25.95	23.04	26.42
	MST : CM_7	P	26.59	26.58	24.99
AER5	WS : B	M	25.14	27.56	19.97
	SST : B : CM_2	G	23.77	21.54	21.36
	WS : B : CM_3	P	26.99	30.44	26.64
AER6	MS	M	32.33	26.44	23.75
	GS : CM_2	G	23.59	22.31	18.89
	MS : CM_5	P	27.82	29.26	26.42
AER7	WS : green sorghum	M	22.97	27.39	20.02
	SST/L/B	G	21.35	24.08	24
	WS : B : CM_4	P	25.49	24.99	23.45
AER8	PS : LL	M	19.75	18.26	15.4
	SST : ST : CM_7	G	17.77	20.74	15.16
	SST : CM8	P	19.89	21.91	12.1
AER9	BST : LL	M	20.38	22.77	15.7
	BST : LL : CM_2	G	20.36	26.78	19.54
	BJS : CM_2	P	24.59	24.17	22.93
AER10	PS : LL	M	14.26	21.3	15.1
	PS : LL : CM_9	G	14.38	23.16	16.37
	PS : LL : CM_9	P	16.5	26.7	16.91

*Each value is a mean of four observations.

relatively lower[24], whereas that from seven commercial dairy rations (30.1–35.9)[25] was comparatively higher than the CH_4 produced from different feeding systems/diets in the present study. CH_4 production (ml/g) from 24 h incubation of production diet in sheep, goat and buffalo inocula was more than growth and maintenance diets in different AERs. Fermentation of diets/feeding systems in goat inocula resulted in relatively higher CH_4 production than buffalo and sheep. Diets/feeding systems of AER4, AER5 and AER6 produced more CH_4 compared to AER8 and AER10 in the inocula of livestock species. The difference in CH_4 emission of AERs may be attributed to the variation in chemical constituents of dietary ingredients as feeding systems/diets of AER8 were tree leaves-based, while those of AER10 had coconut cake as protein ingredient in the concentrate mixture, which has an inhibitory effect on CH_4 production.

CH_4 production (g kg DDM^{-1}) from diets/feeding systems differed significantly on fermentation in inocula of sheep, goat and buffalo in different AERs (Table 5). CH_4 emission (g kg DDM^{-1}) varied from 21.67 to 42.07, 22.30 to 38.80 and 20.50 to 44.10 from fermentation of diets in inocula of buffalo, goat and sheep respectively. The CH_4 (g kg DDM^{-1}) production values for buffalo, sheep and goat on different diets in the present study are marginally lower than those for a number of diets in goat[22]. Loss of energy as CH_4 from diets ranged between 6.48% and 12.56%, 6.60% and 12.19% and 6.16% and 12.62% for buffalo, goat and sheep respectively. Values on energy loss as CH_4 in the present study were within the range of values reported in earlier studies[26,27], but were relatively higher than the CH_4 losses reported for cattle, sheep and goats[19,28,29]. The higher loss of energy as CH_4 in our study may be partly attributed to more acetate production from structural carbohydrate-rich, poor-quality dry roughages. Livestock species (sheep, buffalo and goats) produced more CH_4 on diets/feeding systems of AER4, AER5, AER6 and AER7, and less from AER2 and AER10.

Table 5. CH_4 production (g kg DDM^{-1}) and loss of energy as CH_4 from diets/feeding system fermented in rumen inocula of buffalo, sheep and goats*

			Buffalo		Goat		Sheep	
AER	Dietary components	Feeding systems/diets	CH_4 g/kg DDM	CH_4% GE	CH_4 g/kg DDM	CH_4%GE	CH_4 g/kg DDM	CH_4% GE
AER1	Grass : GL	M	26.67 ± 1.32	8.46 ± 0.45	37.3 ± 0.03	11.83 ± 1.02	28.25 ± 0.30	8.96 ± 0.16
	SST : L : CM_2	G	29.64 ± 1.44	9.35 ± 0.49	35.9 ± 0.01	11.32 ± 0.13	35.46 ± 1.29	11.17 ± 0.34
	WS : B : CM	P	30.73 ± 0.57	9.40 ± 0.24	33.2 ± 0.02	10.17 ± 0.61	27.67 ± 0.55	8.45 ± 0.09
AER2	Grass : LL	M	21.67 ± 1.08	6.48 ± 0.37	22.3 ± 0.03	6.60 ± 0.94	25.38 ± 1.65	7.54 ± 0.54
	PS : LL : CM_1	G	26.50 ± 0.60	8.11 ± 0.21	23.7 ± 0.03	7.28 ± 1.01	25.64 ± 0.28	7.86 ± 0.24
	Grass : LL : CM_1	P	23.78 ± 0.46	7.17 ± 0.13	30.3 ± 0.01	9.15 ± 0.32	27.07 ± 1.19	8.17 ± 0.40
AER3	MST : CM8	M	34.98 ± 0.62	10.68 ± 0.25	29.7 ± 0.03	9.09 ± 0.96	25.50 ± 0.62	7.79 ± 0.22
	PS : Napier : CM_7	G	28.64 ± 0.84	9.05 ± 0.25	34.8 ± 0.03	10.99 ± 0.85	28.09 ± 0.34	8.88 ± 0.12
	MST : Napier : CM_7	P	26.44 ± 0.87	8.43 ± 0.415	36.4 ± 0.02	11.59 ± 0.74	29.15 ± 0.98	9.27 ± 0.23
AER4	WS : Oat	M	35.28 ± 0.41	11.56 ± 0.23	27.3 ± 0.01	8.96 ± 0.63	31.65 ± 1.01	10.35 ± 0.17
	PS : B	G	30.20 ± 0.80	9.46 ± 0.20	38.8 ± 0.08	12.19 ± 1.34	29.65 ± 0.66	9.30 ± 0.30
	MST : CM_7	P	34.34 ± 0.67	10.83 ± 0.16	35.4 ± 0.01	11.17 ± 0.16	32.34 ± 1.16	10.20 ± 0.33
AER5	WS : B	M	30.41 ± 1.27	9.32 ± 0.50	38.3 ± 0.01	11.72 ± 0.25	36.07 ± 1.73	11.07 ± 0.74
	SST : B : CM_2	G	31.78 ± 1.28	10.02 ± 0.36	32.1 ± 0.02	10.11 ± 0.51	32.57 ± 0.62	10.28 ± 0.31
	WS : B : CM_3	P	36.89 ± 1.82	11.33 ± 0.60	35.6 ± 0.05	10.94 ± 0.26	33.58 ± 0.76	10.31 ± 0.27
AER6	MS	M	31.00 ± 1.49	8.87 ± 0.41	37.9 ± 0.01	10.85 ± 0.12	44.10 ± 0.96	12.62 ± 0.31
	GS : CM_2	G	25.58 ± 0.44	8.21 ± 0.17	29.9 ± 0.01	9.58 ± 0.15	31.99 ± 0.15	10.26 ± 0.15
	MS : CM_5	P	33.63 ± 0.49	10.78 ± 0.24	33.1 ± 0.01	10.60 ± 0.14	32.84 ± 0.80	10.52 ± 0.25
AER7	WS : green sorghum	M	33.65 ± 1.19	10.32 ± 0.49	38.0 ± 0.01	11.64 ± 0.20	33.06 ± 0.84	10.14 ± 0.40
	SST/L/B	G	42.07 ± 1.06	12.56 ± 0.33	33.5 ± 0.01	10.00 ± 0.40	35.41 ± 0.91	10.58 ± 0.32
	WS : B : CM_4	P	33.94 ± 0.72	10.04 ± 0.23	27.2 ± 0.01	8.05 ± 0.09	32.97 ± 0.65	9.75 ± 0.16
AER8	PS : LL	M	29.76 ± 0.97	9.79 ± 0.21	23.9 ± 0.01	7.86 ± 0.09	34.00 ± 1.06	11.20 ± 0.38
	SST : ST : CM_7	G	29.31 ± 0.92	9.37 ± 0.30	32.3 ± 0.02	10.34 ± 0.06	32.71 ± 0.34	10.46 ± 0.19
	SST : CM8	P	22.28 ± 1.84	6.92 ± 0.56	36.0 ± 0.02	11.17 ± 0.43	34.62 ± 0.54	10.76 ± 0.02
AER9	BST : LL	M	24.05 ± 1.62	7.33 ± 0.58	30.3 ± 0.01	9.22 ± 0.28	30.26 ± 0.59	9.21 ± 0.24
	BST : LL : CM_2	G	30.03 ± 1.19	8.77 ± 0.35	33.1 ± 0.01	9.67 ± 0.19	29.62 ± 0.25	8.65 ± 0.09
	BJS : CM_2	P	30.90 ± 1.22	9.56 ± 0.40	32.0 ± 0.01	9.89 ± 0.31	31.11 ± 0.77	9.63 ± 0.27
AER10	PS : LL	M	27.58 ± 0.97	8.54 ± 0.24	27.7 ± 0.01	8.58 ± 0.13	21.58 ± 0.80	6.69 ± 0.22
	PS : LL : CM_9	G	28.77 ± 0.54	8.86 ± 0.18	30.0 ± 0.01	9.24 ± 0.06	24.28 ± 0.24	7.48 ± 0.15
	PS : LL : CM_9	P	22.78 ± 0.42	6.84 ± 0.19	26.7 ± 0.01	8.02 ± 0.23	20.50 ± 0.18	6.16 ± 0.01

*Each value is a mean of four observations.

CH_4 emission factors

Average CH_4 emission (g d^{-1}) was higher for male crossbred working stock (112.24) followed by male indigenous cattle working stock (101.29; Table 6). Young male and female calves (< 1 yr) of crossbred and indigenous cattle emitted similar CH_4 of 20.70–21.54 g d^{-1}. However, daily CH_4 production of male and female buffalo calves was higher (22.42–26.67 g d^{-1}) than cattle. This may be attributed to their heavy body weight and more feed intake. Male buffalo stock (breeding, working and breeding-plus-working) emitted more CH_4 (181.16, 189.61 and 184.05 g d^{-1}) than milking stock (166.97 g d^{-1}). Average daily CH_4 emission for different categories of sheep and goat varied from 4.33 to 14.16 g $head^{-1}$ day^{-1}. The values of CH_4 emission for different age groups and physiological stages of ruminants in the present study are marginally low, except male working buffaloes and breeding + working bulls, than those reported by Singhal *et al.*[12]. CH_4 emission values for Indian ruminant species (sheep, goat, cattle and buffalo) as reported by Kamra *et al.*[30] also partially agree with our values. CH_4 emission rate (g d^{-1}) of cattle, sheep and goat for developing countries reported by Leng[31] is consistent with our values. On the other hand, emission values of ruminant animals from developed countries[29,32] are higher than the present values. Low DMI calculated for different feeding systems/diets in the present study may be partly attributed to the relatively low CH_4 emissions in the study. Variability in CH_4 emissions may be attributed to the method of estimation, feed composition and animal weight[33–36].

Table 6. CH_4 emission from different categories of livestock in 2003

Livestock category	Population '000	CH_4 emission (tonnes)	CH_4 kg $head^{-1}\ yr^{-1}$	CH_4 g $day^{-1}\ head^{-1}$
Cattle crossbred (male)				
< 1 yr	1,933	14.84	7.67	21.03
1–1.5 yrs	1,140	12.35	10.83	29.67
Breeding	212	7.50	35.37	96.92
Working	1,384	56.70	40.97	112.24
Breeding + working	162	5.86	36.14	99.03
Others	108	2.88	26.64	72.99
Total	4,939	100.12		
Cattle crossbred (female)				
< 1 yr	3,909	30.74	7.86	21.54
1–2.5 yrs	3,529	51.92	14.71	40.31
Milking	8,179	301.05	36.81	100.84
Dry	3,055	90.58	29.65	81.23
Heifer	818	14.32	17.51	47.97
Others	252	5.06	20.06	54.962
Total	19,742	493.67		
Cattle indigenous (male)				
< 1 yr	9,850	77.02	7.82	21.42
1–1.5 yrs	11,998	137.05	11.42	31.29
Breeding	2,032	74.05	36.44	99.84
Working	50,379	1862.58	36.97	101.29
Breeding + working	2,393	88.35	36.14	101.15
Others	879	22.80	25.93	71.06
Total	77,531	2261.85		
Cattle indigenous (female)				
< 1 yr	14,155	106.99	7.55	20.70
1–3 yrs	14,934	234.03	15.67	42.93
Milking	26,409	975.03	36.92	101.15
Dry	17,919	523.69	29.225	80.07
Heifer	3,711	87.19	23.49	64.37
Others	1,149	30.00	26.11	71.54
Total	78,277	1956.93		
Buffalo (male)				
< 1 yr	7,371	60.33	8.18	22.42
1–2 yrs	3,835	52.93	13.80	37.81
Breeding	640	42.32	66.12	181.16
Working	5,207	360.37	69.21	189.61
Breeding + working	629	42.25	67.18	184.04
Others	203	10.01	49.31	135.11
Total	17,885	568.22		
Buffalo (female)				
< 1 yr	15,265	148.59	9.73	26.67
1–3 yrs	13,795	292.67	21.21	58.12
Milking	33,320	2030.66	60.94	166.97
Dry	13,905	644.56	46.35	126.99
Heifer	3,055	94.82	31.03	85.03
Others	693	23.74	34.26	93.86
Total	80,033	3235.06		
Goat male				
< 1 yr	19,214	30.52	1.58	4.35
> 1 yr	17,749	46.86	2.641	7.23
Total	36,963	77.37		
Goat female				
< 1 yr	24,767	39.18	1.58	4.33
> 1 yr milking	34,241	101.39	2.96	8.11
Dry	29,535	73.08	2.47	6.78
Total	88,543	213.66		

(*Contd*)

Table 6. (*Contd*)

Livestock category	Population '000	CH_4 emission (tonnes)	CH_4 kg $head^{-1}\ yr^{-1}$	CH_4 g $day^{-1}\ head^{-1}$
Sheep crossbred male				
< 1 yr	688	1.31	1.90	5.21
> 1 yr	1,089	5.49	5.04	13.81
Total	1,777	6.80		
Sheep crossbred female				
< 1 yr	942	1.82	1.93	5.30
> 1 yr	3,106	12.38	3.98	10.91
Total	4,048	14.20		
Sheep indigenous male				
< 1 yr	5,984	10.49	1.75	4.80
> 1 yr	8,738	36.72	4.20	11.51
Total	14,722	47.21		
Sheep indigenous female				
< 1 yr	7,494	13.20	1.76	4.82
> 1 yr	33,467	114.06	3.41	9.33
Total	40,961	127.26	5.17	14.16
Grand total	465,421	9098.40		

CH_4 production from livestock species

Annual enteric CH_4 production of 9.10 Tg has been estimated for Indian livestock from prevailing diets/feeding systems (Table 6). Growing calves, producing stock (lactating, breeding, working and breeding-plus-working) and dry and other (maintenance) crossbred stock produced a total of 340,183.52, 1,016,743.57 and 269,906.75 g CH_4 day^{-1} respectively (Table 7). CH_4 production (g $head^{-1}$ day^{-1}) of different categories of crossbred cattle was highest from AER8 and lowest from AER9. The lower population of crossbred cattle in AER9 may be due to the harsh climate of the region which is not conducive for rearing of crossbred cattle. On the other hand, CH_4 production from indigenous cattle was highest from AER3 (growing – 418,234.64, producing – 1,715,347.55 and dry/maintenance – 408,807.47 g d^{-1}). CH_4 production from growing, producing and dry/maintenance buffalo stock was higher in AER4 (371,453.78, 1,067,799.33 and 306,893.02) and AER5 (3,386,398.84, 1,668,737.19 and 351,227.09) and lowest from AER10 (2211.24, 6837.53 and 1819.55 $head^{-1}$ day^{-1}) respectively. CH_4 production from different categories of sheep and goat stock was highest in AER8 (growing – 32,128.09; producing – 207,537.76) and AER6 (growing – 25,510.84, producing – 65,406.51 and dry/maintenance – 51,450.08 $head^{-1}$ day^{-1}) respectively.

CH_4 production recorded for growing calves, producing and dry and other indigenous cattle population (000) was 1,759,669.99, 8,214,139.09 and 1,579,429.54 g $head^{-1}$ day^{-1} respectively. CH_4 production from population (000) of growing, producing and dry, and other buffaloes was 1,779,025.53, 6,782,503.82 and 1,858,406.79 g $head^{-1}$ day^{-1} respectively. Total CH_4 from indigenous and crossbred sheep was 72,383.25 and 457,451.99 g d^{-1} respectively. CH_4 production from growing, producing, and dry (maintenance) goats (000) was 190,944.95, 406,177.42 and 200,222.48 g d^{-1} in all AERs of the country.

Indigenous cattle contributed maximum (46.0%) to the total livestock CH_4 production followed by buffaloes (41.1%; Figure 1). Contribution of crossbred cattle was more (6.46%) than that in goat (3.2%) and sheep (2.1%). This pattern of livestock species contribution to the country's total livestock CH_4 production is similar to earlier reports[12]. CH_4 production was highest for indigenous cattle (4217.0 Gg) and lowest for sheep (193.4 Gg; Table 7). Within the livestock species females of crossbred cattle, buffalo, sheep and goat contributed more (73.0–85.1%) than males (14.94–27.9%), except indigenous cattle where females contributed less (46.4%) than their male counterparts (53.6%; Table 6).

Livestock enteric CH_4 production in different AERs

Total CH_4 production from livestock species (g/d/head) in different AERs regions is given in Table 7. Daily CH_4 production (g $head^{-1}$) was higher from AER6 (4,294,533.70) and AER7 (4,281,958.74) and lowest from AER10 (157,213.33). Of the total 9.10 Tg CH_4 emissions from Indian livestock, AER6 and AER7 constitute 1.56 and 1.57 Tg respectively (Figure 2). Total CH_4 production was as low as 0.06 and 0.32 Tg from AER10 and AER2 respectively, which could be due to low livestock population in these regions. In all the AERs, cattle contribute more than other species, except AER5, where contribution of buffalo was more than other species in the total

TABLE 7. Total CH_4 production from livestock species (000) in different AERs (g d^{-1})

AER	Cross bred cattle			Indigenous cattle			Buffalo			Sheep		Goat			Total
	Growing	Producing	Maintenance	Growing	Producing	Maintenance	Growing	Producing	Maintenance	Growing	Producing	Growing	Producing	Maintenance	
AER1	27,980.15	153,777.74	14,201.54	50,306.71	386,877.64	38,910.70	46,511.92	277,441.37	48,820.13	6,928.68	44,870.25	5203.57	25,584.50	6,595.23	1,134,010.13
AER2	17,752.15	34,344.81	7,564.45	158,092.65	474,920.16	54,919.27	14,926.34	66,706.86	8,298.18	721.44	1,921.79	10,194.02	14,886.01	3,676.82	868,924.97
AER3	34,579.32	84,411.69	29,237.24	418,234.64	1,715,347.55	408,807.47	39,242.32	361,338.13	53,793.78	7,228.67	26,372.12	44,120.09	86,039.92	32,105.59	3,340,858.52
AER4	39,347.37	89,025.76	28,803.90	257,268.16	893,549.38	188,988.61	371,453.78	1,067,799.33	306,893.02	2,674.73	7,271.78	31,351.83	48,244.67	19,905.56	3,352,577.90
AER5	37,633.76	173,354.33	32,774.71	88,327.26	519,422.10	79,480.45	386,398.84	1,668,737.19	351,227.09	1,939.23	10,648.31	9,824.16	23,649.96	9,673.12	3,393,090.51
AER6	12,974.75	62,767.08	13,409.39	214,624.78	1,574,308.28	273,663.13	243,544.83	1,336,501.18	353,450.02	7,367.22	59,555.61	25,510.84	65,406.51	51,450.08	4,294,533.70
AER7	53,982.88	167,907.46	42,410.06	319,934.56	1,680,318.92	260,590.31	289,561.98	1,001,825.07	303,146.12	5,760.28	42,781.73	28,443.02	63,258.76	22,037.59	4,281,958.74
AER8	76,014.08	164,139.48	80,481.66	135,764.46	533,655.35	164,207.57	191,470.86	489,145.59	264,764.69	32,128.09	207,537.76	20,019.35	44,547.31	26,528.10	2,430,404.37
AER9	8,209.31	26,410.58	5,178.29	108,459.22	417,448.94	104,852.03	193,703.43	506,171.57	166,194.20	7,621.01	56,467.21	13,909.76	31,661.73	27,329.28	1,673,616.56
AER10	31,709.75	60,604.63	15,845.52	8,657.56	18,290.76	5,010.00	2,211.24	6,837.53	1,819.55	13.90	25.41	2,368.32	2,898.05	921.10	157,213.33
	340,183.52	1,016,743.57	269,906.76	1,759,670.00	8,214,139.09	1,579,429.54	1,779,025.53	6,782,503.82	1,858,406.79	72,383.25	457,451.99	190,944.95	406,177.42	200,222.48	24,927,188.72

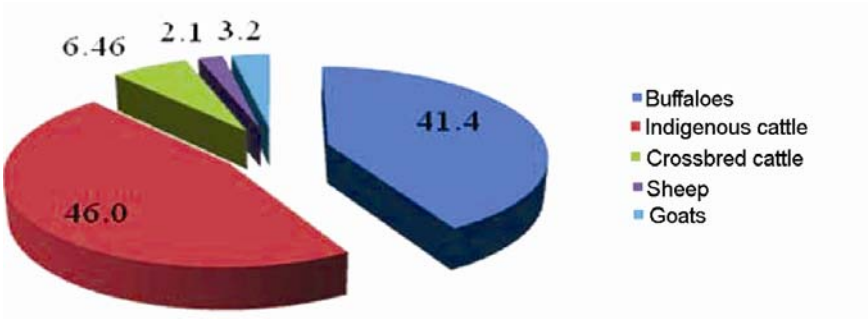

Figure 1. Percentage of CH_4 contribution from different livestock species.

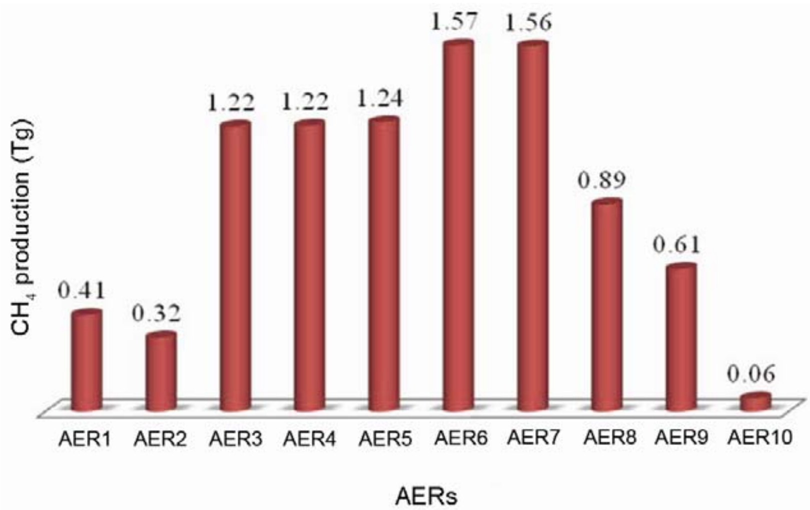

Figure 2. Enteric CH_4 (Tg) production from livestock in different agro ecological regions (AERs).

CH_4 production of the region (Table 7). Production diets/feeding systems (lactating/breeding/working/breeding + working) resulted in higher CH_4 production (6.16 Tg) followed by growing (1.51 Tg) and maintenance diets (1.43 Tg; Table 7).

Conclusion

In India animals are reared on different feeding systems/diets comprising locally available roughage and feed ingredients according to the animal physiological needs in different AERs of the country. Enteric CH_4 emission estimated for Indian livestock using animal population of 2003 was 9.10 Tg, wherein indigenous cattle and buffalo had the major contribution. DMI and digestibility of diets/feeding systems varied significantly among diets of different AERs. Loss of energy as CH_4 from diets/feeding systems varied from 6.48% to 12.56%, 6.60% to 12.19% and 6.16% to 12.62% for buffalo, goat and sheep respectively. Working males and milking females of bovines had a major share in the total CH_4 emissions. Within the species, indigenous cattle stock contributed maximum to CH_4 production followed by buffalo. Female stocks of buffalo, crossbred cattle, sheep and goat contributed more than male stock except indigenous cattle where male contributed more (53.6%) than female (46.4%). Amongst the AERs, livestock from AER6 and AER7 emitted maximum CH_4 against the lowest from AER10. CH_4 emission was higher from cattle in all AERs than other species, except AER5, where buffalo contributed more than the others. Majority of CH_4 came from production diets followed by growing and maintenance. The results of the present study, where a large variation was recorded on the intake, digestibility and CH_4 emission factors from diets of different AERs in different animal species, provide an opportunity for animal agriculture to reduce the CH_4 pollution by dietary manipulation. Location-specific nutritional interventions can be taken up for altered dietary composition to reduce CH_4 production.

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ACKNOWLEDGEMENTS. We thank MoEF, GoI for providing financial support to carryout this work. We also thank the Head, PAR Division and Director, IGFRI, Jhansi for providing the necessary facilities.

Received 23 July 2011; revised accepted 13 February 2012