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Validation of enteric methane emissions by cattle estimated from mathematical models using data from *in vivo* experiments

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ABSTRACT. Several authors have developed equations to estimate methane (CH_4) emissions by cattle according to variables such as dry matter and nutrient intake, live weight, or weight gain. Mathematical models using these variables show a large variability of results, being necessary to identify those which provide more precise and accurate predictions. For this reason, the objective of this study was to validate enteric CH_4 emissions estimated from mathematical models through a comparison with a database of CH_4 emissions obtained from cattle experiments carried out in tropical regions. A database of 495 individual cattle CH_4 emissions data (g day^{-1}) obtained from 19 studies in three tropical Latin American countries was built for this study. Results showed that mathematical models developed for cattle in tropical production systems overestimated CH_4 emissions when they were compared with our database. The mathematical model with higher precision and accuracy was the one that included dry matter intake and organic matter digestibility in the equation (Equation 7. R^2=0.34, Cb=0.94, CCC=0.55, RMSE=60.8%, r=0.58), followed by models that included neutral detergent fiber intake data (Equation 5). Our data did not show a relationship between CH_4 emissions and gross energy intake or live weight.

Keywords: greenhouse gases; modeling; tropical livestock.

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Introduction

The livestock sector is one of the largest contributors to methane (CH_4) emissions, mainly produced through the anaerobic fermentative processes in the rumen. Several methodologies can be used to measure these emissions *e.g.,* laboratory techniques, tracers, and sensors (Hammond et al., 2016). Additionally, mathematical models can be useful when measurements are not feasible due to technical or resource constraints (Hristov et al., 2018; Muñoz-Tamayo et al., 2022; Tedeschi et al., 2022). During the last decades, several equations have been developed by various authors to estimate CH_4 emissions from dry matter and nutrient intake or variables such as body weight or rate of weight gain (Johnson & Johnson, 1995; Ellis et al., 2007; Ku-Vera et al., 2018; Congio et al., 2023). However, most of them were developed using global information available that is not necessarily applicable at a regional level, generating uncertainty in the results when they are used in a specific context.

For this reason, the present study was aimed to validate enteric CH_4 emissions estimated through mathematical models with a database of CH_4 emissions obtained from cattle experiments carried out in tropical regions of Latin America. This information could be useful to governmental and environmental agencies to estimate enteric CH_4 emissions in tropical regions to strengthen their commitments to mitigate greenhouse gas emissions.

Materials and methods

Data collection

Data from *in vivo* experiments was obtained from 19 studies conducted in three tropical Latin American countries (7 unpublished, 12 published: Molina-Botero et al., 2015; Molina-Botero Angarita, Mayorga, Chará, & Barahona-Rosales, 2016; Arceo-Castillo et al., 2017; Valencia-Salazar et al., 2018; Molina-Botero et al., 2019a; 2019b; Gaviria-Uribe et al., 2020; Montoya-Flores et al., 2020; Díaz-Céspedes, Hernández-Guevara, & Gómez, 2021; Congio et al., 2021; Jiménez-Ocampo et al., 2021; 2022): Mexico (n=182 from 12 studies), Colombia (n=165 from 5 studies) and Peru (n=148 from 2 studies). Four different techniques to measure CH_4 emissions were used in these studies: sulfur hexafluoride (n=172), open-circuit respiration chambers (n=158), laser CH_4 detector (n=123), and polytunnel (n=42).

As a result, a database containing 495 individual cattle CH_4 measurement data (g/d) was generated. From this total, two-thirds of the data corresponded to growing females (n=312) and one-third from males (n=183), in the growing (n=94.1%) or finishing stage (n=5.1%) (Table 1.). Cattle breeds considered in this study were: Blanco Orejinegro (n=70), Brahman (n= 160), Romosinuano (n=8), Lucerna (n=8), and crossbreeds such as Brahman x Angus (n=25), Brahman x Holstein (n=156), Brahman x Romosinuano (n= 36), and Brown Swiss x Criollo (n=27).

Diets used in the studies were mainly based on tropical grasses ($\geqslant$ 90% of the diet) such as *Urochloa brizantha* cv. Mombasa, *U. decumbens* cv. Basilisk, *U. hybrid* cv. Cayman-CIAT BR02/1752, *Dichanthium aristatum* (Poiret) C. E. Hubbard, *Pennisetum purpureum schumach, Cenchrus clandestinus, Panicum maximum* cv. Sabanera, *Megathyrsus maximus* cv. Mombasa, *Cynodon nlemfuensis, U. ruziziensis* cv. Ruziziensis, *U. brizanta* cv. Marandu, *U. arrecta* (Hack. Ex T. Durand & Schinz) Stent (Missouri Botanical Garden), *U. mutica* (Forssk.) Stapf, *Megathyrsus maximus* (Jacq.), *Paspalum sp, Cynodon dactylon* (Bermudagrass), and *Echinochloa polystachya* (Kunth) Hitch.

Data containing additives like nitrate, tannins, saponins, and lipid supplements in the diets were removed from the database, as they may affect the prediction of CH_4 production. The chemical composition of diets from cattle experiments presented on average the following values: 146 (±183) g of crude protein per kg of dry matter (DM), 632 (±80) g of neutral detergent fiber per kg of DM, 357 (±56) g of acid detergent fiber per kg of DM, 17.5 MJ gross energy kg DM^{-1}. The digestibility of organic matter was 594 g kg^{-1} (Table 1).

Table 1. Descriptive statistics of animal diets, nutrient intake, and CH_4 emission from 19 studies conducted in tropical Latin American countries.

Items		Descriptive statistical values					
		n	Min	Max	Average	Median	SD
Description of the animals	Age (months)	413	10.8	30.5	20.5	19.5	4.62
	Body weight (kg)	468	162	521	333	313	80.5
Nutrient supply and digestibility	CP (g kg DM^{-1})	469	10.8	88.3	84.4	146	183
	EE (g kg DM^{-1})	134	10.0	199	19.0	20.9	15.9
	NDF (g kg DM^{-1})	469	427	760	621	632	80.1
	ADF (g kg DM^{-1})	469	241	508	349	357	55.9
	Ash (g kg DM^{-1})	469	58.5	279	90.9	96.9	24.7
	GE (MJ kg DM^{-1})	469	13.1	28.8	17.2	17.5	2.41
	dOM (g kg^{-1})	260	367	776	605	594	77.1
	dNDF (g kg^{-1})	187	391	853	685	665	106
Intake	DMI (kg day^{-1})	495	1.93	14.0	8.53	7.78	2.34
	OMI (kg day^{-1})	446	1.70	12.8	7.19	6.72	1.69
	CPI (g day^{-1})	459	0.10	5.04	1.08	0.77	0.86
	NDFI (kg day^{-1})	471	0.44	8.90	4.21	2.25	2.21
	ADFI (kg day^{-1})	471	0.76	7.90	3.27	2.88	1.14
	GEI (MJ day^{-1})	469	31.3	278	149	134	43.4
	dNDFI (kg day^{-1})	192	0.69	6.68	3.58	2.49	1.74
	dOMI (kg day^{-1})	211	0.87	6.42	4.01	3.66	1.09
Methane	(g day^{-1})	495	74.2	453	191	169	71.6
	Ym (%)	355	1.97	28.3	8.36	6.04	4.88

Abbreviations: n: number of observations; Min: minimum; Max: maximum; SD: standard deviation; DM: dry matter; DMI: dry matter intake; OMI: organic matter intake; dOM: digestibility of organic matter, dOMI: digestibility of organic matter intake; GE: gross energy; GEI: gross energy intake; CP: crude protein; CPI: crude protein intake; NDF: dietary neutral-detergent fiber content; NDFI: neutral-detergent fiber intake; dNDF: digestibility of neutral-detergent fiber; dNDFI: digestibility of neutral-detergent fiber intake; ADF: acid-detergent fiber; ADFI: acid-detergent fiber intake; EE: dietary ether extract content; Ym: Energy loss as methane, % GE intake.

Mathematical models

A total of 53 equations were selected to estimate CH_4 emissions (Table 2). Models developed for dairy cattle in the lactation phase were not considered for this study. Mathematical models took into account information related to daily weight gain (kg day^{-1}), body weight (kg), dry and organic matter intake (g kg DM^{-1}), nutrient intake (protein, neutral detergent fiber, acid detergent fiber, ether extract, g kg DM^{-1}), gross energy intake (MJ kg DMI^{-1}), and dry matter digestibility (%). Nine models were discarded because they did not consider variables measured in the studies we were evaluating or because they were part of the original data set (Ku-Vera et al., 2018; Gaviria-Uribe et al., 2020).

Table 2. List of equations used to predict methane production in cattle.

N	Equation	Unit	Comments	Source
1	$-66+39.2 \times DMI-0.64 \times DMI^2$	g day^{-1}	Beef cattle, non-lactating	Charmley et al., 2016
2	$20.7 \times DMI$	g day^{-1}	Beef cattle, non-lactating	Charmley et al., 2016
3	$((35.1 \times DMI) +14.7) \times 0.714$	g day^{-1}	Beef cattle	Yan, Porter, & Mayne, 2009
4	$(1.959 \times GEI+ 8.8) \times 0.714$	gday^{-1}	Beef cattle	Yan et al., 2009
5	$(5.58+0.848 \times NFDI)$	MJ day^{-1}	Beef cattle	Ellis et al., 2007
6	$(20+35.8 \times DMI-0.5 \times DMI^2) \times 0.714$	g day^{-1}	Beef, dairy, and sheep	Ramin and Huhtanen, 2013
7	$(7.14+0.22 \times dOM) \times DMI$	g day^{-1}	Beef, dairy, and sheep	Sauvant and Noziere, 2016
8	$0.44 \times BW$	g day^{-1}		Benaouda et al., 2020
9	$19.4+16.7 \times DMI$	g day^{-1}		Benaouda et al., 2020
10	$63.8+0.57 \times GEI$	g day^{-1}	Growing cattle	Benaouda et al., 2020
11	$17.0 \times DMI+0.03 \times NDF$ (g kg^{-1} DM)	g day^{-1}		Benaouda et al., 2020
12	$23.3 \times DMI$	g day^{-1}	Forage diet ⩾75%	Intergovernmental Panel on Climate Change - IPCC, 2019
13	$-1.47+1.28 \times DMI$	MJ day^{-1}	Beef cattle, non-lactating	Storlien et al., 2014
14	$-1.012+0.308 \times DMI+0.0404 \times DMI^2+2.424 \times NDFI-0.29 \times NDFI$	MJ day^{-1}	Beef cattle, non-lactating	Ribeiro et al., 2020 (Equation 9)
15	$1.006+0.97^2 \times DMI$	MJ day^{-1}	Beef cattle, non-lactating	Ribeiro et al., 2020 (Equation 1)
16	$1.1010+0.906 \times DMI$	MJ day^{-1}	Beef, dairy, and sheep	Ribeiro et al., 2020 (Equation 1)
17	$0.065 \times GEI$	MJ/day^{-1}	Beef, dairy, and sheep	Intergovernmental Panel on Climate Change - IPCC, 2006
18	$1.289+0.051 \times GEI$	MJ day^{-1}	Beef cattle, non-lactating	Moraes, Strathe, Fadel, Casper, & Kebreab, 2014
19	$-0.221+0.048 \times GEI+0.005 \times BW$	MJ day^{-1}	Beef, dairy, and sheep	Ribeiro et al., 2020 (Equation 6)
20	$-0.163+0.051 X GEI+0.038 X NDF(\%)$	MJ day^{-1}	Beef cattle, non-lactating	Moraes et al., 2014
21	$1.067+0.051 \times GEI$	MJ day^{-1}	Beef, dairy, and sheep	Ribeiro et al., 2020 (Equation 49)
22	$-0.3+0.753 \times DMI+0.007 \times BW$	MJ day^{-1}	Beef, dairy, and sheep	Ribeiro et al., 2020 (Equation 17)
27	$0.983+0.0368 \times GEI+0.0098 \times BW$	MJ day^{-1}	Beef cattle, non-lactating	Ribeiro et al., 2020 (Equation 65)
28	$1.002+0.0497 \times GEI$	MJ day^{-1}	Beef cattle, non-lactating	Ribeiro et al., 2020 (Equation 49)
29	$-1.02+0.681 \times DMI+4.81 \times Forrage$	MJ day^{-1}	Beef cattle	Ellis et al., 2007
30	$0.060 \times GEI$	MJ day^{-1}	Beef, dairy, and sheep	Intergovernmental Panel on Climate Change - IPCC, 1997
31	$117+36.1 \times ADG$	g day^{-1}		Benaouda et al., 2020
32	$1.289+0.051 \times GEI$	MJ day^{-1}	Heifers	Moraes et al., 2014
33	$0.163+0.051 \times GEI+0.038 \times NDF (\%)$	MJ day^{-1}	Heifers	Moraes et al., 2014
34	$-1.487+0.046 \times GEI+0.032 \times NDF (\%) + 0.006 \times BW$	MJ day^{-1}	Heifers	Moraes et al., 2014
35	$0.743+0.054 \times GEI$	MJ day^{-1}	Steers	Moraes et al., 2014
36	$-0.221+0.048 \times GEI+0.005 \times BW$	MJ day^{-1}	Steers	Moraes et al., 2014
37	$0.2433 \times DMI$	Mcal day^{-1}	Beef cattle, non-lactating	Hales et al., 2022
38	$22.71 \times DMI+8.91$	g day^{-1}	Beef cattle, non-lactating	Suzuki et al., 2018
39	$22.67 \times DMI-3.73 \times EE+23.32$	g day^{-1}	Beef cattle, non-lactating	Suzuki et al., 2018
40	$52.8+13.8 \times DMI$	g day^{-1}	High forage diets	Van Lingen et al., 2019
41	$23.8+13.5 \times DMI+0.844 \times NDF (\%)$	g day^{-1}	High forage diets	Van Lingen et al., 2019
42	$66.4+13.3 \times DMI-3.69 \times EE$	g day^{-1}	High forage diets	Van Lingen et al., 2019
43	$23.4+13.2 \times DMI+0.571 \times Forraje$	g day^{-1}	High forage diets	Van Lingen et al., 2019
44	$-6.41+11.3 \times DMI+0.557 \times Forraje+0.0996 \times BW$	g day^{-1}	High forage diets	Van Lingen et al., 2019
45	$17.9+0.732 \times Forraje+0.226 \times BW$	g day^{-1}	High forage diets	Van Lingen et al., 2019
46	$1.29+0.878 \times DMI$	MJ day^{-1}		Patra, 2017
47	$4.41+0.50 \times DMI$	MJ day^{-1}		Pires Sobrinho et al., 2019
48	$5.26+2.53 \times DMI-59.7 \times EEI$	MJ day^{-1}		Pires Sobrinho et al., 2019
49	$4.32+1.85 \times ADFI$	MJ day^{-1}		Pires Sobrinho et al., 2019
50	$4.35+0.543 \times OMI$	MJ day^{-1}		Pires Sobrinho et al., 2019
51	$4.50+3.40 \times CPI$	MJ day^{-1}		Pires Sobrinho et al., 2019
53	$7.4-3.28 \times Fl$	g kg^{-1} DMI	High forage diets	Congio et al., 2023

Abbreviations: DMI: dry matter intake; OMI: organic matter intake; GEI: gross energy intake; BW: body weight; FL: feeding level; NDF: dietary neutral-detergent fiber content; NDFI: neutral-detergent fiber intake; ADFI: acid-detergent fiber intake; EE: dietary ether extract content; EEI: ether extract intake; CPI: crude protein intake; Forage: forage percentage in the diet, dOM: digestibility of organic matter; ADG: average daily weight gain; Fl: Feeding level.

Data analysis

Inconsistent data (outliers) was deleted before analysis. Then, CH_4 emissions were estimated based on mathematical models found in the literature shown in Table 2. Next, a comparison between CH_4 data (g/d) obtained from *in vivo* experiments (observed data) and data estimated from published models (Table 2) was performed through statistical calculations, including average values, standard deviation, mean, concordance correlation coefficients (CCC), mean squared prediction error (MSPE), errors in central tendency (ECT), errors due to regression (ER), and errors due to disturbances (ED), among others. Total MSPE values, determined as the sum of ECT, ER, and ED (Bibby & Toutenburg, 1977), were calculated as follows:

$Total\ MSPE=ECT+ER+ED$
$ECT=(\underline{P}-\underline{O})^2$
$ER=(S_p-r \times S_o)^2$
$ED=(1-r^2) \times S_0^2$
$RMSPE=\sqrt{MSPE}$

where:
$\underline{P}$ and $\underline{O}$ are the estimated and observed CH_4 parameter means,
S_p is the SD of the estimated values,
S_o is the SD of the observed values and
r is the Pearson correlation coefficient. ECT, ER, and ED were expressed as a percentage of total MSPE (Kaewpila & Sommart, 2016). RMSPE: root-mean-square prediction error.

The CCC to evaluate the accuracy and prediction precision of a model (Lin, 1989) was calculated as follows:

$CCC=r \times C_b$
$C_b= 2/((S_o/S_p)+(1/(S_o/S_p))+\mu^2)$
$\mu= ((\underline{O}-\underline{P}))/\sqrt{(S_o \times S_p)}$

where:
C_b is the bias correction factor (range = 0-1, perfect score = 1) that measures accuracy. The CCC is a metric that accounts for both precision and accuracy, and values closer to 1 indicate better model performance (Tedeschi, 2006). This r measures accuracy and μ is a measure of location offset with respect to the scale (range = negative-positive infinity, perfect score = 0). A positive value of μ indicates under-accuracy, while a negative one indicates over-accuracy (Kebreab, Johnson, Archibeque, Pape, & Wirth, 2008).

Results and discussion

Figure 1 shows values of *in vivo* experiments (black) obtained in the measurements of CH_4 emissions in tropical conditions (n=497) and values predicted by mathematical models using variables such as body weight, nutrient and gross energy intake, and apparent digestibility of the diet. On average, the CH_4 production per animal was 191 (±71) g day^{-1}. This value is equivalent to obtaining a CH_4 conversion factor (Y_m) of 8.34 (±5) %.

Estimation models for enteric CH_4 emission were developed using body weight, intakes of DM, nutrients (NDF, ADF, and CP), gross energy (GE), and dietary composition of nutrients (CP, NDF, ADF) as predictors (Table 3). In general, values of the bias correction factor (C_b) were positive in all models (between 0.4 and 4.3), which suggests that there was an overestimation. These values agree with studies reported by Hegarty (2004) and Patra (2017). Hegarty (2004) stated that the estimation of CH_4 production by statistical models is more precise when there are low levels of CH_4 production in animals. In contrast, in conditions of high levels of CH_4 production, other physiological and microbiological factors may affect the result in addition to nutrient intakes, such as rumen volume and fermentation parameters.

The coefficient of determination (R^2) observed was low (R^2=0.07 on average). In contrast, the RMSPE parameter was high (80% on average) compared to other authors such as Niu et al., (2018). This is perhaps because the data set used in the present study was constructed based on a wide range of experiments developed in three countries with different techniques and cattle breeds, as shown by Cottle and Eckard (2018) in their meta-analysis.

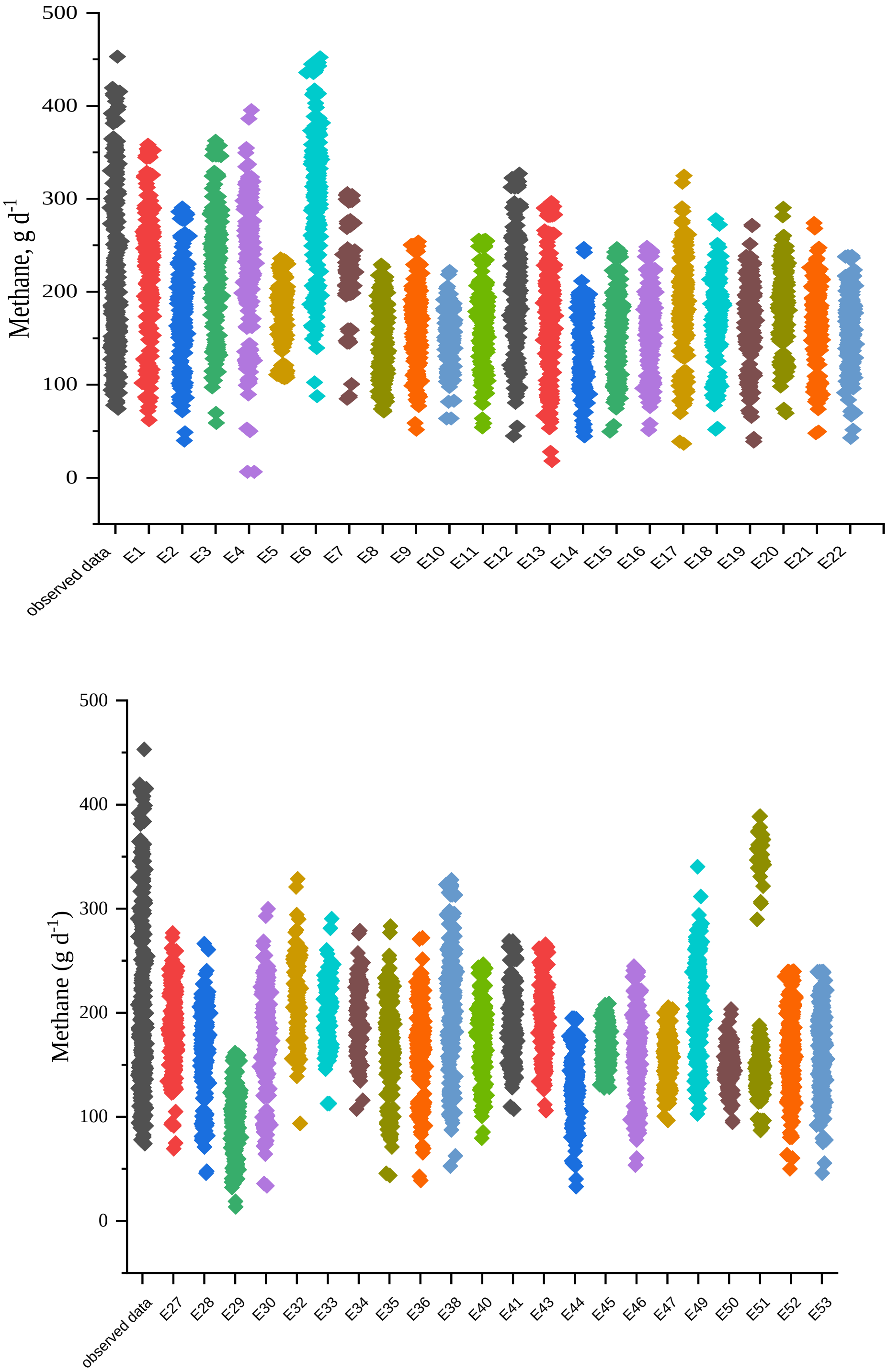

Figure 1. Methane emissions from observed and model-estimated data.

The mathematical model with higher precision and accuracy compared to the data obtained in the experiments was the one that included variables such as dry matter intake and organic matter digestibility (Equation 7. R^2=0.34, Cb=0.94, CCC=0.55, RMSE=60.8%, r=0.58. Eugène et al. (2019) developed a robust equation for methane prediction by incorporating digestible organic matter intake (DOMI) for the Tier 3 cattle inventory in France. Sauvant and Nozière (2016) followed models that included neutral detergent fiber intake data (Equation 5. Ellis et al., 2007). This collection of data did not show a relationship between CH_4 emissions and gross energy intake plus body weight. This result could be verified in Equation 35 and 36, which included these two variables and presented the lowest values of the CCC parameter. Similar results were reported by Pires Sobrinho et al. (2019) in their work with Nellore cattle (392 ± 27 days of age) in the tropics; however, it is different from what was reported by Yan, Agnew, Gordon, and Porter (2000), who found an R^2 of 0.85 between CH_4 and GE intake.

Table 3. Summary statistics for methane prediction using the complete dataset of *in vivo* experiments.

Equation	*n*	Minimum	Maximum	Mean	SD	r	R^2	CB	CCC	MSPE, %	ECT, %, MSPE	ER, %, MSPE	ED, %, MSPE	RMSPE, %
1	493	62.0	358	195	65.2	0.25	0.06	1.22	0.31	76.6	8.36	28.7	63.0	87.5
2	495	40.0	291	161	48.4	0.28	0.08	0.87	0.24	56.1	1.31	14.1	84.6	74.9
3	495	58.9	362	207	58.6	0.28	0.08	1.36	0.38	75.9	18.2	19.3	62.5	87.1
4	471	6.3	395	173	62.0	0.11	0.01	1.02	0.11	80.2	0.13	36.5	63.4	89.5
5	471	107	236	157	33.7	0.49	0.24	0.70	0.34	41.0	3.96	0.09	95.9	64.0
6	495	87.8	452	279	69.5	0.27	0.07	4.33	1.17	191	62.2	12.9	24.9	138
7	260	84.9	306	164	58.8	0.58	0.34	0.94	0.55	36.9	0.91	7.01	92.1	60.8
8	495	71.3	229	137	35.0	0.24	0.06	0.63	0.15	62.4	17.15	5.03	77.8	79.0
9	495	51.6	254	151	39.1	0.28	0.08	0.73	0.20	54.3	6.16	6.47	87.4	73.7
10	471	63.8	222	144	25.3	0.11	0.01	0.52	0.06	60.5	11.1	4.97	83.9	77.8
11	495	54.1	256	152	39.5	0.29	0.08	0.74	0.22	53.3	5.56	6.18	88.3	73.0
12	495	45.0	327	181	54.5	0.28	0.08	1.06	0.29	60.5	2.25	19.3	78.4	77.8
13	495	18.0	297	148	53.8	0.28	0.08	0.82	0.23	63.5	7.61	17.6	74.7	79.7
14	471	44.5	247	140	34.8	0.31	0.10	0.64	0.20	56.5	15.4	2.50	82.1	75.2
15	495	49.5	247	147	38.1	0.28	0.08	0.70	0.19	55.9	9.34	5.68	85.0	74.7
16	495	51.2	248	149	38.1	0.28	0.08	0.71	0.20	55.1	8.12	5.73	86.1	74.2
17	469	36.5	325	157	50.7	0.11	0.01	0.86	0.09	70.9	2.36	26.0	71.7	84.2
18	469	51.8	278	149	39.7	0.11	0.01	0.73	0.08	65.4	6.65	15.7	77.7	80.9
19	469	38.8	272	142	41.4	0.14	0.02	0.71	0.10	67.6	11.2	14.3	74.5	82.2
20	469	69.4	290	168	37.8	0.15	0.02	0.81	0.13	57.2	0.04	12.3	87.7	75.6
21	469	47.8	274	144	39.7	0.11	0.01	0.71	0.07	67.4	9.43	15.2	75.4	82.1
22	495	42.9	238	141	36.8	0.30	0.09	0.66	0.20	56.8	14.0	3.80	82.2	75.4
23	471	45.8	316	125	70.6	0.49	0.24	0.77	0.37	71.6	28.1	17.0	54.8	84.6
24	471	74.3	512	208	69.7	-0.02	0.00	1.38	-0.03	117	12.5	43.6	43.9	108
25	495	95.4	314	206	42.3	0.28	0.08	1.22	0.34	65.3	20.0	7.37	72.7	80.8
26	446	88.1	300	187	32.0	0.22	0.05	0.85	0.19	54.3	5.24	4.65	90.1	73.7
27	469	69.3	277	167	37.5	0.18	0.03	0.80	0.14	55.9	0.15	10.8	89.1	74.8
28	469	45.9	266	140	38.7	0.11	0.01	0.68	0.07	69.2	12.7	13.9	73.4	83.2
29	495	13.5	162	83	28.6	0.28	0.08	0.42	0.11	122	60.7	0.56	38.8	111
30	469	33.7	300	145	46.8	0.11	0.01	0.76	0.08	72.3	8.63	21.1	70.3	85.0
32	306	66.4	329	159	51.0	0.14	0.02	0.87	0.13	67.8	1.59	24.2	74.3	82.3
33	306	88.7	290	166	36.1	0.18	0.03	0.78	0.14	55.3	0.20	9.77	90.0	74.4
34	306	87.2	279	158	38.8	0.21	0.04	0.76	0.16	56.1	2.47	9.87	87.7	74.9
35	343	43.7	283	158	40.5	-0.09	0.01	0.78	-0.07	74.5	1.95	29.7	68.4	86.3
36	343	38.8	272	155	39.6	-0.04	0.00	0.75	-0.03	72.0	3.19	25.6	71.2	84.8
38	495	52.7	328	187	53.1	0.28	0.08	1.10	0.30	61.1	4.76	17.6	77.6	78.2
41	469	107	269	187	31.5	0.34	0.11	0.84	0.28	48.9	5.90	0.92	93.2	69.9
42	495	106	266	188	30.9	0.28	0.08	0.84	0.23	51.9	6.46	2.15	91.4	72.1
45	495	128	209	164	18.0	0.24	0.06	0.45	0.11	48.9	0.67	0.01	99.3	69.9
46	495	53.6	245	148	36.9	0.28	0.08	0.69	0.19	54.8	8.37	5.02	86.6	74.0
47	495	96.6	205	153	21.0	0.28	0.08	0.48	0.13	50.2	5.53	0.01	94.5	70.9
49	471	103	340	179	37.8	-0.02	0.00	0.89	-0.02	67.8	1.33	22.9	75.8	82.3
50	420	94.8	204	147	16.7	0.23	0.05	0.38	0.09	53.8	9.58	0.00	90.4	73.3
53	495	45.9	240	146	36.2	0.25	0.06	0.68	0.17	56.8	9.51	5.63	84.9	75.4

Abbreviations: n= number of observations; MSPE: mean square prediction error; RMSPE: root-mean-square prediction error (% of the observed mean); ECT: errors in central tendency (% of total MSPE); ER: errors due to regression (% of total MSPE); ED: errors due to disturbances (% of total MSPE). CCC: concordance correlation coefficient; r: Pearson correlation coefficient; CB: bias correction factor; R2: coefficient of determination; SD: standard deviation.

Conclusion

Methane production per animal was on average 191 (±74) g day^{-1}, which is equivalent to a Y_m of 8.34 (±5) %. The current validation showed that the prediction capabilities of the models used are yet to be improved. Concerning the mathematical models developed for cattle in tropical production systems, it can be concluded that they overestimated CH_4 emissions when they were compared with the compiled database. The mathematical model with higher precision and accuracy included dry matter intake and organic matter digestibility in the equation ([7.14+0.22 x dOM] x DMI), followed by models that included neutral detergent fiber intake data ([5.58+0.848 x NFDI]). The analysis of the data did not show any relationship between CH_4 emissions and gross energy intake or body weight.

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