Development of mathematical models to predict methane emissions by cattle in Latin America

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INTRODUCTION

Determining emission factors of enteric methane in Latin America has recently started.

The methodology to quantify methane production *in vivo* is expensive and requires a large number of animals.

Thus, the objective of this work was to develop mathematical models to predict enteric methane production in cattle in Latin America, using commonly measurable dietary variables, from studies performed *in vivo* in Latin America.

Materials y Methods

1. Database

27 studies published in journals and conference proceedings were found.

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2. Inclusion criteria

- *in vivo* study (2 studies excluded)
- Experimental unit: Cattle (1 study excluded)
- Report BW, DMI, Digestibility and chemical composition of diet (5 studies excluded)

-Total: 19 studies, which included 66 mean observations of methane outputs measured on 490 cattle.

- CH_4 production was expressed as g/day, l/day, MJ/day, or as a proportion of GE; therefore, the following factors were used in converting units:

1g = 1,40L = 55,5kJ y 1L = 0,716g = 39,54kJ

MATERIALS Y METHODS

3. Calculation of Nutrient Supply and Concentrations:

- When the concentration of the nutrient in the forage and the concentrate was reported separately, nutrient supply was calculated as follows (Ramin and Huhtanen, 2013):

$$\text{Xi (g/d)} = \text{CMDI (kg/d)} \times \text{cX (g/kg of DM)} + \text{FDMI (kg/d)} \times \text{fX (g/kg of DM)},$$

where Xi = intake of that specific nutrient, CDMI = concentrate DMI, cX = concentration of that specific nutrient in concentrate, FDMI = forage DMI, fX = concentration of that specific nutrient in forage. The concentration of that specific nutrient was then calculated as

$$\text{XX (g/kg of DM)} = \text{Xi (g/d)/DMI (kg/d)},$$

where XX = concentration of that specific nutrient.

Materials y Methods

4. Dietary variables

- When the organic matter digestibility (OMD) was not reported, that was estimated by the following equation developed from the database :

$$OMD\ (\%) = -14{,}65_{\ (\pm 7{,}56)} + 1{,}2_{\ (\pm 0{,}13)} * DMD(\%)$$

$$(R^2 = 0{,}80 \text{ y } n = 30)$$

- The concentration of NFC (g/kg of DM) was calculated according to NRC (2001)

  - $NFC\ (\%) = 100 - ash - CP - EE - NDF$

- The daily intake of each nutrient was calculated as:

Nutrient intake (kg/day) = [dietary concentration (%) x DMI (kg/day)] / 100

Materials y Methods

2. Statistical Analysis:

- The data were analyzed using mixed regression methodology (PROC MIXED in SAS; as in St-Pierre 2001):

$$\mathbf{Y = B_0 + B_1X_{1ij} + b_0 + b_1X_{1ij} + B_2X_{2ij} + \ldots + B_nX_{nij} + e_{ij}}$$

where $\mathbf{B_0}$, $\mathbf{B_1X_{1ij}}$ and $\mathbf{B_2X_{2ij}}$ . . ., $\mathbf{B_nX_{nij}}$ are the fixed effects (intercept and effects of independent variables)-

And $\mathbf{b_0}$ (intercept), $\mathbf{b_1}$(slope), and $\mathbf{e_{ij}}$ are the random experiment effects (i = 1 . . . n studies and j = 1, . . ., ni values).

First, we did a simple regression of each dietary factor on methane production then combinations of two or more factors searched was performed.

Materials y Methods

3. Comparison between models

Selection of the best-fit equation was based on the smallest RMSE and Akaike's information criterion (**AIC**).

$$\mathrm{MSPE} = \frac{\sum_{i=1}^{n}(Oi - Pi)2}{\mathrm{n}}$$

where Oi is the observed value for the ith observation, Pi is the predicted value for the ith observation, and n is the number of observations.

Square root of the MSPE (RMSPE), which provides an estimate of the overall prediction error, was expressed as a proportion of the observed mean (MSPE divided by the observed mean) so that comparisons of RMSPE (%) values can be made between equations with different predicted means and so that deviation from observed values can be evaluated.

RESULTS AND DISCUSION

Table 2: statistical description of the characteristics of the diet and the animals included in the database for predicting methane production.

Variable	n	Mean	SD.	Min	Max
		Animal Factor			
BW	68	402,52	105,24	215,00	641,70
BW^0,75	68	89,29	17,69	56,15	127,50
		Composition			
DM (%)	52	46,66	24,93	17,51	93,40
GE (MJ/d)	66	16,88	1,34	10,92	19,20
ME (MJ/d)	43	8,16	2,33	5,10	12,18
CP (%)	66	12,55	4,55	3,33	21,10
EE (%)	62	1,24	0,77	0,64	2,38
NDF (%)	66	54,53	12,33	32,18	84,26
ADF (%)	66	29,28	8,34	12,00	51,90
HEMI(%)	66	24,58	5,46	12,40	36,12
CEL(%)	61	24,63	7,50	10,00	43,59
LIG (%)	61	4,50	2,11	0,59	8,40
Ash (%)	63	7,52	2,28	3,70	12,50
NFC (%)	63	23,54	11,33	1,04	48,35
DMD (%)	66	61,19	11,15	33,33	85,34
OMD (%)	66	58,15	14,33	25,35	87,76
		Intake			
DMI(kg/d)	66	10,05	4,15	3,50	20,10
BEi (MJ/d)	66	173,36	69,58	63,96	338,69
MEi (MJ/d)	42	79,87	23,84	40,40	146,94
CPi (kg/d)	69	1,4	0,97	0,2	4,24
EEi (kg/d)	62	0,15	0,16	0,04	0,46
NDFi (kg/d)	66	5,23	1,91	1,97	10,05
ADFi (kg/d)	66	2,81	1,04	0,7	5,8
HEMIi(kg/d)	66	2,47	0,99	0,99	4,51
CELi(kg/d)	61	2,39	0,95	0,58	4,76
LIGi (kg/d)	61	0,41	0,2	0,1	1,04
NFCi(kg/d)	63	2,43	1,44	0,08	6,23
DDMi(kg/d)	66	6,52	3,42	2,21	16,99
		Producción de metano			
CH4L/d	66	279,96	129,30	68,98	564,48
CH4L/kg of DM	66	27,50	7,33	12,86	50,85
CH4%GE	66	6,44	1,74	3,34	12,30

RESULTS AND DISCUSION

Producción de metano					
Variable	**n**	**Mean**	**SD.**	**Min**	Max
CH_4L/d	66	279,96	129,30	68,98	564,48
CH4L/kgMS	66	27,50	7,33	12,86	50,85
CH4%GE	66	6,44	1,74	3,34	12,30

- Default emisonsi factor recommended by the IPCC varies between 150 and 220 L/d.

- Probably, underpredicting CH4 inventories for LA.

- Several studies agree that the energy lost as methane accounts for 2-13% of the GE consumed by the animal (Johnson and Johnson 1995;. Hristov et al 2013)

- Moe and Tyrrell (1979), Elllis et al. (2007) and Ramin and Huhtanen (2013) found that the emission of methane expressed in liters per unit of food consumed ranges from 28.3 to 32.3 L/kg DMI.

RESULTS AND DISCUSION

Table 3: Pearson correlation coefficient (r) between dietary variables and animals and the production of methane (L / d) in the database (NS = not significant).

Variable	n	R	P value
		Animal factor	
PV	68	0,77	<0,0001
		Diet composition	
DM (%)	52	-0,50	0,0002
GE (MJ/d)	66	0,19	NS
ME (MJ/d)	43	-0,53	0,0003
CP (%)	66	0,ºº	<0,0001
EE (%)	62	0,16	NS
NDF (%)	66	-0,25	0,0380
ADF (%)	66	-0,24	0,0460
HEMI (%)	69	-0,19	NS
CEL (%)	61	-0,18	NS
LIG (%)	61	-0,33	0,0093
Ash (%)	63	0,35	0,0048
NFC (%)	63	-0,04	NS
DMD (%)	64	0,16	NS
OMD (%)	66	0,09	NS
		Nutrient intake	
DMI(kg/d)	66	0,83	<0,0001
GEi(MJ/d)	66	0,84	<0,0001
MEi(MJ/d)	43	0,29	0,0623
CPi(kg/d)	66	0,82	<0,0001
EEi (kg/d)	62	-0,43	<0,0001
NDFi(kg/d)	66	0,73	<0,0001
ADFi(kg/d)	66	0,66	<0,0001
HEMIi(kg/d)	66	0,73	<0,0001
CELi (kg/d)	61	0,82	<0,0001
LIGi (kg/d)	61	0,29	0,0252
NFCi(kg/d)	63	0,57	<0,0001
DDMi (kg/d)	64	0,75	<0,0001

RESULTS AND DISCUSION

Correlation between dietary and animal variables and methane production.

Variable[1]	Mean	SD	Minimum	Maximum	CH_4, g/d[2]	
					r	*P*-value
CH_4, g/d	216.2	101.02	62.1	478.7	–	–
CH_4, g/kg DMI	20.6	4.58	6.4	33.4	–	–
MBW, kg	95.9	20.56	61.0	131.1	0.643	<0.001
DMI, kg/d	10.8	4.77	3.6	20.1	0.837	<0.001
GEI, MJ/d	198.7	85.71	66.7	373.7	0.840	<0.001
DEI, MJ/d	133.9	63.83	41.1	265.4	0.831	<0.001
MEI, MJ/d	109.5	54.84	30.7	237.4	0.800	<0.001
FP, %	79.5	25.29	9.0	100.0	0.046	0.51
CP	172.4	34.37	52.0	290.0	0.203	0.003
NDF	444.3	124.87	127.0	731.0	0.086	0.21
ADF	270.4	88.18	35.0	464.0	–0.040	0.57
Lignin	52.8	26.53	10.2	154.0	–0.220	0.001
Fat	31.6	12.87	16.0	90.0	–0.105	0.13
DMD	627.0	76.46	402.9	813.0	0.186	0.007

(Ricci et al. 2013)

Pearson correlation coefficients (*r*) for dietary variables and methane production (MJ/d) in the database.

Items	*r*	*P*-value	*r*	*P*-value
Body weight (kg)	0.76	<0.001	–	–
DM intake, kg/d	0.88	<0.001	–	–
GE intake, MJ/d	0.90	<0.001	–	–
ME intake, MJ/d	0.84	<0.001	–	–
	Intake (kg/d)		Composition (g/kg of DM)	
Total digestible nutrient	0.85	<0.001	<0.01	1.0
Crude protein	0.70	<0.001	0.03	0.84
Ether extract	–0.24	0.09	0.20	0.20
Neutral detergent fiber	0.89	<0.001	0.07	0.65
Acid detergent fiber	0.85	<0.001	–0.02	0.90
Crude fiber	0.78	<0.001	–0.08	0.62
Nitrogen free extract	0.77	<0.001	0.06	0.67
Non-fibrous carbohydrate	0.39	0.01	–0.22	0.16

(Patra, 2014)

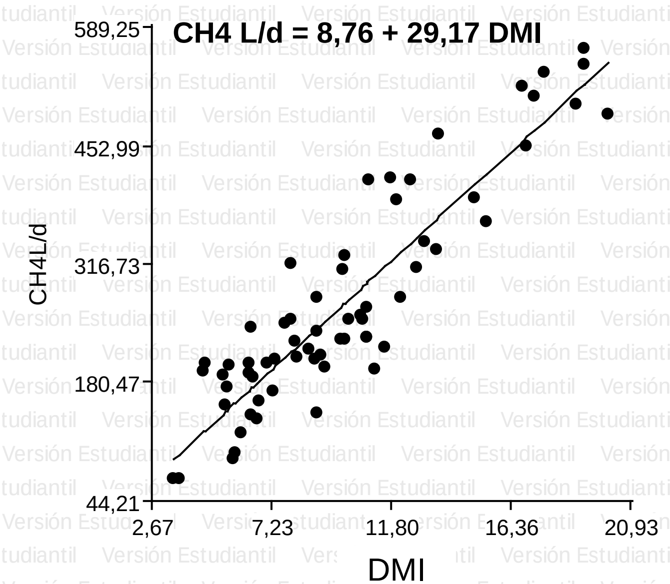
RESULTS AND DISCUSION

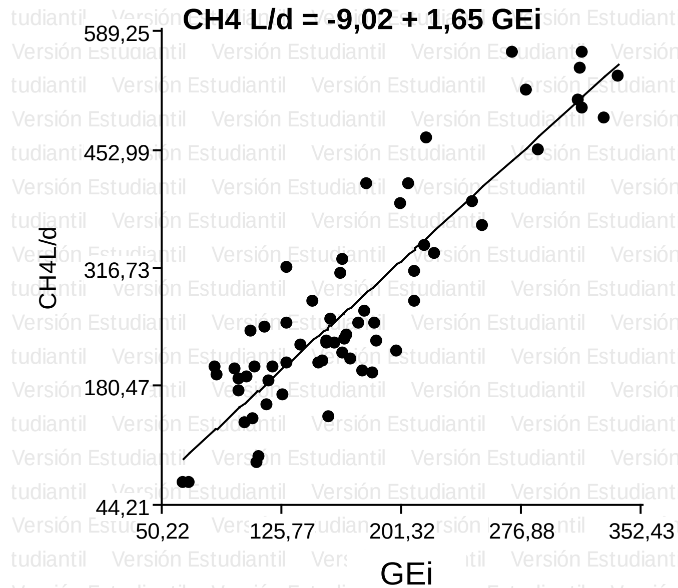
Table 4: Simple regression models developed for predicting methane production by cattle in Latin America.

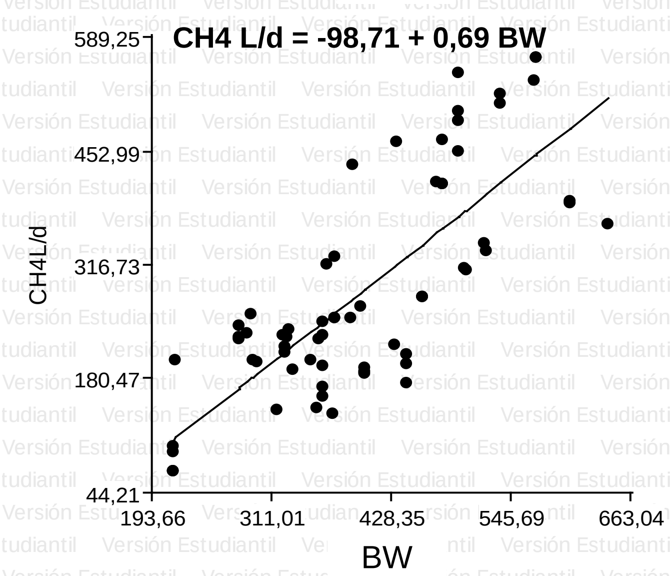
Nº eq		RMSPE	AIC	R^2	P value
1	**CH4 L/d** = -98,71 (±4,09) + 0,96 (±0,1) x **BW (kg)**	28%	762	0,60	<0,0001
2	**CH4 L/d** = 8,76 (±2,7) + 27,19 (±3,5) x **DMI (kg/d)**	22%	651	0,78	<0,0001
3	**CH4 L/d** =-19.97 (±2,5) + 56,32 (±4,4) x **NDFi (kg/d)**	23%	736	0,72	<0,0001
4	**CH4 L/d** =-0,66 (±2,7) + 98 (±9.1) x **ADFi (kg/d)**	26%	751	0,65	<0,0001
5	**CH4 L/d** = -9,02 (±1,9) + 1,65 (±0,1) x **GEi (Mj/d)**	19%	691	0,81	<0,0001
6	**CH4 L/d** = 109,71 (±12,65) + 112,94 (±7,4) x **CPi (kg/d)**	25%	715	0,79	<0,0001
7	**CH4 L/d** = 80,5 (±20.9) + 31,14 (±2.8) x **DDMi**	29%	704	0,67	<0,0001

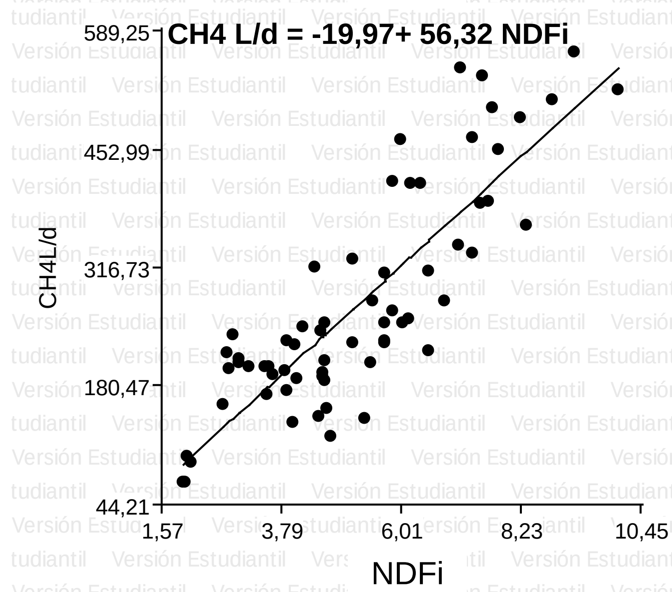
RESULTS AND DISCUSION

Simple regression models developed for predicting methane production by cattle in Latin America









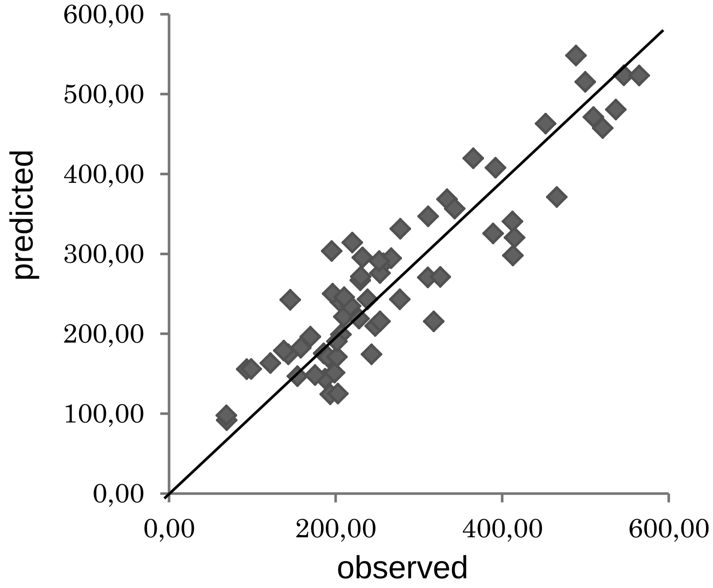
RESULTS AND DISCUSION

Table 5: Multiple regression equations developed for predicting methane production in Latin America.

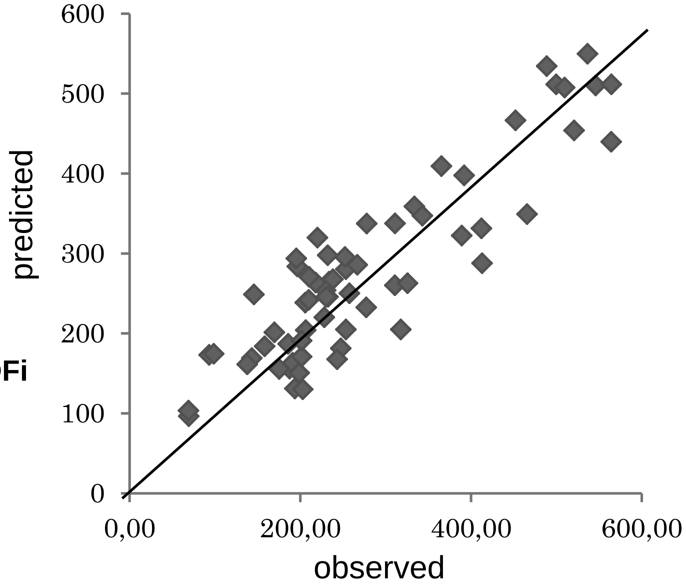
Nº eq		RMSPE	AIC	R^2	P value
8	**CH4 L/kgMS** = 27,97 (±2,3) + 0,04 (±0,04) x **DMI**–0,41 (±0,01) x **EEi**	39%	785	0,22	0,9275
9	**CH4 L/d** = -2,68 (±1,8) + 27,54 (±10,3) x **DMI**–0,02 (±0,01) x **GEi**	18%	660	0,84	<0,0001
10	**CH4 L/d** = -24,21 (±18,3) + 20,71 (±3,1) x **DMI**+ 16,83 (±6,7) x **NDFi**	20%	687	0,84	<0,0001
11	**CH4 L/d** = -32,88 (±18,3) + 22,17 (±2,6) x **DMI**+ 25,95 (±10,43) x **ADFi**	21%	688	0,84	<0,0001
12	**CH4 (L/d)** = 130,08 (±8, 15) + 38,83 (± 6,81) x **DMI**- 0,8 (±0,13) x **DMD**- 76,62 (± 23,47) x **NDFi**+ 70,68 (± 33,87) x **ADFi**	19%	464	0,93	<0,0001
13	**CH4 (L/d)** = -41,73 (±23,4) + 30,44 (± 6,08) x **NFCi**+ 28,2 (±13,9) x **HEMi**+ 77,9 (± 14,3) x **CELi**	22%	684	0,83	<0,0001

Estudio	Modelo
Ellis et al. 2007	**CH4 MJ/d** = 2,70 (±1,4) + 1,16 (± 0.,3) × **DMI**− 15,8 (± 6,9) × **EEi**
Moe y Tyrrell 1979	**CH4 MJ/d** = 0,34 + 0,51 x **NFCi**+ 1,74 x **HEMi**+ 2,65 x **CELi**

RESULTS AND DISCUSION



Eq nº2: CH4 L/d = 8,76 + 29,17 **DMI**



Eq nº14:

CH4 L/d = 130,1 + 38,8 **DMI** - 0,8 **DMD** -76,6 **NDFi** + 70,7 **ADFi**

Conclusions

Methane production by cattle in Latin America ranges from 70 to 570 L/day with an average of about 300 L/d, which is bigger from the values recommended by IPCC for Latin America.

The variability in methane emission depends mainly on the BW of the animal, its ability to ingest DM, DMD and the amount of fiber ingested in the diet (NDFi, ADFi).

Models developed in this work could be useful to develop regional inventories of methane emissions from enteric fermentation.

THANK YOU