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METHANE FOOTPRINT OF MILK IN INTEGRATED CROP-LIVESTOCK FARMS IN INDIAN PUNJAB

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ABSTRACT

The present study was undertaken to examine the methane footprint of milk in integrated crop-livestock farms in Indian Punjab by taking stock of a crucial narrative, i.e., the methane emission in relation to the specie-specific milk production. The formulations of the study are based on the primary data from 180 mixed farms with a herd volume of 1064 heads from all three agro-climatic zones (Central Plain Zone: Zone 1, South-western Zone: Zone 2, and Sub-mountainous Zone; Zone 3) of Punjab. The enteric methane emission at the farm level has been quantified by using Tier II methodology given by The Intergovernmental Panel on Climate Change (IPCC, 2007), The estimation has provided evidence that the methane emission rate has been the lowest in the case of indigenous cattle in comparison to buffalo and crossbred cattle. The entire in-milk herd accounted for 81.2% of the farm level enteric methane emission, the contribution of lactating buffalo being the highest (50.3%) followed by crossbred (27%) and indigenous cattle (3.9%). The study has conclusively established the supremacy of crossbred cattle from the environmental sustainability standpoint, with the carbon footprint of crossbred cows' milk being the lowest (681.6 g CO_2-e/kg milk) in comparison to that of buffalo (836.1 g CO_2-e/kg milk) and indigenous cattle (900.9 g CO_2-e/kg milk). The long-term solution for enhancing the sustainability of livestock sector lies in lowering the quantum of methane emission, which calls for policy prescriptions to address the issue of lowering the emissions and enhancing the productivity.

Keywords: *Bubalus bubalis*, buffaloes, enteric methane, livestock agriculture, integrated crop-livestock farms, methane footprint, Punjab

INTRODUCTION

The livestock sector emerges as one of the major contributors to the environmental issues at every scale from local to global. Greenhouse gases emanating from livestock farming and in particular enteric methane (CH_4) are criticized for being one of the major contributors to climate change (FAO, 2006; FAO, 2010; Rotz, 2017; Golub *et al*., 2013; Eisler *et al*., 2014). Among GHGs emitted from global livestock sector, the contribution of methane (CH_4) stands at 44% followed by nitrous oxide (29%)

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and carbon dioxide (27%) (IPCC, 2007; Gerber *et al*., 2013). Methane emissions from livestock are estimated to be approximately 2.2 billion tonnes of CO_2 equivalents, accounting for about 80% of agricultural methane and 35% of the total global anthropogenic methane emissions (FAO, 2006, Sejian *et al*., 2016). Methane, mainly produced by enteric fermentation and manure storage, is a gas which has far-fetched effect on global warming. Due to higher trapping capacity of methane (roughly 28 times more heat that of carbon dioxide), methane emission from the livestock sector has far greater role in devising adaption strategies for climate change (Durocher *et al*., 2014). In global terms, milk production systems alone are responsible for approximately 2.7% of all the anthropogenic greenhouse gas emissions (Thoma *et al*., 2013). GHG emissions are expected to increase by 35% by 2050, especially in developing countries due to animal population growth (Patra, 2012).

The livestock wealth of India is one of the largest in the world wherein, India ranks first in buffalo population and second in cattle population at the global level (Anonymous, 2019). India emerged as the largest contributor to the livestock methane budget, simply because of its enormous livestock population, although the emission rate per animal in the country happens to be much lower than that in the developed countries (Crutzen *et al*., 1986; Lerner *et al*., 1988). Indian livestock is an integral part of the agricultural production system and plays an important role in the national economy by contributing 4.6% to the country's GDP and about 20% to the agricultural GDP (Kashish and Kataria, 2020). Milk contributes more than one third to the total value of output from livestock sector in India. However, in the case of Punjab, milk contributes more than 80% to the state's value of output from the livestock sector (Anonymous, 2019).

Against this backdrop, the present study was undertaken to examine the methane footprint of milk production by taking stock of a crucial narrative, i.e., the methane emissions from the livestock component of mixed farms of Punjab in relation to the specie-specific milk production.

MATERIALS AND METHODS

The study, based on primary data, has covered all the three agro-climatic zones (Central Plain Zone, South-western Zone and Sub-mountainous Zone) of Punjab state. Four stage sampling technique was used for the selection of sampling units. At the first stage, one district each from Zone 1 (Sub-Mountainous Region) and Zone 3 (South Western Region) and two districts from Zone 2 (Central Plain Region) were randomly selected to account for the differences in the size of the zones to some extent. The random selection of one block from each of the four districts marked the second stage. At the next stage, a cluster of three villages from each of the selected blocks, making a total of 12 villages were selected. The selection of crop livestock farms synonymously referred to as mixed farms (wherein more than 10% of the dry matter fed to livestock comes from crop sector FAO 2010), 45 each from Zone 1 and Zone 3 and 90 mixed farms from Zone 2 marked the final stage. The data for the study culminated in the year 2020 were collected through a specially structured interview schedule. The interview schedule was pre-tested on non-sampled mixed farms before the actual administration and based on that, necessary modifications were incorporated to extract the valid responses.

The estimation of enteric methane emission at the farm level has been done by using Tier II methodology given by The Intergovernmental Panel on Climate Change (IPCC) on the premise that it would better capture the zonal differentials in herd composition, feeding practices and fodder availability (IPCC, 2007). The estimation details are appended in the Appendix. For meaningful presentation of the results the Analysis of Variance technique was used for ascertaining the statistical significance of interzonal and inter farm size groups differentials with respect to study variables (Anderson *et al*., 2012).

RESULTS AND DISCUSSIONS

Livestock sector at large and the dairy sector in particular occupy an important position in the Punjab economy. There is enough justification for this as 82% of the value of output from livestock sector in Punjab originates from milk group (Kashish and Kataria, 2020). In this context, the sustainability of livestock agriculture and its likely impact on environment is a matter of concern. In the sections that follow, the various facets of livestock agriculture in Punjab, considered pertinent for the accomplishment of the objectives, have been portrayed.

Narratives of crop-livestock farm

The herd size was observed to be the highest in case of Zone 2 (7.09) followed by that in Zone 3 (5.40) and Zone 1 (4.07), the overall figure being 5.91. The livestock intensity measured in terms of livestock units per 10 acre was found to be the highest in the case of Zone 2 (7.09) followed by Zone 3 (5.88) and Zone 1 (5.44). It can be readily observed that among the different zones, both Net Sown Area (10.00 acre) and Gross Cropped Area (21.07 acre) was observed to be the highest for Zone 2 and the lowest for Zone 1 (7.47 and 15.21 respectively). The fodder area has been observed as 0.87 acres in case of Zone 1, 2.07 acres in case of Zone 2 and 1.52 acres in case of Zone 3 with the overall being 1.64 acres (Table 1).

Details of livestock heads reared

A total of 180 mixed farms of Punjab selected for the present study had a herd volume of 1064 heads with average herd size of 5.91 per farm (Table 2). The herd size in a typical mixed farm of Punjab was observed to be the highest in the case of Zone 2 (7.09) followed by that in Zone 3 (5.40) and Zone 1 (4.07). An average mixed farm selected for the present study comprised of 3.76 buffalo, 1.84 crossbred and 0.32 indigenous cattle with buffalo, crossbred and indigenous cattle being in the ratio of 6.4: 3.1: 0.5 for a herd of ten.

The pattern remained the same in the case of all the zones. The lesser preference to crossbred cattle over buffalo can be attributed to non-adaptability of crossbred cattle to extreme weather conditions of Punjab. The number of in milk buffalo was the highest in Zone 2 (2.58) followed by that in Zone 3 (1.69) and Zone 1 (1.29). The lactating indigenous cows in absolute terms were observed to be the maximum in the case of Zone 2 (0.26) followed by Zone 1 (0.20) and Zone 3 (0.09). Driven by the higher productive performance, the farmers' preference for crossbred over indigenous cattle has been very well reflected in the findings of the present study. The number of crossbred cattle has been reported as 1.64 in Zone 1, 1.87 in Zone 2 and 1.98 in Zone 3 in relation to indigenous cattle recorded as 0.40 in Zone 1, 0.39 in Zone 2 and 0.09 in Zone 3, respectively. The dry animals were conspicuous by their absence in Zone 1, which may be indicative of the phenomenon of the abandonment of the milch animals once they get dry.

Enteric methane emission by species and physiological status

The quantification of methane emission by animals of different species and physiological status has been done by using Tier 2 methodology given by IPCC by subjecting each entity of the sample herd of 1064 animals to the strict assessment protocol.

The average annual enteric methane emission per lactating buffalo varied from 75.54 kg CH_4 observed for Zone 1 to 84.8 kg CH_4 in the case of Zone 3, the differences attributed to quantity and quality of feed available and other variables factored in the assessment (Table 3). As expected, the enteric methane emission factors for lactating animals were comparatively higher in relation to heifers and young stocks. Enteric methane emission for buffalo heifer was assessed to be the highest in the case of Zone 1 (34.39 kg CH_4/animal/annum) closely followed by Zone 2 (34.30 kg CH_4/animal/annum) and Zone 3 (34.25 kg CH_4/animal/annum). No conspicuous difference was recorded for enteric emission of buffalo heifers among different zones of the state. None of the sampled farms of Zone 1 was found to have reared dry buffalo, hence the study could not derive the emission factor for dry buffalo particularly in this zone. In case of Zone 2 and Zone 3, the emission factor for dry buffalo was estimated at 57.7 kg CH_4/animal/annum. The annual enteric methane emission factor for the draft buffalo was recorded as the maximum for Zone 3 (46.06 kg CH_4/animal) and the minimum in the case of Zone 2 (43.76 kg CH_4/animal). The lactating buffalo were found to emit far more methane than their counterparts with different physiological status.

The annual enteric methane emission per lactating crossbred cow varied from 74.78 kg CH_4/animal in Zone 1 to as high as 83.98 kg CH_4/animal/annum in Zone 2. In Zone 2, in-milk crossbred animals emitted higher enteric methane (83.98 kg CH_4/animal) in comparison to that reared in Zone 1 (74.78 kg CH_4/animal/annum) and Zone 3 (78.79 kg CH_4/animal), while in the case of draft animals, the emission factor was recorded as the highest for Zone 3 (43.03 kg CH_4/animal) and the lowest for the Zone 2 (38.88 kg CH_4/animal). Similar trend was recorded for the crossbred heifers wherein annual enteric emission factor was observed to be the highest in the case of Zone 3 (37.60 kg CH_4/animal) and the lowest in the case of Zone 2 (32.50 kg CH_4/animal). None of the farmers in Zone 1 and Zone 3 had reared dry crossbred cattle on their farm so the study could not derive emission factors for the respective zones while for Zone 2, the enteric emission factor of dry animals was computed to be 55.27 kg CH_4/animal. As in the case of buffalo, lactating crossbred cattle emits higher enteric methane in comparison to the rest of the heads with different physiological status.

The annual enteric methane emission per lactating indigenous cow was recorded to be the highest in the case of Zone 2 (67.56 kg CH_4/animal) followed by Zone 3 (66.39 kg CH_4/animal) and Zone 1 (58.59 kg CH_4/animal). However indigenous heifer, dry and young stocks were not reared on any of the mixed farms of Zone 1 and Zone 3, attributed primarily to lower preference of indigenous cattle due to low milk productivity. The annual enteric emission factor for indigenous heifers in the case of Zone 2 was estimated to be 39.45 kg CH_4/animal while for indigenous young stocks, the factor was to the tune of 11.55 kg CH_4/animal. The enteric emission factor for indigenous draft animals was 41.26 kg CH_4/animal/annum in the case of Zone 1 and 39.17 kg CH_4/animal/annum in the case of Zone 2.

Farm level enteric methane emission

The average enteric methane emission was recorded as the highest in the mixed farms of Zone 2 (397.37 kg CH_4/farm) followed by that in Zone 3 (303.80 kg CH_4/farm) and Zone 1 (228.61 kg CH_4/farm) (Table 4). Comparatively higher per farm methane emission in the case of Zone 2 farms may be related to the interplay of higher herd intensity and larger lactating population with higher emission factors in comparison to other two zones. In absolute terms, the annual methane emission for buffalo was recorded as the highest in the case of Zone 2 (270.11 kg CH_4/farm) being 1.5 and 2.3 times higher than that observed in the case of Zone 3 and Zone 1 farms. In percentage terms, buffalo accounted for the maximum share in farm level emission, the quantum being 50.8% in Zone 1, 68% in Zone 2 and 60.8% in Zone 3, which is very much in consonance with the buffalo herd size. In case of crossbred cattle, the annual methane emission ranged from 94.99 kg CH_4/farm in Zone 1 to as high as 113.26 kg CH_4/farm of Zone 3. Crossbred cattle contributed nearly 42% to the farm emission in the case of Zone 1, 37% in the case of Zone 3 and more than one fourth (26.8 % to be more precise) in the case of Zone 2. The annual methane emission from indigenous cattle on per farm basis was recorded as the highest in the case of Zone 2 (20.57 kg CH_4/farm), being 3.4 and 1.2 times higher than that observed in the case of Zone 3 and Zone 1. The share of indigenous cow in farm level enteric methane was the highest (7.6 %) in Zone 1, in relation to 5.2% in Zone 2 and only 2% in the case of Zone 3 farms, although in absolute terms, indigenous cattle in Zone 2 farms produced more methane (20.58 kg CH_4/farm) than their counterparts from other zones. The relatively smaller contribution of indigenous cattle to the total farm emission in the state could be primarily attributed to lesser preference of indigenous cattle in comparison to crossbred cattle and buffalo due to the lower milk productivity.

In the case of all the zones, the entire lactating herd accounted for more than 80% of the farm level enteric methane emission. The corresponding value at the state level has been recorded at 81.2%, the contribution of lactating buffalo being the highest (50.3%) followed by crossbred (27 %) and indigenous cattle (3.9%).

Milk production details

In the table that follows, the information pertaining to the productivity level of different species and quantum and composition of milk production at farm level, which would be subsequently related to methane emission, has been presented. If we look at the milk productivity, as expected it was observed to be the highest in the case of crossbred cattle for all the selected zones of the state (Table 5). For crossbred cattle, the highest milk productivity was observed for Zone 2 (9.31 kg/d/animal) followed by Zone 3 (9.18 kg/d/animal) and Zone 1 (8.61 kg/d/animal). Similar trend was recorded for the productivity of buffalo and indigenous cattle i.e., the highest for Zone 2 (8.01 and 6.31 kg/d/animal) and the lowest for Zone 1 (6.89 and 4.95 kg/d/animal). The total milk production was recorded to be the highest in the case of Zone 2 (32.30 kg/d/farm) followed by that in Zone 3 (24.78 kg/d/farm) and Zone 1 (19.44 kg/d/farm).

Narratives of livestock component of mixed farms

As discussed earlier, buffalo occupied the place of prominence in the lactating herd of all the zones, their proportion being the maximum for Zone 2 (65.8%), followed by Zone 3 (56.3%) and Zone 1 (49.6%) (Table 6). In case of all the three zones, the contribution of buffalo to the milk production was less than proportionate, while it was more than proportionate in methane emission relative to the share in in-milk herd, the percentage being 50.8 vs. 49.6 in the case of Zone 1, 66.6 vs 65.8 in Zone 2 and 58.2 vs 56.3 in Zone 3. Similar trend has been observed in the case of crossbred cattle of Zone 1 and Zone 2. The high productivity potential of crossbred cattle has been well reflected in the proportionately higher share in milk production in relation to its share in lactating herd. In the case of low methane emitting indigenous cattle, the share in methane emission has been lower than that in the case of in-milk herd connoting their low emission status.

Specie-wise comparison of methane footprint of milk

Ruminants are known to be, a large contributor of greenhouse gas emissions particularly due to enteric fermentation. Since, enteric methane emissions from ruminants raised for their milk and meat account for 30% of the global anthropogenic methane emissions, its quantum has special significance in ascertaining the sustainability of livestock component of mixed farms. The sustainability of milk production in the present study has been measured by a catch-all factor termed ‘methane footprint', which is methane emission expressed in carbon equivalents per unit of milk production. The present section focuses on comparing the different livestock species in terms of their methane emission intensity to pinpoint environmentally most sustainable livestock species in the case of Punjab.

In case of Zone 1, the methane emission intensity was statistically higher ($P<0.05$) in the case of indigenous cattle (920.7 g CO_2-e/ kg milk) in comparison to both buffalo (852.7 g CO_2-e/kg milk) and crossbred cattle (675.5 g CO_2-e/ kg milk) establishing the supremacy of crossbred cattle in terms of its sustainability (Table 7). A similar trend was observed in the case of Zone 2 and Zone 3, wherein the methane footprint of milk production was the lowest in the case of crossbred cattle in comparison to that in the case of buffalo and indigenous cattle. Specifically in the case of Zone 2, the methane emission intensity was found to be the highest in the case of indigenous cattle (832.8 g CO_2-e/kg of milk) and statistically at par with that observed in the case of buffalo (803.2 g CO_2-e/kg milk) and significantly higher than that observed in the case of crossbred cattle (701.6 g CO_2-e/ kg milk) as enunciated by ANOVA application. The conspicuously higher emission intensity in the case of indigenous cattle can be attributed to poor genetic potential leading to lower milk productivity. The analysis focused on comparing the different livestock species in terms of their methane emission in relation to milk productivity has established the supremacy of crossbred cattle as being environmentally the most sustainable in the case of Punjab, the methane footprint being the lowest in the case of crossbred cows (681.6 g CO_2-e/kg milk) in comparison to buffalo (836.1 g CO_2-e/kg milk) and indigenous cattle (900.9 g CO_2-e/kg milk).

Since the sustainability of milk production and its likely impact on environment is a matter of concern for Punjab’s economy, the policy prescriptions should weigh the trade-off between propagating the rearing of low methane emitting indigenous cattle or crossbred cattle characterised by lower methane footprint attributed to higher milk productivity. The long-term solution for

Table 1. Narratives of crop-livestock farms of Punjab.

Particulars	Zone 1(n_1 = 45)	Zone 2 (n_2 = 90)	Zone 3 (n_3 = 45)	Overall (N = 180)
Herd size, No.	4.07	7.09	5.40	5.91
Livestock intensity*	5.44	7.09	5.88	6.45
Net Sown Area, acres	7.47	10.00	9.19	9.16
Gross Cropped Area, acres	15.21	21.07	18.71	19.02
Fodder area, acres	0.87	2.07	1.52	1.64

*Livestock units/10 acre of land.

Table 2. Herd composition in selected crop-livestock farms of Punjab. (No. /farm)

Particulars buffalo	**Zone 1 (n_1 = 45)**	**Zone 2 (n_2 = 90)**	**Zone 3 (n_3 = 45)**	**Overall (N = 180)**
Lactating	1.29	2.58	1.69	2.03
Dry	-	0.10	0.04	0.06
Heifers	0.29	0.67	0.44	0.52
Young stock: Male	0.09	0.47	0.22	0.31
Young stock: Female	0.29	0.86	0.73	0.68
Draught animals	0.07	0.17	0.20	0.15
Sub total (I)	2.02	4.83	3.33	3.76
Crossbred cow				
Lactating	1.11	1.08	1.22	1.12
Dry	-	0.02	-	0.01
Heifers	0.13	0.18	0.24	0.18
Young stock: Male	0.02	0.09	0.09	0.07
Young stock: Female	0.31	0.47	0.40	0.41
Draught animals	0.07	0.03	0.02	0.04
Sub total (II)	1.64	1.87	1.98	1.84
Indigenous cow				
Lactating	0.20	0.26	0.09	0.20
Dry	-	-	-	-
Heifers	-	0.06	-	0.03
Young stock: Male	-	-	-	-
Young stock: Female	0.09	0.04	-	0.04
Draught animals	0.11	0.03	-	0.04
Sub total (III)	0.40	0.39	0.09	0.32
Total herd size (I+II+III)	4.07	7.09	5.40	5.91

Table 3. Enteric methane emission factors (kg CH_4/animal/annum) for different species and physiological status of dairy animals.

Particulars	Zone 1	Zone 2	Zone 3
Buffalo			
Lactating (n_{1L}: 58, n_{2L}: 50, n_{3L}:9)	75.54	82.71	84.84
Heifer (n_{1H}: 13, n_{2L}: 60, n_{3L}:20)	34.39	34.30	34.25
Dry (n_{1D}: 0, n_{2D}: 9, n_{3D}:2)	-	57.72	57.65
Young stock (n_{1Y}: 17, n_{2Y}: 119, n_{3Y}:43)	14.97	15.43	15.86
Draft animal (n_{1DF}: 3, n_{2DF}: 15, n_{3DF}:9)	43.81	43.76	46.06
Crossbred cattle			
Lactating (n_{1L}: 50, n_{2L}: 97, n_{3L}:55)	74.78	83.98	78.79
Heifer (n_{1H}: 6, n_{2L}: 16, n_{3L}:11)	37.14	32.50	37.60
Dry (n_{1D}: 0, n_{2D}: 2, n_{3D}:0)	-	55.27	-
Young stock (n_{1Y}: 15, n_{2Y}: 50, n_{3Y}:22)	15.13	14.00	13.60
Draft animal (n_{1DF}: 3, n_{2DF}: 3, n_{3DF}:1)	41.43	38.88	43.03
Indigenous cattle			
Lactating (n_{1L}: 9, n_{2L}: 23, n_{3L}:4)	58.59	67.56	66.39
Heifer (n_{1H}: 0, n_{2L}: 5, n_{3L}:0)	-	39.45	-
Dry (n_{1D}: 0, n_{2D}: 0, n_{3D}:0)	-	-	-
Young stock (n_{1Y}: 0, n_{2Y}: 4, n_{3Y}:0)	-	11.55	-
Draft animal (n_{1DF}: 5, n_{2DF}: 3, n_{3DF}:0)	41.26	39.17	-

Table 4. Enteric methane (kg CH_4/annum) emission from different species of livestock animals on per farm basis.

Particulars	Zone 1 (n_1= 45)		Zone 2 (n_2= 90)		Zone 3 (n_3 = 45)		Overall (N = 180)	
	Enteric methane		Enteric methane		Enteric methane		Enteric methane	
	kg CH_4/annum	%	kg CH_4/annum	%	kg CH_4/annum	%	kg CH_4/annum	%
Buffalo	116.15	50.8	270.11	68.0	184.58	60.8	211.59	63.5
Lactating	97.31	42.6	213.78	53.8	142.45	46.9	167.65	50.3
Others	18.84	8.2	56.33	14.2	42.13	13.9	43.94	13.2
Crossbred cattle	94.99	41.6	106.68	26.8	113.26	37.3	105.27	31.6
Lactating	82.24	36.0	90.8	22.9	96.33	31.7	89.88	27.0
Others	12.75	5.6	15.88	4.0	16.93	5.6	15.39	4.6
Indigenous cattle	17.47	7.6	20.58	5.2	5.96	2	16.45	4.9
Lactating	11.89	5.2	16.56	4.2	5.96	2.0	13.04	3.9
Others	5.58	2.4	4.02	1.0	-	-	3.41	1.0
Farm Total	228.61		397.37		303.8		333.31	

Table 5. Milk production details of different species of dairy animals. (kg/d)

Particulars	Zone 1 (n_1= 45)		Zone 2 (n_2= 90)		Zone 3 (n_3 = 45)	
	Per animal	Per farm	Per animal	Per farm	Per animal	Per farm
Buffalo	6.89	8.89	8.01	20.67	7.74	13.08
Crossbred cattle	8.61	9.56	9.31	10.05	9.18	11.20
Indigenous cattle	4.95	0.99	6.31	1.64	5.44	0.49
Total milk		19.44		32.36		24.77

Table 6. Contribution of different species in methane emission in relation to in-milk herd and its output.

Particulars	Contribution (%) of different species in		
	In-milk herd	**Milk production**	**Methane emission***
Zone 1			
Buffalo	49.6	45.7	50.8
Crossbred cattle	42.7	49.2	43.0
Indigenous cattle	7.7	5.1	6.2
Zone 2			
Buffalo	65.8	64.0	66.6
Crossbred cattle	27.6	31.0	28.3
Indigenous cattle	6.6	5.0	5.2
Zone 3			
Buffalo	56.3	52.8	58.2
Crossbred cattle	40.7	45.3	39.4
Indigenous cattle	3.0	1.9	2.4

*From farm's in-milk herd

Table 7. Species wise methane footprint of milk production.

(g CO_2-e/kg of milk)			
Particulars	**Buffalo**	**Crossbred cattle**	**Indigenous cattle**
Zone 1 (n_{1B}: 58, n_{1CB}: 50, n_{1IC}: 9)	852.7^b	675.5^c	920.7^a
Zone 2 (n_{2B}: 232, n_{2CB}: 97, n_{2IC}: 23)	803.2^a	701.6^b	832.8^a
Zone 3 (n_{3B}: 76, n_{3CB}: 55, n_{3IC}:4)	852.6^b	667.5^c	949.2^a
Overall (n_{pB}: 366, n_{pCB}: 202, n_{pIC}:36)	836.1^b	681.6^c	900.9^a

^{abc}Figures with different superscripts in a row differ significantly (P<0.05). Figures in parentheses indicate the number of lactating animals.

enhancing the sustainability of livestock sector lies in lowering the quantum of methane emission from livestock production and directing the efforts towards the productivity enhancement of low methane emitting indigenous cattle, which would ultimately culminate the methane footprint.

CONCLUSIONS

The analysis of the field level data from Indian Punjab has testified that the methane emission rate has been the lowest in the case of indigenous cattle in comparison to buffalo and crossbred cattle. However, high methane emitting crossbred cattle due to their higher milk productivity have realized lower methane emission intensity (methane per unit of milk) in comparison to indigenous cattle and buffalo. The assessment of sustainability of milk production has established the supremacy of crossbred cattle as being environmentally the most sustainable. It needs to be reaffirmed that the conspicuously higher emission intensity in the case of indigenous cattle is due to lower milk productivity attributed primarily to poor genetic potential needing urgent attention. The long term solution for enhancing the sustainability of livestock sector lies in lowering the quantum of methane emission from livestock production and directing the efforts towards the productivity enhancement of low methane emitting indigenous cattle, which would reduce the methane intensity, Taking into consideration the ‘3P Dimension’ (People, Profit and Planet) of sustainability of livestock sector, the policy makers need to work in tandem with economists, agricultural scientists, livestock professionals and extension workers to attain and sustain the goal of white revolution surpassing the green revolution in true sense of words.

REFERENCES

Anonymous. 2019. *Livestock Production Statistics of India - 2019.* Vet Extension Prosperous Livestock Prosperous Nation. Available on: https://www.vetextension.com/livestock-animal-production-statistics-of-india-2019/

Anderson, D.R., D.J. Sweeney and T.A. Williams. 2012. *Statistics for Business and Economics*. Cengage Learning India Private Limited, New Delhi, India.

Crutzen, P.J., I. Aselmann and W. Seiler. 1986. Methane production by domestic animals, wild ruminants, other herbivorous fauna, and humans. *Tellus B: Chemical and Physical Meteorology*, **38B**: 271-284. DOI: 10.1111/j.1600-0889.1986.tb00193.x

Durocher, G.Y., A.P. Andrew, D. Bastviken, R. Conrad, C. Gudasz, A. St-Pierre, N. Thanh-Duc and P.A. del- Giorgio. 2014. Methane fluxes show consistent temperature dependence across microbial to ecosystem scales. *Nature*, **507**(7493): 488-491. DOI: 10.1038/nature13164

Eisler, M.C., M.R.F. Lee, J.F. Tarlton, G.B. Martin, J. Beddington, J.A.J. Dungait, H. Greathead, J. Liu, S. Mathew, H. Miller, T. Misselbrook, P. Murray, V.K. Vinod, R.V. Saun and M. Winter. 2014. Agriculture: Steps to sustainable livestock. *Nature*, **507**(7490): 32-34. DOI: 10.1038/507032a

FAO. 2006. *Livestock Long Shadow: Environmental Issues and Options*. Food and Agriculture Organization, United Nations, Rome, Italy.

FAO. 2010. *Greenhouse Gas Emissions from the Dairy Sector: A Life Cycle Assessment.*

Food and Agriculture Organization, United Nations, Rome, Italy. Available on: https://www.fao.org/4/k7930e/k7930e00.pdf

Gerber, P.J., H. Steinfeld, B. Henderson, A. Mottet, C. Opio, J. Dijkman, A. Falcucci and G. Tempio. 2013. *Tackling Climate Change Through Livestock: A Global Assessment of Emissions and Mitigation Opportunities*. Food and Agriculture Organization, United Nations, Rome, Italy.

Golub, A.A., B.B. Henderson, T.W. Hertel, P.J. Gerber, S.K. Rose and B. Sohngen. 2013. Global climate policy impacts on livestock, land use, livelihoods and food security. *In The Proceedings of the National Academy of Sciences*, USA. **110**(52): 20894-20899. Available on: https://www.pnas.org/content/pnas/110/52/20894.full.pdf

IPCC. 2007. Climate change 2007: The physical science basis. p. 129-234. *In* Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, H.L. Miller. (eds.) *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK. Available on: https://www.ipcc.ch/site/assets/uploads/2018/05/ar4_wg1_full_report-1.pdf

Kashish and P. Kataria. 2020. Livestock economy of India with particular reference to Punjab. *International Journal of Livestock Research*, **10**(9): 81-90. DOI: 10.5455/ijlr.20200523040433

Lerner, J., E. Matthews and I. Fung. 1988. Methane emission from animals: A global high-resolution data base. *Global Biogeochemical Cycles*, **2**: 139-156. DOI: 10.1029/GB002i002p00139

Patra, A.K. 2012. Estimation of methane and nitrous oxide emissions from Indian livestock. *J. Environ. Monitor.*, **14**: 2673-2684.

Patra, A.K. 2014. Trends and projected estimates of GHG emissions from Indian livestock in comparisons with GHG emissions from world and developing countries. *Asian-Austral. J. Anim. Sci.*, **27**(4): 592-599.

Rotz, A.C. 2017. Modeling greenhouse gas emissions from dairy farms. *J. Dairy Sci.*, 101**(7)**: 6675-6690. DOI: 10.3168/jds.2017-13272

Sejian, V., R. Bhatta, P.K. Malik, B. Madiajagan, Y.A.S. Al-Hosni, M. Sullivan and J.B. Gaughan. 2016. Livestock as sources of greenhouse gases and its significance to climate change. *In* Moya, B.L. and J. Pous. (eds.) Greenhouse Gases. *IntechOpen*, DOI: 10.5772/62135.

Thoma, G., J. Popp, D. Shonnard, D. Nutter, M. Matlock, R. Ulrich, W. Kellogg, D.S. Kim, Z. Neiderman, N. Kemper, F. Adom and C. East. 2013. A regional analysis of greenhouse gas emissions from USA dairy farms: A cradle to farm-gate assessment of the American dairy industry circa 2008. *International Dairy Journal*, **31**: S29-S40. DOI: 10.1016/j.idairyj.2012.09.010

APPENDIX

Estimation of Enteric Methane from the Livestock Sector

Information on feed consumption level by different categories of animals at country level is the precondition to estimate greenhouse gases emission from livestock production system. Intergovernmental Panel on Climate Change (IPCC) guidelines gave two methods to estimate emission factors (IPCC, 2006). In Tier I method, default emission factors and data on number of animals for different livestock groups are needed. Tier II method requires country specific data on:

a) Animal population,

b) Average daily feed intake and

c) Methane conversion rate (% of feed energy converted to methane)

The Tier II characterization methodology also seeks to define animal productivity, diet quality and management circumstances to support a more accurate estimate of feed intake for use in estimating methane production from enteric fermentation, thus requiring enormous efforts. The Tier II methodology was considered more appropriate than the Tier I method because it incorporates location specific information. The formulations of the present study are based on Tier II methodology on the premise that it would better capture the zonal differentials in herd composition, feeding practices and fodder availability.

For the calculation of enteric methane emission from the livestock sector particularly for Tier II, following variables are required:

1. Herd size
2. Animal Body weight
3. Daily feed and fodder intake
4. Calculation of Digestible energy
5. Daily milk production (kg) and fat content (%) of milk

Herd size

Herd size includes the number of animals reared on the farm by the mixed farms. All the animals viz. lactating, non- lactating, heifers and young stocks etc. were considered for the study.

Conversion into Standard Animal Units (SAU)

In order to reasonably infer the results, the varied dairy animals were transformed into Standard Animal Units (SAU), synonymously known as Adult Cattle Units (ACUs). The ACUs were therefore formed as Table 1.

Estimation of Animal Body Weight

In order to estimate the animal body weight, *Shaeffer's* formula was used. For estimation, measurement of length, L (from the point of shoulder to the point of pin bone) and heart girth, G (around the thoracic cavity just behind the elbow joint), were taken with the measuring tape. The *Shaeffer's* formula (Sastry *et al.* 1982 and Garg *et al.* 2013) is as follows:

$$\text{Animal Body Weight (kg)} = \frac{(G)^2 \times (L)}{300} \times 0.454$$

Where,

G = Heart Girth, inch

L = Body Length, inch

0.454 is the conversion factor for pound to kilogram

Daily feed and fodder intake

Daily feed and fodder fed to dairy animals asked during the survey from the respondents with the help of pre-structured interview schedule.

Estimation of feed and fodder availability on dry matter (DM) basis

Livestock fodder availability was estimated on DM basis and the dry matter content of different fodders utilized by the respondent farmers is as follows:

a. Maize : 25.0 %
b. Pearl millet : 19.4 %
c. Sorghum : 28.1 %
d. Berseem : 12.5 %
e. Oats : 26.3 %
f. Tree leaves : 35.2%

Feedipedia (Animal feed resources information system).

Calculation of digestible energy

Feed intakes estimates were calculated by using daily dry matter intake for each animal category and from daily dry matter intake (kg), digestible energy (MJ/ kg DM) for different feeds and fodder was calculated separately. The factors for each feed and fodder were taken from the *Feedipedia (Animal feed resources information system)* website and Ranjan,1991.

Step I Conversion of feed intake on fresh matter basis into dry matter intake (DMI)

The average daily feed intakes on fresh matter basis, as collected from various sources mentioned earlier are converted into dry matter based on the percentage dry matter in the feeds. The respective conversion factors were taken from the book Ranjhan, 1991. For the dry fodder and concentrates, the dry matter was taken as 90% of fresh matter. Wherever more than one type of green fodder was fed to the animals and separate quantities of each type is not available, apportionment of total quantity of green fodder into different types of green fodder is done, on the basis of share of each fodder type in total green fodder in the zone. The details of apportionment / weighting pattern are enumerated in detail in the next step.

Step II Conversion of dry matter intake into digestible energy (%)

Based on the cropping pattern, area under fodder crops and pasture and grazing land, the availability of dry fodder and concentrate was worked out in each zone as per the methodology and assumptions in a comprehensive study on availability of feed and fodder in various states of India (Jain *et al*., 1996).

1) The ratio of major feed types in total dry fodder, green fodder and concentrate availability in the zone (eg. Paddy/wheat/coarse cereal straw in total dry fodder/oats/sorghum etc. in total green fodder; mustard / cottonseed / groundnut cake in total oilcake concentrates) was to apportion dry matter from dry fodder, green fodder and concentrates into dry matter from different types of respective feeds.

2) The DMI from each feed type was then multiplied by the digestible energy (in Mega Joules per Kg DMI, MJ/Kg DMI) of that feed to arrive at digestible energy from intake of feed type. The total digestible energy intake of the respective category of animals was obtained by summing up the gross values of percentages of digestible energy expressed in dry matter basis. The conversion values of different feed types are obtained from the composition and nutritive value of feeds. (Sen *et al*., 1978; Ranjhan, 1991) and are as follows:

a. Berseem: 69.8 %
b. Oat: 74.8 %
c. Pearl Millet: 65.5 %
d. Jowar: 60.3 %
e. Maize: 64.2 %
f. Tree Leaves: 72.5 %

Daily milk production (kg) and Fat content (%) of milk

Daily milk production from each category (buffalo, indigenous and crossbred) of dairy animal is asked during the survey from each of farm selected for the study for all the three seasons viz. summer, rainy and winter. To see the fat content milk, generally the cooperative societies were visited which generally keeps the record of each and every farmer. The price of the milk is determined as per the fat content available in the milk.

Estimation of enteric methane

The formulations of the present study are based on Tier II methodology The step wise estimation procedure is detailed below.

Net Energy for maintenance;

$$NE_{ma} = C_i \times (\text{weight})^{0.75}$$

Where,

NE_{ma} = Net Energy for maintenance, MJ/day

C_i = Coefficient which varies for each animal category, MJ/day/kg

= 0.322 for Non-lactating cattle/buffalo;

= 0.386 for lactating cattle/ buffaloes;

= 0.370 for bulls

Weight = Live animal weight, kg

Net Energy for activity;

$$NE_a = C_a \times NE_{ma}$$

Where,

NE_a = Net Energy for activity, MJ/day

C_a = Coefficient corresponding to animal feeing situation (Stall fed or Pasture fed)

C_a = 0.00 for Stall fed

= 0.17 for Pasture fed

NE_{ma} = Net Energy for maintenance, MJ/day

Net Energy for growth;

$$NE_{gr} = 22.02 \times \left[\frac{BW}{C \times MW}\right]^{0.75} \times WG^{1.097}$$

Where,

NE_{gr} = Net Energy for Growth, MJ/day)

BW = Average live body weight of the animal, kg

MW = Mature body weight of the animal, kg

WG = Weight gain of the animal, kg/day

C = Coefficient with a value of 0.8 for females, 1.0 for castrates and 1.2 for bulls

Net Energy for lactation;

$$NE_{la} = \text{Milk} \times (1.47 + 0.40 \times \text{fat})$$

Where,

NE_{la} = Net energy for lactation, MJ/day

Milk = amount of milk produced, kg/day

Fat = Fat content of milk, %

Net energy for work;

$$NE_{work} = 0.10 \times NE_{ma} \times \text{Hours}$$

Where,

NE_{work} = Net energy for work, MJ/day

NE_{ma} = Net energy for maintenance

Hours = Number of hours of work per day

Net energy for pregnancy

$$NE_{pr} = C_{pr} \times NE_{ma}$$

Where,

NE_{pr} = Net energy for pregnancy, MJ/day

C_{pr} = Pregnancy coefficient

NE_{ma} = Net energy for maintenance, MJ/day

C_{pr}= 0.10 for cattle and buffaloes

Ratio of net energy available in diet for maintenance to digestible energy consumed (REM).

$$REM = \left[1.123 - (4.092\times10^{-3}\times DE\%) + \left[1.126\times10^{-5}\times(DE\%)^2\right] - \left(\frac{25.4}{DE\%}\right)\right]$$

Where,

REM = Ratio of net energy available in a diet for maintenance to digestible energy consumed

DE = Digestible energy expressed as a percentage of gross energy, %

Ratio of net energy available for growth in a diet to digestible energy consumed (REG).

$$REG = \left[1.164 - (5.160\times10^{-3}\times DE\%) + \left[1.308\times10^{-5}\times(DE\%)^2\right] - \left(\frac{37.4}{DE\%}\right)\right]$$

Where,

REG = Ratio of net energy available for growth in a diet to digestible energy consumed

DE = Digestible energy expressed as a percentage of gross energy, %

Gross energy

$$GE = \left[\frac{\left(\frac{NE_{ma}+NE_{a}+NE_{1a}+NE_{work}+NE_{pr}}{REM}\right)+\left(\frac{NE_{gr}}{REG}\right)}{\frac{DE\%}{100}}\right]$$

Where,

GE = Gross energy, MJ/day

NE_{ma} = Net energy required by the animal for maintenance, MJ/day

NE_{a} = Net energy for animal activity, MJ/day

NE_{la} = Net energy for lactation, MJ/day

NE_{work} = Net energy for work, MJ/day

NE_{pr} = Net energy required for pregnancy, MJ/day

REM = Ratio of net energy available in a diet for maintenance to digestible energy consumed

NE_{gr} = Net energy for growth, MJ/day

REG = Ratio of net energy available for growth in a diet to digestible energy consumed

DE % = Digestible energy expressed as a percentage of gross energy

Methane emission factor for enteric fermentation from livestock animals

$$\text{Emission Factor (EF)} = \left[\frac{GE \times \left(\frac{Y_m}{100}\right) \times 365}{55.65}\right]$$

Where,

EF = emission factor, kg CH_4 /head/yr

GE = Gross energy intake, MJ/head/ day

Y_m = Methane conversion factor, per cent of gross energy in feed converted to methane

The factor 55.65 (MJ/kg CH_4) is the energy content of methane.

Methane conversion factor (Y_m), percent of gross energy in feed converted to methane was taken as 6.5% (IPCC, 2006; Garg *et al*., 2016).

REFERENCES

Garg, M.R., P.L. Sherasia, B.M. Bhanderi, B.T. Phondba, S.K. Shelke and H.P.S. Makkar. 2013. Effects of feeding nutritionally balanced rations on animal productivity, feed conversion efficiency, feed nitrogen use efficiency, rumen microbial protein

Table 1. Conversion factors for estimating ACUs.

Animals	Age (years)	ACU
Buffalo	>2.5	1.14
	1-2.5	0.50
	<1.0	0.17
Cattle	>2.5	1.00
	1-2.5	0.34
	<1.0	0.11

Source: Ramachandra *et al.* (2007).

supply, parasitic load, immunity and enteric methane emissions of milking animals under field conditions. *Anim. Feed Sci. Tech.*, **179**(1-4): 24-35. DOI: 10.1016/j.anifeedsci.2012.11.005

Garg, M.R., B.T. Phondba, P.L. Sherasia and H.P.S. Makkar. 2016. Carbon footprint of milk production under smallholder dairying in Anand district of Western India: A cradle-to-farm gate life cycle assessment. *Anim. Prod. Sci.*, **56**(3): 423-36. DOI: 10.1071/AN15464

IPCC. 2008. 2006 IPCC Guidelines for national greenhouse gas inventories-A primer. *In* Eggleston, H.S., L. Buendia, K. Miwa, T. Ngara and K. Tanabe. Eggleston, H.S., L. Buendia, K. Miwa, T. Ngara and K. Tanabe. *The Intergovernmental Panel on Climate Chance, National Greenhouse Gas Inventories Programme*. Institute for Global Environmental Strategies, Kanagawa, Japan. Available on: https://www.ipcc-nggip.iges.or.jp/support/Primer_2006GLs.pdf

Jain, D.K., K.N.S. Sharma, T.K. Walli and S.N. Rai. 1996. *Estimates of Nutrients Requirement and Availability for Bovine Population Across Major States in India*. National Dairy Research Institute, Indian Council of Agricultural Research, National Dairy Research Institute, Karnal, India.

Ramachandra, K.S., V.K. Taneja, K.T. Sampath, S. Anandan and U.B. Angadi. 2007. *Livestock Feed Resources in Different Agro-Ecosystems of India: Availability, Requirement and Their Management*, National Institute of Animal Nutrition and Physiology, Bangalore, India.

Ranjhan, S.K. 1991. *Chemical Composition and Nutritive Value of Indian Feeds and Feeding of Farm Animals*. Indian Council of Agricultural Research, New Delhi, India.

Sastry, N.S.R., C.K. Thomas and R.A. Singh. 1982. *Farm Management and Poultry Production*, 2nd ed. Vikas Publishing House, New Delhi, India.

Sen, K., S.N. Ray and S.K. Ranjhan. 1978. *Nutritive Value of Indian Cattle Feeds and Feeding of Dairy Animals.* Indian Council of Agricultural Research, New Delhi, India.