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Pilot study on carbon footprint of small-scale beef cattle production at South-West region of Bangladesh

N G Das*, N Sultana, M T Islam, M A Kabir, S M J Hossain

Bangladesh Livestock Research Institute, Savar, Dhaka – 1341, Bangladesh

Abstract

The study was conducted to investigate feed basket composition, greenhouse gas (GHG) emission factors and carbon footprint of beef cattle production at Khulna division, Bangladesh. Data were collected on herd structure, farm feedstuff, manure management and farm operation of 231 beef cattle farms by interviewing farmers and filling up open questionnaires. The feed basket of 75 beef cattle of different genotypes in 24 farms was studied by keeping a record of individual feedstuff intake for three months. Results indicated that the feed basket of a 321 (±131) kg beef cattle, irrespective of genotype, was consisted of rice straw, Napier grass, maize fodder, jumbo grass and concentrate mixture at 3.61 (±1.60), 3.25 (±4.66), 0.21 (±1.34), 0.07 (±0.58), 1.73 (±3.08) and 3.69 (±1.40) kg/d, respectively. The digestibility of diet, volatile solids in manure and nitrogen excretion rate were estimated as 65 (±3.89) %, 8.3 (±2.01) and 0.29 (±0.07) kg/d/1000 kg LW, respectively. The emission factors of enteric CH_4, manure CH_4 were 46 (±18), and 9.06 (±10.86) kg CH_4/yr/animal. The direct and indirect N_2O emission factors due to volatilization and leaching were 2.96 (±0.01), 0.06 (±0.07) and 0.017 (±0.019) kg N_2O/yr/animal, respectively. Based on the results of emission factors, including the carbon footprint of farm feedstuff (0.33 (±0.33) kg CO_2e/yr/t fresh) and farm operation emission factor (131 (±109) kg CO_2e/yr/cattle), the carbon footprint of beef cattle production was estimated as 7.68 (±0.98) kg CO_2e/kg LW of beef cattle. Estimation of GHG emission factors for all sources in each livestock enterprise, and then accounting for carbon footprint may help realize the environmental cost of production and undertake appropriate mitigation measures.

Key words: Beef cattle genotypes, Feed basket composition, Greenhouse gas emission factors, Carbon footprint, Life cycle assessment

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Introduction

Anthropogenic greenhouse gas (GHG) emissions (such as CO_2, CH_4 and N_2O) are a global concern due to their global warming and climate change impacts. Such GHG emission from agriculture forestry and land use change (AFOLU) was about 12 Giga tonne (Gt) CO_2 equivalent (CO2e)/yr (23%, total anthropogenic emission; 52 Gt CO_2e/yr) wherein emission from livestock production was 4.1 Gt CO_2e/yr (Mbow et al., 2019: IPCC, 2019a). In Bangladesh,

* Correspondence: nani.gd@hotmail.com

agricultural GHG emission in 2014-15 was 77 million tonnes (Mt) of CO_2e, and mitigation of about 10 Mt by 2030 would be possible if climate-smart crop and livestock management could be adopted (Sapkota *et al.*, 2021). Improvement of GHG inventory (Das *et al.*, 2020) from Tier 1 to Tier 2 needs data on production categories and detail subcategories of livestock species with their specific emission factors. Also, studying livestock subcategories for their specific emission factors in their on-farm production and management practices may help understand effective mitigation actions for unconditional reduction of GHG emission by 0.64 Mt CO_2e in 2030 including conditional reduction of 0.40 Mt CO_2e (total 1.04 Mt CO_2e) from business-as-usual emission of 55.01 Mt CO_2e from AFOLU sector (MoEFCC, 2021). The GHG emission factors of a livestock category/subcategory for their enteric fermentation and manure are determined by the quantity and quality of the feed basket (feedstuff, chemical composition, and digestibility) with other environment and management facets.

When farm feedstuff is consumed by cattle, about 45-85% of feedstuff is lost through feces due to their indigestibility, which contributes to GHG emission at different levels according to the excretion of volatile solids and nitrogen through manure and the existing manure management systems (IPCC, 2019b). During the metabolism of nutrients, about 2-12% of the gross energy (GE) of the ruminant's diet is lost as methane (Johnsen and Johnsen, 1995). The dietary energy utilization efficiency of different beef cattle genotypes may vary (Cabezas-Garcia *et al.*, 2021). In Bangladesh, the most common feedstuff of beef cattle among farmers was reported to be roadside local grass (61%), followed by cultivated fodders (30%) and rice straw (9%), with supplementation of concentrates at different levels – either commercial or hand-mixed (Kamal *et al.*, 2019). However, specific data on feed basket amount and its feedstuff composition of a beef cattle at farm level are scanty to estimate different GHG emission factors.

Bangladesh produces about 10 million beef cattle in a year of which about 6 million is produced and marketed during the period of Eid ul-Adha – a religious festival (Oman and Liang, 2019). These beef cattle come from different cattle-producing zones of the country, although cattle production is distributed throughout the country. The proportion of cattle with 1000 human population in different districts of Khulna division is 200-300 which is next to the northern region of the country (300-464; Rangpur division) (Huque and Khan, 2017). Also, this region (Khulna) experienced a great rise in livestock population over 70 years (1949 to 2008; 2.77-3.46 livestock unit/ha) according to different agricultural censuses (Rahman et al., 2014). Therefore, the study was undertaken at the Khulna division of the country to investigate:

a) Feedstuff composition of feed-basket of beef cattle at Khulna region during the study period
b) Greenhouse gas emission factors of farm feedstuff, enteric fermentation and manure of beef cattle, and farm operation
c)Carbon footprint of beef cattle production.

Materials and Methods

To determine the carbon footprint of beef cattle production, the emissions of CO_2, CH_4 and N_2O from various sources, including farm feedstuff, enteric fermentation of beef cattle, manure management, and farm operation activities, were estimated and then summed up. The methods used for this estimation are explained in detail below:

Figure 1. Study area (Khulna Division, Bangladesh)

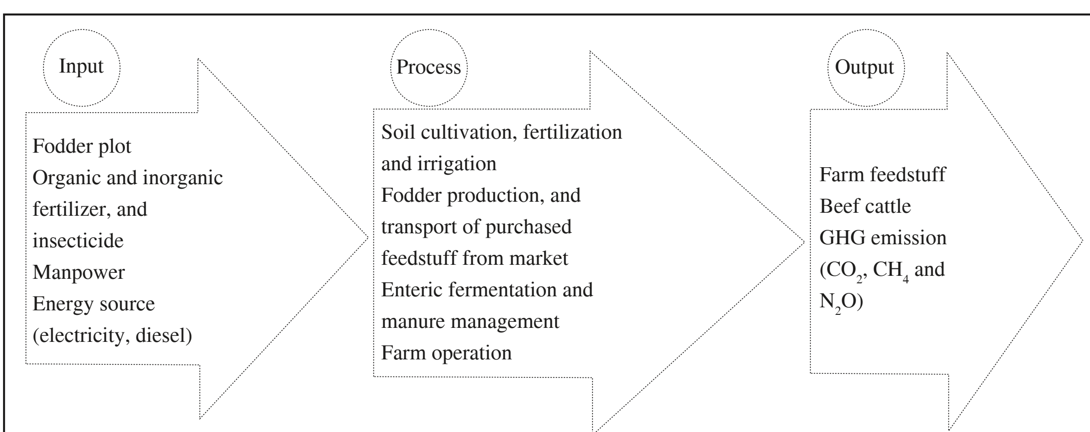

Figure 2: System boundary of the study

Study area and duration

The study was conducted at the southwest division of Bangladesh – Khulna (89° 14' 60.00" E, 22° 54' 59.99" N) – during August 2019 and February-May, 2021. It included Kustia (Kumarkhali), Chuadanga (Alomdanga), Jashore (Sadar), Maghura (Sadar), Jhinaidaha (Harinakunda), and Khulna (Fultola) districts of the division. On average, the area is about two meters above sea level, and classified under the tropical climatic region (Figure 1).

System boundary and functional units

The carbon footprint of beef cattle production was estimated in a life cycle assessment (LCA) of the cradle-to-gate system boundary of small-scale beef cattle production (FAO 2016ab) where CO_2, CH_4, and N_2O emissions from all farming inputs associated with beef cattle management were considered (Figure 2). While estimating the carbon footprint of farm feedstuff, GHG emissions from farm-own rice straw were not included because the production of rice straw is the byproduct of rice production and is not directly related to beef cattle farming. Similarly, concentrate ingredients are byproducts of main crop or grain production activities, and emissions at their production level are not part of beef cattle farms. When local grasses are part of beef cattle feed baskets, their emission was

Table 1. List of life cycle inventory data of beef cattle production

Data types	Parameters
Herd structure	o Number of total beef cattle and their genotypes (Deshi cattle, Pabna cattle, and crosses of Holstein, Sahiwal and Sindhi).
	o Number of other cattle (cow, calf heifer and bulls)
Farm feedstuff	o Sources of farm feedstuff (cultivated or purchased)
	o Annual average farm feedstuff deficiency (D, %)
	o Distance between farm and feed market (km)
	o Name of fodder, size of the plot (ha) and biomass yield (t/cut)
	o Application of chemical fertilizer (kg), organic fertilizer (cattle manure, kg), and insecticide (L).
	o Number of irrigations applied.
	o Diesel burnt by tractor to till the plot (L)
	o Number of man-day workers (8 h/d work) needed from cultivation to harvest
Feed basket	o Age of beef cattle
	o Live weight of beef cattle
	o Daily allowance of feedstuff (straw, grasses, fodder, and concentrate kg/d/beef cattle)
	o Refusals of feedstuff (kg)
	o Daily allowance of concentrate (kg)
	o Ingredient composition of concentrate (%)
Manure management	o Fractions of average annual animal waste management systems.
Farm operation	o Man-day (8-hour work basis) worker needed to manage the farm

also not included in estimating the carbon footprint of farm feedstuff because their production is not anthropogenic. The functional unit of carbon footprint for beef cattle and fodder production was kg CO_2e/yr/kg LW of beef cattle and kg CO_2e/ha/yr, respectively. The global warming potential of CH_4, and N_2O, compared to CO_2 in a 100-year time horizon, was considered as 28 and 265, respectively (Myhre *et al.*, 2013).

Data collection

The distribution pattern of beef cattle farms in the study areas was obtained from Upazila Livestock Offices. After that, we visited 231 stall-fed beef cattle farms and conducted open questionnaires by interviewing farmers, family workers, and regular farm workers to collect data on herd structure, farm feedstuff, feed basket, animal waste management system (AWMS), and farm operation from August 2019 to February-May 2021 (as shown in Table 1).

Farmers were interviewed to estimate the annual average deficiency of animal feedstuff that needs to be purchased from the market, as well as the distance between their farms and the nearest feedstuff market in kilometers. For farmers who have their own fodder plots, agronomical data on fodder production were collected by interviewing them. Data on biomass yield of fodder, measured in tonnes per hectare, was recorded by weighing mature fodder harvested from five different sampling spots (3x3 ft^2) of the plots. The application of animal waste (manure) to the fodder plot was estimated by multiplying the estimated number of baskets applied by 50 (50 kg/basket) and recorded as kilograms per hectare. The estimated quantity of diesel burned to cultivate the plot (tractor, mower, and thresher) was estimated by interviewing local tractor drivers and recorded as liters per hectare (L/ha).

Regarding the study on feed baskets, 24 farmers at Kustia (Kumarkhali), Chuadanga (Alomdanga) and Jhinaidaha (Harinakunda) (10, 10, and 4 farmers, respectively) were randomly selected, wherein data were recorded for 75 beef cattle of different genotypes. The duration of the feed basket study was 3 months (February-May 2021, during which daily allowance of different feedstuff and concentrate mixtures to each beef cattle and the orts the next morning was measured by using a digital balance every ten-day interval and recorded. The age of beef cattle was estimated according to dental formula (Torell *et al.*, 1998) and farmer's record where available. The live weight of beef cattle was estimated for three times (once a month) according to Shaeffer's formula (Johnson *et al.*, 1939) before morning feeding and average was used as live weight of beef cattle and expressed in kg. Farmers were provided with a digital weighing balance (for weighing feedstuff and orts), a measuring tape (length and heart girth), and a notebook to keep records with training and sufficient incentives. During the period, three samples of each feedstuff and concentrate mixtures from each farm were collected (about 500 g), kept in an air-tight bag, and stored in deep freeze (-20°C). At the end of the study, they were thawed at room temperature, pooled, and mixed thoroughly. A portion of the sample of each feedstuff (about 2.5 kg) was sent to the laboratory to determine the DM content of fresh feedstuff. Another portion of a similar amount was dried in a forced air oven at 60°C for 72 h and ground by passing through a 1-mm sieve and sent to the laboratory for determining chemical composition. For determining DM and other chemical composition of rice straw and concentrate mixtures, about 500 g representative samples were processed. The average amount of fresh concentrate ingredients was wheat bran, rice polish, wheat broken, maize broken, rice broken, formulated feed, soybean meal, mustard oil cake, di-calcium phosphate, and common salt at 360, 250, 50, 130, 70, 60, 10, 40, 10, and 20 g/kg.

Farmers were asked to describe how to use their manure in different seasons of the year and the average management systems were recorded (%). They were also interviewed to mention who works for the farm management for how many hours daily. The total hours were divided by 8 to estimate the man-day worker (8 working hour basis) needed for farm management. The farm electricity consumption (kWh/d) was calculated by checking the monthly electricity bill, and the ratio of electric equipment used for the farm and the household.

Chemical composition of feedstuff

The dry matter (DM), organic matter (OM), and crude protein (CP) of feedstuffs and concentrate mixtures were determined according to methods described by the AOAC (2006). The methods of determining DM, ash, and CP (or nitrogen) were 934.01, 934.05, and 981.10, respectively. Briefly, freshly collected roughage samples (about 500g) were chopped into 1-2 cm pieces. Then, about 50g well-mixed samples were taken by repeated mixing, coning, and quartering, and dried in an oven (NF 400, NUVE dry heat oven; NUVE, Turkey) at 105°C for 24 h to determine the DM content. In the case of the concentrate sample, about 10g sample was used. After that, the remaining portion of the samples was dried at 60°C for 48 h, ground in a Willey mill (Thomas-Wiley Laboratory Mill, Thomas Scientific, USA), and passed through a 1-mm sieve. The neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined following the methods of Van Soest *et al.* (1991). The GE contents were determined in a Shimadzu auto-calculating bomb calorimeter (Shimadzu CA-4PJ, Shimadzu Corporation, Japan). The chemical composition of feedstuffs is presented in Table 2.

Table 2. Chemical composition of feedstuff (% DM)

Feedstuff	DM (% fresh)	OM	CP	NDF	ADF	EE	GE
Napier	20.7	89.9	8.9	71.5	42.5	2.0	17.4
Jumbo	22.4	90.5	8.6	75.0	48.6	1.5	17.0
Maize	27.3	92.2	7.9	63.0	31.0	1.9	18.2
Local grass	14.3	89.2	12.4	67.3	41.7	1.6	15.5
Rice straw	87.8	83.8	4.5	71.3	43.2	1.4	15
Concentrate mixture	86.1	95.1	15.3	25.1	8.7	5.2	19.1

DM, dry matter; OM, organic matter; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; EE, ether extract; GE, gross energy.

Emission factors of farm feedstuff

Farm feedstuff consists of cultivated fodder at the farm and/or purchased feedstuff from the market. For cultivated fodder (such as Napier, *Penissetum purpureum;* Jumbo, *Sorghum bicolor;* and Maize, *Zea mays)*, the direct nitrous oxide emission of soil from the application of synthetic fertilizer (FSN) and cattle manure (FON) nitrogen (kg/yr) was calculated according to IPCC (2019b) (IPCC Equation 11.1), as follows:

$$N_2O_{direct}=[F_{SN}+F_{ON}]\times EF_1\times \frac{44}{28}\times 265, \text{ kg/yr } CO_2e.$$

The F_{SN} and F_{ON} were calculated from the amount of urea and manure applied to plots and their nitrogen content. The nitrogen content of urea fertilizer was considered 46% and that of cattle manure nitrogen was 2.9% (fresh basis) (Huang *et al.*, 2017). The default value for EF_1 (kg N_2O-N/ kg nitrogen applied) was taken from IPCC (2019b) (0.01, IPCC Table 11.1). The factor $\frac{44}{28}$ and 265 represents the conversion factor of N_2O-N to N_2O, and CO_2 equivalent factor of N_2O, respectively. Carbon dioxide emission from application of urea was estimated according to IPCC (2019b) (equation 11.13), as follows:

CO_2 emission,kg/yr = Urea applied (kg/yr)×EFc×$\frac{44}{12}$, where EFc is the carbon fraction of urea (0.20), and $\frac{44}{12}$ represents the conversion factor of CO_2-C to CO_2. Carbon dioxide emission during cultivation operations was estimated by the amount of diesel consumed (by tractor, mower or thresher) and diesel emission factor (3.30 kg/L CO_2e, Nielsen *et al.*, 2013). Carbon dioxide emission associated with the irrigation of fodder plots was estimated by multiplying the irrigation emission factor (91.67 kg CO_2e/ha; Dubey and Lal, 2009) with the number of irrigations needed and plot size (ha). Emission associated with worker employed (8-h daily basis) in fodder plots from land preparation to fodder harvest was estimated by the number of workers needed and its emission factor (0.09 kg/man-day CO_2e; Yang, 1996).

Indirect nitrous oxide emission from the application of synthetic fertilizer (F_{SN}) and cattle manure (F_{ON}) was calculated according to (IPCC 2019b; IPCC Equation 11.9 and 11.10), as follows:

N_2 O(Indirect) $=[(F_{SN}\times Frac_{GASF}+F_{ON}\times Frac_{GASM})\times EF_4+(F_{SN}+F_{ON})\times Frac_{(LEACH-(H)}\times EF_5]\times\frac{44}{28}\times 265$, kg/yr CO_2e.

The fractions of fertilizer and manure nitrogen volatilized ($Frac_{GASF}$ and $Frac_{GASM}$), leaching of nitrogen from them ($Frac_{LEACH-(H)}$) and emission factor due to volatilization and leaching (EF_4 and EF_5) were taken from IPCC (2019b; Table 11.3). Indirect carbon dioxide emissions due to manufacturing of fertilizer and insecticide was calculated by multiplying the amount applied to plots (kg or L) and their emission factor (0.70 kg CO_2e /kg urea; IPCC, 2013) and 1.32 kg CO_2e/L insecticide; Hillier *et al,* 2009). Finally, carbon footprint of different cultivated fodder was calculated by the following equation:

CF of fodder production= $\frac{1}{\text{Fodder biomass production}(\frac{tonne}{ha})}\times$ (DNOEFF+ DCEFU+DCEFC+DCEFI+DCEFW+INOEFF+ICEFMU+ICEFMI) kg CO_2e/yr/t fresh fodder biomass.Where CF, carbon footprint; DNOEFF, direct N_2O emission factor from fodder plot; INOEFF, indirect N_2O emission factor from fodder plot; DCEFC, direct CO_2 emission factor from cultivation operation of fodder plots; DCEFI, direct CO_2 emission factor from irrigation of fodder plots; DCEFU, direct CO_2 emission factor for urea application; DCEFW, direct CO_2 emission factor for man-day workers (8 h/d work); ICEFMU and ICEFMI; indirect CO_2 emission factor for manufacture of urea and insecticide, respectively. The following equation estimated the carbon footprint of farm feedstuff:

CF of farm feedstuff= $[(\sum\frac{IDFF}{1000}\times EFDF)\times\frac{100-D}{100}]+[(0.38\times k\times\frac{FB}{1000})\times\frac{D}{100}]$, kg CO_2e/yr/t fresh farm feedstuff; where CF, carbon footprint; IDFF, intake of different farm feedstuff (kg/d/beef cattle, fresh basis); EFDF, emission factor of different fodder production (kg CO_2e/yr/t fresh fodder biomass); D, annual average farm feedstuff deficiency (%); 0.38, transportation emission factor (kg CO_2e/t/km; Kristensen *et al.*, 2015); k, distance between farm and market (km); and FB, average amount of feed basket of a beef cattle (kg/d of total fresh feedstuff intake).

Estimating digestibility and enteric CH_4 emission factor

The intake of nutrients was determined from the DM intake of bulls and the chemical composition of feed basket constituents. The digestibility of the diet was estimated by the following formula (Nolan and Savage, 2009):

Digestibility of DM (%) = 83.6 – 0.82 × ADF + 2.62 × N, where ADF and N represent the percentage of dietary acid detergent fiber and nitrogen, respectively. Metabolizable energy intake was estimated according to Lofgreen and Garrett (1968). Enteric CH_4 emission factor was estimated according to Patra (2017), as follows:

Enteric CH_4 emission factor $(\frac{kg}{yr}) = \frac{1}{0.05565} \times [0.91 + (1.472 \times DMintake(\frac{kg}{d})) - (1.388 \times FL\,(\%live\,weight)) - (0.669 \times ADFintake(\frac{kg}{d}))] \times \frac{365}{1000}$.

Volatile solids (VS) in manure were estimated according to IPCC (2019b), as follows:

$VS(\frac{kg}{d}) = [GE\ intake \times (1 - \frac{DE}{100}) + (UE \times GE\ intake)] \times [\frac{1-ASH}{18.45}]$, where GE, gross energy (MJ/d); DE, digestibility of diet (%); UE, the fraction of GE excreted as urinary energy (0.04; IPCC, 2019b); and ASH, the ash content of manure as a fraction of DM (0.06; IPCC, 2019b). The daily nitrogen excretion of an animal was estimated by summing its fecal and urinary excretion according to Waldrip *et al.* (2014):

Nitrogen excretion $(\frac{g}{d}) = [0.15 \times NI + 24.28] + [0.56 \times NI - 21.18]$, where NI denotes nitrogen intake (g/d). The estimated average VS in manure and nitrogen excretion rate were used in estimating CH_4 and N_2O emission factors from different manure management systems.

Estimating CH_4 and N_2O emission factor from AWMS

Estimation of from manure is determined based on manure characteristics and average animal waste management systems (dimensionless). Taking the AWMS of the present study (dimensionless) and default maximum CH_4 producing capacity of manure (B_0 = 0.13 m^3/kg dry VS; IPCC, 2019b) and the CH_4 conversion factors of different manure management systems in warm tropical and moist climatic conditions (IPCC, 2019b; Table 10.17), CH_4 emission factor from manure management ($MEFM_{anure}$) was calculated according to the following equation:

$MEF_{Manure} = [VS(\frac{kg}{d}) \times 365 \times [B_0 \times 0.67 \times \sum_S(\frac{MCFs}{100} \times AWMS_s)]$, kg/year CH4.

The direct N_2O emission factor for the combined nitrification and denitrification of manure nitrogen under different management systems (NEF_{Dms}) was calculated by the following equation:

$NEF_{Dms} = \sum [\{\sum_S(N_{ex} \times AWMS_S) + N_{cdg}\} \times EF_3] \times \frac{44}{28}$, kg/year N_2O; where Nex, average nitrogen excretion of an animal (kg/year); Ncdg, nitrogen from co-digested such as food wastes or crops in anaerobic digestion (considered 0.00, kg/year); EF_3, direct nitrous oxide emission factor of a manure management system "S" (N_2O-N, kg/kg N; IPCC, 2019b; default values from Table 10.21); 44/28, conversion of N_2O-N to N_2O emissions. The indirect N_2O emission factors for the volatilization and leaching of manure nitrogen (NEF_{Gms} and $NEFL_{ms}$) were calculated by the following equations:

$NEF_{Gms} = N_{Volatilization} \times EF_4 \times \frac{44}{28}$, and $NEF_{Lms} = N_{Leaching} \times EF_5 \times \frac{44}{28}$, kg/year N_2O; where $N_{Volatilization,}$ or $N_{Leaching,}$ amount of manure nitrogen lost due to volatilization, or leaching in different management systems (kg/year), respectively; EF_4 and EF_5, indirect

N_2O emission factors due to atmospheric deposition of nitrogen on soils and water surfaces, and nitrogen leaching (IPCC, 2019b; from Table 11.3). The $N_{Volatilization}$ and $N_{Leaching}$ were calculated by the following equations:

$N_{Volatilization} = \sum s[[(N_{ex} \times AWMS_S)+N_{cdg}] \times Frac_{GasMS}]$, kg/d and $N_{Leaching} = \sum s[[(N_{ex} \times AWMS_S)+N_{cdg}] \times Frac_{LeachMS}]$, where N_{ex}, the manure nitrogen excretion rate of an animal (kg/year); N_{cdg}, nitrogen from co-digested such as food wastes or crops in anaerobic digestion (considered 0.00, kg/year); FracGasMS or FracLeachMS, percent of manure nitrogen that volatilizes as N2O-N and NOX-N or leached in a manure management system "S" (IPCC, 2019b; default values from Table 10.22).

Estimating farm operation emission factor

Exploitation of energy (electricity or diesel) and daily workers (8-hour/d basis) to run farm activities contributes to anthropogenic GHG emissions. Therefore, the farm operation emission factor (FOEF) was calculated by the following equation:

$FOEF = \frac{[0.54 \times E)+(0.90 \times W)]}{Herd\ size} \times 365$, kg/year, CO_2e; where 0.54 and 0.90 denotes emission factor of electricity (kg/kWh CO_2e; CER, 2007) and man day worker (kg/d CO_2e; Yang, 1996); and E and W denotes electricity consumption of the farms (kWh/d) and number of workers employed (man/d).

Carbon footprint of beef cattle production

The carbon footprint of beef cattle production was estimated according to following equation:

Carbon footprint of beef cattle = $[((\frac{CFFF \times FB \times FP}{1000} + FOEF)+(EMEF+MMEF) \times 28+(DNOEF+NOEFV+NOEFL) \times 265] \times \frac{1}{LW}$, $kgCO_2e$/kg LW of beef cattle; where FB, feed basket; FP, fattening period of beef cattle; LW, live weight of beef cattle; EMEF, enteric CH_4 emission factor; MMEF, manure CH_4 emission factor; DNOEF, direct N_2O emission factor; NOEFV, N_2O emission factor due to manure nitrogen volatilization; NOEFL, N_2O emission factor due to manure nitrogen leaching; FOEF, farm operation emission factor.

Statistical analysis

Data are presented in tables by calculating mean, standard deviation (SD), minimum value (Min) and maximum value (Max), using Microsoft Excel Worksheet (Microsoft Office Standard 2013).

Results

Herd Structure

In the study area, the size of the beef cattle farm's herd was 6.26 (±11), out of which 4.84 (±8) were beef cattle. These beef cattle make up 85% of the total cattle population on the farm. Among them, 46% are indigenous cattle genotypes such as Deshi or Pabna (refer to Table 3 for more details).

Table 3. Herd structure of beef cattle

Parameters	Mean	SD	Min	Max	N
Number of beef cattle	4.84	8	2	110	231
Number of other cattle (cow, calf, heifer, ox etc.)	1	3	0	30	231
Herd size (number of total cattle of the farm)	6.26	11	2	140	231
Beef cattle (% total herd)	85	18.2	23	100	231
Indigenous beef cattle (Deshi and Pabna cattle, % beef cattle)	46	39	-	-	231
Beef cattle fattening period (months)	8.24	4.21	3.00	24.33	231

SD, standard deviation; Min, minimum value; Max, maximum value; N, number of observations.

Carbon footprint of farm feedstuff

The Table 4 and 5 present the carbon footprint of fodder cultivation and farm feedstuff, respectively. The cultivation of Napier grass resulted in a greater carbon footprint compared to jumbo or maize fodder. The carbon footprint value of the three fodder types followed the same trend when expressed in biomass productivity. The carbon footprint of farm feedstuff, which combines cultivated fodder and purchased feedstuff in the total feed basket, was 0.333 kg CO_2e/yr/t fresh biomass (Table 5). All farmers fed rice straw and a concentrate mixture to beef cattle (Table 5). Approximately half and a third of farmers fed Napier grass and local grass to beef cattle, respectively. Feeding of maize and jumbo to beef cattle was reported by less than 5% of farmers.

Table 4. Carbon footprint of fodder production

Variables	Napier	Jumbo	Maize
Number of plots	110	12	7
Plot size (ha)	0.13 (±0.20)	0.47 (±0.38)	0.41 (±0.33)
Biomass yield (t/cut/ha)	73 (±31)	35 (±3)	61 (±3)
Urea applied (kg/ha)	155 (±83)	95 (±56)	122 (±42)
Manure applied (kg/ha)	247 (±1514)	106 (±292)	0
Man-day worker needed (8-h man/ha)	125 (±79)	89 (±18)	91 (±7)
Number of irrigations applied	4 (±0.50)	5 (±1)	4 (±1)
Insecticide applied (L/ha)	2.4 (±12)	0	0
Diesel needed for tillage (L/ha)	49 (±6)	47 (±2)	48 (±3)
Greenhouse gas emission from fodder plots (kg/yr/ha CO_2e)			
Direct N_2O emission factor from soil fertilization	328 (±283)	194 (±121)	432 (±80)
Direct CO_2 emission factor from urea	114 (±61)	69 (±41)	90 (±31)
Direct CO_2 emission factor from cultivation operation	162 (±19)	155 (±7)	157 (±10)
Direct CO_2 emission factor from irrigation	350 (±46)	451 (±73)	367 (±53)
Direct CO_2 emission factor from man-day work	11.3 (±7.07)	8 (±2)	8.15 (±0.61)
Indirect N_2O emission factor from soil fertilization	109 (±108)	64 (±41)	76 (±26)
Indirect CO_2 emission from urea manufacture	109 (±58)	66 (±39)	86 (±29)
Indirect CO_2 emission from insecticide manufacture	3.3 (±16.3)	0	0
Carbon footprint of fodder production (kg CO_2e/yr/ha)	1187 (±473)	1008 (±252)	1017 (±193)
Carbon footprint of fodder production (kg CO_2e/yr/t fresh)	359 (±377)	29 (±8)	124 (±152)

Values within parenthesis are the standard deviations of means.

Table 5. Carbon footprint of farm feedstuff

Intake of farm feedstuff (kg/d, fresh)	Mean	SD	Min	Max	F%
Rice straw	3.61	1.60	0.00	6.74	99
Napier grass	3.25	4.66	0.00	20.00	47
Maize fodder	0.21	1.34	0.00	10.00	3
Jumbo grass	0.07	0.58	0.00	5.00	1
Local grass	1.73	3.08	0.00	14.00	31
Concentrate mixture	3.69	1.40	0.81	7.50	100
Total feed basket of a beef cattle* (kg/d fresh)	12.55	5.37	5.31	27.10	-
Annual average farm feedstuff deficiency (%)	73	27	0	100	-
Distance between farm and animal feed market (km)	2.78	1.61	0.50	8.00	-
Carbon footprint of farm feedstuff (kg CO_2e/yr/t fresh biomass)	0.333	0.33	0.002	1.19	-

SD, standard deviation; Min, minimum value; Max, maximum value; F, percentage of farmers who use this feedstuff; *Feed basket data were based on data from 75 beef cattle.

Nutrient intake, digestibility, and enteric methane emission

The table 6 presents the nutrient intake, digestibility, and enteric methane emission factor of different beef cattle genotypes. During the fattening period, cattle genotypes, with weights ranging from 207-519 kg and age ranging from 25-33 months, displayed variation in their feed basket (5.5-8.8 kg DM/d). The average feed basket of beef cattle, regardless of genotype, was 7.3 (±2.15) kg DM/d, consisting of rice straw, green fodder, and local grasses, and concentrate mixtures at 43%, 14%, and 34%, respectively. With similar digestibility rates (65%), they produced comparable amounts of volatile solids and nitrogen excretion rate in manure (8.3 kg/d/1000 kg LW and 0.29 kg/d/1000kg LW, respectively).

Animal waste management systems and greenhouse gas emission factors

Based on the animal waste management systems, it was found that 50% of manure was utilized as burning fuel, followed by daily spreading to croplands, solid storage, pasture/paddock, and other management systems, as illustrated in Figure 3. Table 7 presents the emission factor for manure CH4 and N2O, which is determined by the volatile solids, nitrogen, and manure management systems.

Farm operation emission factor

Farm operation activities require energy and their emission contributing to carbon footprint are presented in Table 8. Results indicate that a farm of about 6.26 (±11) cattle may emit about 131 (±109) kg CO2e/yr due to farm operation activities.

Table 6. Intake of feedstuff, digestibility, and enteric methane emission from beef cattle

Parameters	Indigenous cattle		Crossbred genotypes			Overall
	Deshi	Pabna	Holstein	Sahiwal	Sindhi	
N	25	13	28	7	2	75
Age, months	25 (±7)	28 (±10)	28 (±7)	33 (±3)	27 (±4)	27 (±8)
Live weight, kg	207 (±56)	355 (±89)	359 (±111)	519 (±133)	314 (±36)	321 (±131)
Feedstuff of a beef cattle diet, kg DM/d						
Rice straw	2.0 (±0.78)	3.7 (±1.50)	3.7 (±1.35)	3.6 (±0.95)	4.0 (±1.04)	3.2 (±1.4)
Fodder and local grasses	0.8 (±1.05)	0.9 (±0.90)	1.1 (±1.29)	0.9 (±0.52)	1.9 (±0.05)	0.9 (±1.08)
Concentrate mixture	2.6 (±0.90)	3.5 (±1.28)	3.3 (±1.32)	4.2 (±0.50)	2.6 (±0.30)	3.2 (±1.21)
Total feed basket	5.5 (±1.3)	8.1 (±2.29)	8.2 (±1.79)	8.8 (±1.53)	8.4 (±1.40)	7.3 (±2.15)
FL (DM intake, % LW)	2.7 (±0.38)	2.3 (±0.55)	2.4 (±0.47)	1.9 (±0.68)	2.6 (±0.14)	2.43 (±0.52)
Digestibility (%)	66 (±3.34)	65 (±5.14)	64 (±3.70)	66 (±2.40)	61 (±0.64)	65 (±3.89)
GE intake (MJ/d)	94 (±23)	138 (±38)	139 (±31)	152 (±25)	139 (±23)	125 (±36)
ME intake (MJ/d)	51	73	73	83	69	66 (±19)
Nitrogen intake (g/d)	91 (±25)	128 (±36)	125 (±31)	134 (±19)	120 (±14)	116 (±33)
Enteric CH_4 emission factor, kg CH_4/yr/animal	28 (±11.50)	53 (±16.48)	53 (±15.28)	64 (±7.02)	51 (±10.03)	46 (±18.64)
VS, kg/d/animal	1.8 (±0.43)	2.7 (±0.90)	2.9 (±0.62)	2.9 (±0.62)	3.1 (±0.55)	2.5 (±0.78)
VS, kg/d/1000 kg LW animal	8.9 (±1.59)	7.9 (±2.11)	8.4 (±1.93)	6.2 (±2.52)	9.7 (±0.61)	8.3 (±2.01)
Nitrogen excretion, g/d	68 (±18)	94 (±67)	92 (±22)	105 (±13)	88 (±10)	85 (±24)
Nitrogen excretion rate, kg/d/1000 kg LW	0.33 (±0.05)	0.27 (±0.08)	0.27 (±0.06)	0.22 (±0.07)	0.28 (±10^{-4})	0.29 (±0.07)

N, number of beef cattle studied; FL, feeding level (DM intake, % live weight); GE, gross energy; ME, metabolizable energy; VS, volatile solids in manure; values within parenthesis are standard deviations of the means.

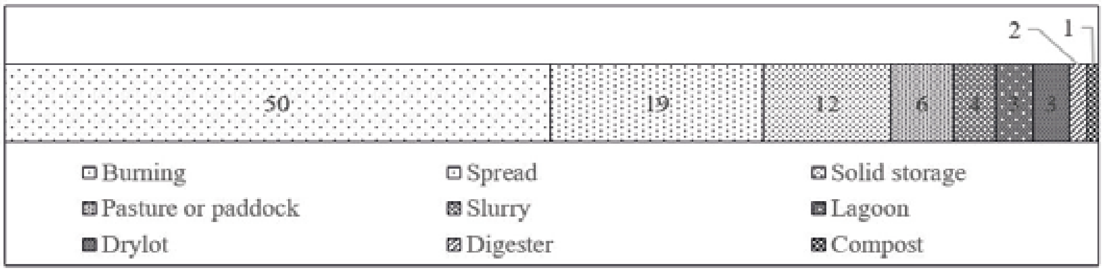

Figure 3. Annual average manure management systems of beef cattle farms (%)

Table 7. Methane and nitrous oxide emission factors from AWMS

Parameters	Mean	SD	Min	Max	N
CH_4 emission factor from manure management, kg CH_4/yr/animal	9.06	10.86	0.79	63.33	231
Direct N_2O emission factor, kg N_2O/yr/animal	2.96	0.01	2.95	3.05	231
Nitrogen volatilization, kg N/yr/animal	3.75	4.36	0.00	20.17	231
Nitrogen leaching, kg N/yr/animal	1.46	1.58	0.00	10.86	231
N_2O emission factor for volatilization of nitrogen, kg N_2O/yr/animal	0.06	0.07	0.00	0.32	231
N_2O emission factor for leaching of nitrogen, kg N_2O/yr/animal	0.017	0.019	0.00	0.13	231

SD, standard deviation; Min, minimum value; Max, maximum value N, number of beef cattle farm studied.

Table 8. Farm operation emission factor

Parameters	Mean	SD	Min	Max	N
Herd size (number of total cattle in the farm herd)	6.26	11	2	140	231
Electricity consumption (kWh/d)	1.82	2.42	0.17	16.67	231
Man-day work employed (8-h man work/d)	1.42	0.87	0.67	8.00	231
Emission from electricity use (kg/d CO_2e)	0.98	1.30	0.09	8.97	231
Emission from man day work (kg/d CO_2e)	1.26	0.81	0.60	7.20	231
Farm operation emission factor (kg CO_2e/yr/farm)	818	673	361	5901	231
Farm operation emission factor (kg CO_2e/yr/cattle)	131	109	58	943	231

SD, standard deviation; Min, minimum value; Max, maximum value; N, number of beef cattle farm studied.

Table 9. Carbon footprint of beef cattle production

Greenhouse gas emissions (kg CO_2e/kg LW of beef cattle)	Mean	SD	Min	Max
CO_2 emission from farm feedstuff	0.003	0.004	8E-06	0.03
CH_4 emission from enteric fermentation	3.976	6E-15	3.98	3.98
CH_4 from manure management	0.790	0.948	0.07	5.52
Direct N_2O emission from manure management	2.440	0.007	2.44	2.52
Indirect N_2O emission due to manure nitrogen volatilization	0.049	0.057	0.00	0.26
Indirect N_2O emission due to manure nitrogen leaching	0.014	0.015	0.00	0.11
CO_2 emission from farm operation	0.408	2E-15	0.41	0.41
Carbon footprint (kg CO_2e/kg LW of beef cattle)	7.680	0.980	6.94	12.60

SD, standard deviation; Min, minimum value; Max, maximum value N, number of beef cattle farm studied.

Carbon footprint of beef cattle production

Table 9 presents the carbon footprint of beef cattle. The estimated carbon footprint of beef cattle was 7.68 (±0.98) kg CO_2e/kg LW, which was mainly attributed to enteric CH_4 emission (52%), followed by direct N_2O emission from manure (32%), CH_4 emission from manure (10%), CO_2 from farm operation (5%), and indirect N_2O emission from manure and farm feedstuff CO_2 emission (1%). Assuming a dressing percentage of 49% for slaughtered cattle in Bangladesh (Ali et al., 2013), the carbon footprint of beef production would be 15.67 kg CO_2e/kg beef (7.68÷49%), excluding GHG emissions associated with slaughtering activities and slaughterhouse installation.

Discussion

Herd structure

Based on a study conducted by Kamal et al. (2019) in Gazipur, Mymensingh, Sirajgonj, and Rajshahi districts of Bangladesh, the average herd size of beef cattle farms was found to be 6.26 (± 11). Most beef cattle farmers in the study area preferred crossbred cattle, as compared to indigenous cattle, which were found to be less than the national average of 30% (Siddiky, 2018). Indigenous cattle in Bangladesh, known as Bos indicus, have diverse physical characteristics and are named after their natural habitats (such as Deshi, Red Chittagong, Pabna, North Bengal Grey, Madaripur, and Munshigonj). These cattle are often crossed with Holstein, Sahiwal, Sindhi, and Jersey breeds (Siddiky, 2018).

Carbon footprint of farm feedstuff

The carbon footprint of Napier grass production at study area was found significantly lower than the values reported by Pawlowski *et al.* (2018) in a field experiment (2254 kg CO_2e/ha/year). In New Zealand, the carbon footprint of maize silage production was reported to be 125 kg CO_2e/t (Barber *et al.*, 2011). Data on GHG emission and sink from different fodder production are scanty; variation in carbon footprint of fodder production in different studies may exist due to difference in fresh biomass yield in different agro-ecological zones, organic and inorganic soil amendments at different rates and different methods of estimation. The response of beef cattle farmers to feeding different feedstuff was different from Mamun *et al.* (2018) who didn't report feeding of rice straw by farmers (60 farmers) in Jhenaidah district (Jhenaidah Sadar, Kaliganj and Maheshpur upazilas) of Khulna division.

Nutrient intake, digestibility and enteric methane emission

Live weight of indigenous deshi beef cattle is higher, but that of Pabna and other crossbred cattle are similar to values reported by BLRI (2004) (180, 350 and 350-550 kg, respectively deshi, Pabna and crossbred cattle). The age of beef cattle, irrespective of genotype (27±8 months), were suitable to obtain more daily gain, closely trimmed boneless retail cuts and more profitability (Sultana *et al.*, 2017). Data on composition of feed basket of a beef cattle at farm level are scanty. The average ME and nitrogen intake by a 321 kg bull are sufficient to meet nutritional needs for maintenance and production according to BSTI (2008) (37 MJ/d and 65 g/d, maintenance requirement). The enteric CH_4 emission factor for beef cattle under high productivity system in Indian subcontinent is 53 kg/yr CH_4 for a 309 kg mature male cattle with diet digestibility of 57% (IPCC 2019b; Table 10A.2 (New)), which is not similar to values found in this study. Similarly, volatile solids and nitrogen excretion rate in manure (kg/d/1000 kg LW) were lower than the values mentioned in IPCC (2019b; 8.7 and 0.37, respectively in Table 10A.2 (New)), implying that estimating GHG emissions according to Tier 1 approach would overestimate the emissions from beef cattle AWMS. Nitrogen excretion rate of a recent study was estimated as 0.22-0.25 kg/d/1000 kg LW of a 240 kg indigenous Red Chittagong cattle with diet digestibility of 52-65% (Sultana *et al.*, 2021).

Animal waste management systems and greenhouse gas emission factors

The Animal Waste Management Systems (AWMS) observed in the study area did not match the estimated AWMS for the Indian subcontinent in IPCC (2019b). The default AWMS as per IPCC comprised of drylot, pasture/range/paddock, burned for fuel, and solid storage, at 49%, 30%, 20%, and 1%, respectively. In contrast, the AWMS of this study differed from the study of Huque et al. (2017), who reported that solid storage, burned for fuel, anaerobic digester, and liquid/slurry systems occupied 56%, 37%, 5%, and 2% of cattle manure, respectively, by studying 120 farms in different regions of Bangladesh. The variation in AWMS in different studies could be attributed to differences in the number of farms studied, study locations, and time.

The CH_4 emission factor from manure management in other cattle weighing 110 kg was estimated to be 2 kg CH_4/head/year by the IPCC (2006), while a study by Huque et al. (2017) found it to be 6.4 kg CH4/head/year based on manure management practices across 120 farms in various regions of the country. This study's manure management emission factor was based on Animal Waste Management Systems (AWMS) of 321 farms, each with a 321 kg beef cattle that had a manure Volatile Solids (VS) of approximately 8.3 kg per day per 1000 kg Liveweight (LW), which may explain the variation in emission factors. The differences in VS and nitrogen excretion rate between different studies may be responsible for the variation in GHG emission factors from AWMS. Implementing annual solid storage manure management in biogas digester plants or vermicomposting could help reduce GHG emissions from AWMS in the study area (Table 7). This variation suggests that studying AWMS for different animal categories and their feed basket characteristics in different beef cattle production zones is necessary to identify suitable adaptation and mitigation strategies for combating climate change in various regions of the country.

Carbon footprint of beef cattle production

The carbon footprint of beef cattle production in study areas (7.68 ± 0.98, kg CO_2e/year/kg LW) was slightly below to values reviewed by Desjardins et al. (2012) in different countries at different production systems (8-22 kg/year/kg LW of beef cattle CO_2e). The variation in carbon footprint value may be caused by the methodology of calculation, geographical location, management practices, allocation, and boundaries of the study. On percent basis, the enteric CH_4 had the highest share in carbon footprint of beef cattle production (51.77%), followed by direct N_2O from manure (31.77%), manure CH_4 (10.77%), farm operation (5.31%), indirect N_2O from manure (0.82%) and farm feedstuff (0.04%). The cumulative CH_4 emission from enteric and manure sources accounted for 62%, which was slightly higher than the findings of Verge *et al.* (55%; 2008).

Conclusion

The study estimated the environmental cost of beef cattle production (7.68 kg CO_2e/year/kg LW) by measuring the amount of feed-basket (7.3 kg DM/d) at farmer's level, chemical composition, diet digestibility (65%), and carbon footprint of farm feedstuff (0.33 kg CO_2e/yr/t fresh biomass), and GHG emission factors of enteric fermentation (46 kg CH_4/yr/animal), animal waste management systems (9.06 kg CH_4/yr/animal and 2.96 kg N_2O/yr/animal) and farm operation (131 kg CO_2e/yr/cattle) during February-May, 2021 at Khulna Division, Bangladesh. It also investigated the volatile solids in manure and its nitrogen excretion rate (8.3 and 0.29 kg/d/1000 kg LW, respectively) that determines the level of GHG emissions under different animal waste management systems. Measuring feed-basket, its chemical composition and estimating digestibility, manure characteristics (volatile solids and nitrogen excretion rate), along with animal waste management systems are crucial in estimating specific GHG emission factors for different livestock categories under different production systems. Once specific GHG emission factors are generated, upgrading livestock GHG inventory by following Tier 2 approach of IPCC (2019b) could be possible. To achieve that such study may be undertaken at all livestock hotspots for all key livestock categories and sub-categories under different production systems. Also, estimating GHG emission factors for all sources in each livestock enterprise, and accounting for carbon footprint may help undertake appropriate mitigation measures to minimize the environmental cost of each livestock products.

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