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Prediction of Ruminal Methane Production from Cattle

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Abstract: Methane, one of the major greenhouse gases is produced primarily from cattle among livestock. Many researches have been conducted to reduce methane production and also to develop methods and/or equations to predict methane production in cattle. The objectives of this study were thus to construct a database containing experimental observations of methane production from cattle and to develop equations that predict methane production by cattle accurately. The database developed in this study contains experimental observations from the research articles published in the Journal of Dairy Science, Journal of Animal Science, Animal Feed Science and Technology, Canadian Journal of Animal Science, International Congress Series and Journal of Nutrition from 1964 till 2009. A total of 350 treatment means from 75 studies were obtained from the scientific journal articles that were found by searching for with methane and cattle as keywords. There were different methods measuring methane production; a chamber system, indirect respiratory hood, Sulfur hexafluoride (SF_6) and stoichiometric calculation. Only measured data were used in the subsequent analysis. Consequently the actual database used for the analysis is composed of a total of 256 treatment means from 57 studies. The types of animal in the database were 110 lactating dairy cows, 12 non-lactating dairy cows, 47 heifers, 65 steers, 10 calves, 10 bulls and 2 mixed. The mean (±SD) methane (g day^{-1}) methane (Mcal day^{-1}) and methane (GE%) of the data were 204.50 (±104.22), 2.76 (±1.38) and 5.56 (±1.87), respectively. Among the variables tested, DMI (kg) or NDF intake (NDFI, kg) was the most significant single variable that correlates with methane production. Using a random coefficient model with study as a random effect, researchers obtained -24.27 (±17.76) + 13.93 (±1.68) DMI (kg) + 0.57 (±0.20) FpDM + 8.43 (±4.16) NDFI (kg) (n = 145, -2 Res log likelihood = 1434.9) for predicting methane production (g). Using a simple linear regression, the best equation was CH_4 (g) = −18.53 (±14.90) + 11.89 (±1.50) DMI (kg) + 0.49 (±0.18) FpDM + 14.19 (±3.77) NDFI (kg) (R^2 = 0.84, root mean square error = 42.25). Although, DMI and NDFI are inherently correlated, a single variable was not sufficient to explain the variations in methane production of cattle. When both NDFI and DMI were present in the model statement type of animal or method of methane measurement was no longer significant. The results from this study suggest that methane production from cattle can be predicted accurately with DMI and NDFI. More research however is needed to improve accuracy of the model predictions.

Key words: Methane, modeling, cattle, animal, green house, bulls

INTRODUCTION

The Greenhouse Gas (GHG) emissions have become one of the major concerns in the modern human society due to their effects on global climate change. It was estimated that the average temperature of the earth could increase 3.6°C by the year 2100 which may possibly increase a sea level >0.9 m (Garton and Birkenholz, 1998). The primary GHG emitted by agriculture are methane (CH_4) and Nitrous Oxide (N_2O). Enteric methane production, especially is a major contributor to GHG emissions by cattle (Kebreab *et al*., 2006) and also represents a loss of nutrient that can be used for animal production otherwise. Enteric methane production varies between 2-12% of gross energy intake (Johnson and Johnson, 1995).

A recent statistics showed that enteric methane emissions from livestock, mostly cattle, represent about 24% of the total methane emissions in the US (EPA, 2009). In 2007, methane emissions from enteric fermentation by beef and dairy cattle were estimated to be 100.2 and 31.9 Tg CO_2 equivalent which contributed 53 and 17% of the methane emissions from the agriculture sector in the US

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(EPA, 2009). Although, the total amount of methane emissions by beef cattle is larger than by dairy cattle, individual dairy cattle produce more methane than beef cattle, primary due to high feed intake and high forage content in a dairy diet (Ellis *et al.*, 2007). In order to find better ways to reduce methane emissions, accurate estimation is a pre-requisite.

The most accurate and reliable way of estimating methane emissions may be to directly measure methane emissions from each cow herd or farm experimentally. Experimental measurement however, requires a large amount of time money and labor and the measurements vary by methods (Grainger *et al.*, 2007). Especially for constructing an inventory of methane production in animal sector and searching for effective mitigation strategies, experimental measurement is not easy to be applied but models can be used without undertaking extensive and costly experiments. In this regards there have been attemps to develop an empirical model for predicting methane production from cattle (Ellis *et al.*, 2007, 2009).

Due to a recent increase in the interest of reducing methane emissions, the number of publications that measure methane production of cattle increases dramatically each year. Thus, there is still a strong rationale for constructing a database that incorporates these recent observations and developing a model to accurately predict methane production based on this accumulated knowledge. The objectives of this study were thus to construct a database containing recent experimental observations of methane production from cattle, to identify the most critical variables related with ruminal methane production and to develop equations that predict ruminal methane production by cattle accurately.

MATERIALS AND METHODS

Database construction: The database developed in this study contains experimental observations from the research articles published in the Journal of Dairy Science, Journal of Animal Science, Animal Feed Science and Technology, Canadian Journal of Animal Science, International Congress Series and Journal of Nutrition from 1964 till 2009. A total of 350 treatment means from 75 studies were obtained from the scientific journal articles that were found by searching for with methane and (cattle or beef or dairy) as title, topic or keywords. There were different methods measuring methane production among treatment means; 77, 112, 67 and 94 methane measurements were obtained using a chamber system, indirect respiratory hood, Sulfur hexafluoride (SF_6) and stoichiometric calculation, respectively. Among these only measured data were used in the following analysis.

Consequently the actual database used for the analysis is composed of a total of 256 treatment means from 57 studies. The types of animal in the database were 110 lactating dairy cows, 12 non-lactating dairy cows, 112 growing heifers or steers, 10 bulls, 10 calves, 2 mixes of beef and dairy cattle. The mean (±SD) of methane (g day^{-1}), methane (Mcal day^{-1}) and methane (GE%) of the database were 204.50 (±104.22), 2.76 (±1.38) and 5.56 (±1.87), respectively. The detailed descriptive statistics of the database is shown in Table 1.

Model development: Before identifying significant variables for predicting methane production, a total of 12 outliers were omitted from the database. Outliers were determined using the difference in fits statistic (DFFITS). Data points with absolute values of DFFITS ≥0.4 which is a conservative value based on Neter *et al.* (1996) were omitted. When more than one absolute value of DFFITS was >0.4, data corresponding to the largest value was omitted first and the model was refitted to examine whether any other absolute value of DFFITS remained ≥0.4. The procedure continued until no apparent outlier was observed. To prevent erroneously removing acceptable observations data that previously were omitted were added back sequentially to the model and re-evaluated. As a result, a total of 244 treatment means from 57 studies were used for subsequent analysis.

The initial independent variables used for explaining the variations in methane production (g day^{-1}) were Dry Matter Intake (DMI, kg) Body Weight (BW, kg), DMI as

Table 1: Descriptive statistics for the database used for developing equations

Parameters	N	Mean	SD	Median	Max.	Min.
Animal inputs						
BW (kg)	253	452.23	157.65	488.00	740.00	130.00
DMI (kg day^{-1})	251	10.950	5.8300	8.8600	26.500	1.3500
DMI (BW%)	251	2.3600	0.7600	2.3000	4.5300	0.9000
GEI (Mcal day^{-1})	195	49.950	25.670	43.260	6.9400	119.91
Forage (DM%)	238	66.190	26.900	74.000	100.00	2.0000
Nutrient composition						
DM (AF%)	133	570990	24.520	52.100	97.800	22.300
CP (DM%)	195	15.840	3.7000	15.900	28.880	5.1000
EE (DM%)	95	4.0300	2.8700	3.0000	16.400	0.5000
Ash (DM%)	92	7.5400	2.0600	7.2200	12.100	4.2800
CF (DM%)	33	13.430	7.7000	16.500	30.400	0.4000
NDF (DM%)	150	41.160	14.810	37.700	78.400	1.5000
ADF (DM%)	168	23.830	10.920	21.480	53.500	0.4000
Methane production						
Methane (g day^{-1})	244	202.50	104.22	186.16	466.97	1.7300
Methane (Mcal day^{-1})	237	2.760	1.3800	2.5200	6.2000	0.0200
Methane (GE%)	202	5.560	1.8700	5.8400	10.370	0.2800

BW: Body Weight, DMI: Dry Matter Intake, GEI: Gross Energy Intake, CP: Crude Protein, EE: Ether Extract, CF: Crude Fiber, NDF: Neutral Detergent Fiber, ADF: Acid Detergent Fiber, GE: Gross Energy a percentage of BW (DMIpBW, %), forage as a percentage of dietary DM (FpDM, %), Crude Protein (CP, DM%), CP Intake (CPI, kg), Neutral Detergent Fiber (NDF, DM%), NDF Intake (NDFI, kg), Acid Detergent Fiber (ADF, DM%) and ADF Intake (ADFI, kg). Ether Extract (EE, DM%) and ash (DM%) were excluded from the candidate variable list because a small number of observed means reported these values. Among these variables, predictive variables that significantly and sufficiently explained the variations in each dependent variable were selected using step-wise regression.

Statistical analysis: The regression equation was developed in two phases. In the first phase, a random coefficients model was used using the MIXED procedure of SAS (2002) with study as a random variable to identify independent variables that were statistically significant ($p<0.05$). Among the acceptable regression models that had a linear combination of significant fixed effect variables, a model that had the lowest value of -2 restricted log likelihood, Akaike's Information Criterion (AIC), the corrected AIC (AICC) and Schwarz's Bayesian Criterion (SBC) was selected. The lowest value of those criteria above indicates a better model considering the number of observations, the number of parameters and the maximum likelihood estimates.

In the second phase, the parameters of the variables in the best model to predict methane production, identified in the first phase were estimated by fitting the prediction equation to a multiple regression model using GLM procedure of SAS (SAS Institute, Inc.).

RESULTS AND DISCUSSION

Among the variables tested, DMI, NDFI and ADFI were the most significant single variable that correlates with methan production. DMI alone explained 76.7% of the variations in methane production (Fig. 1). It is consistent with other previous reports (Axelsson, 1949; Ellis *et al*., 2007; Kriss, 1930; Mills *et al*., 2003). DMI and Metabolisable Energy (ME) intake (MJ day^{-1}) have been recognized as the most significant variable that affects ruminal methane production (Ellis *et al*., 2007; Mills *et al*., 2003). In this study however, researchers omitted ME intake from the candidate variables because ME content of a diet is normally calculated from digestible energy content of the diet (NRC, 2000, 2001) and ME is the amount of energy subtracting energy losses via urine and gas from digestible energy and it may be double accounting if ME intake is used for predicting methan production.

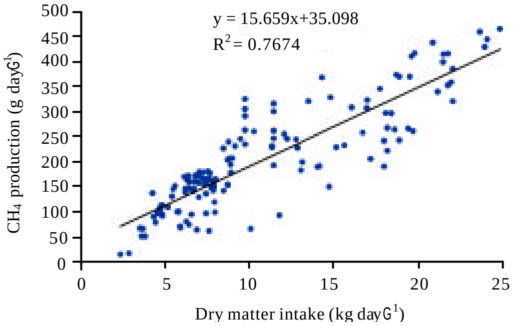

Fig. 1: Linear relationship of CH_4 production (g day^{-1}) with dry matter intake (kg day^{-1})

Out of a total of 8 candidate variables, the first phase of analysis using step-wise regression and a random coefficient model selected combinations of DMI, NDFI, BW, DMIpBW and FpDM. The amount of ADF and ADFI also showed significant effects on ruminal methane production and thus combinations with ADF instead of NDF were also possible. However, at the second phase of analysis using GLM procedure it turned out that ADFI was not significant while NDFI was a significant variable for predicting methane production in both MIXED and GLM procedure. NDF represents the total amount of fiber (i.e., hemicellulose, cellulose and lignin) while ADF contains cellulose and lignin without hemicellulose (Van Soest, 1994). Methane production may be related with ADF which is related with digestibility of forage (Rohweder *et al*., 1978). However, digestibiliyt of fiber is more related with the amount of lignin in the fiber (Weiss, 1993) which was not normally measured in the past, neither NDF nor ADF was a significant variable for estimating rate of passge of forage out of the rumen (Seo *et al*., 2006) and NDF is correlated with ADF and is more widely measured in the field. Moreover, since the objective of this study was to develop a prediction equation for ruminal methane production in the field and the significance of a variable in GLM Model is more important, researchers decided to select NDFI as a variable for the next analysis. Nevertheless, the equations developed using variable combinations with ADFI are also shown in Table 2.

The selected variables (DMI, NDFI, BW, DMIpBW and FpDM) were significantly and linearly related with ruminal methane production. Each of DMI, NDFI, BW and DMIpBW explained the variations in observed methane production by 76.7, 74.9, 47.8 and 43.9%, respectively (Fig. 1-4). FpDM alone was not a significant variable (Fig. 5) however, adding FpDM in the model statement can explain more variations and FpDM became statistically significant ($p<0.05$). Using a random coefficient model with study as a random effect,

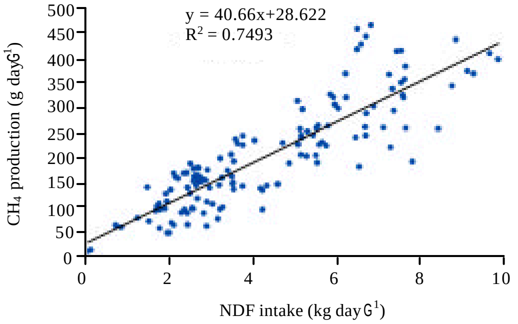

Fig. 2: Relationship of CH_4 production (g day^{-1}) with neutral detergent fiber intake (kg day^{-1})

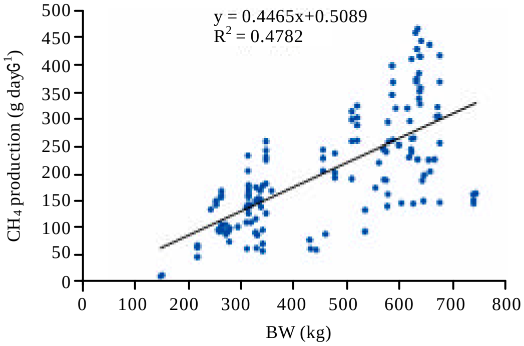

Fig. 3: Relationship of CH_4 production (g day^{-1}) with animal body weight (kg)

Table 2: List of equations developed for predicting methane production of cattle with acid detergent fiber inatke

Equation No.	Variable[a]	p-value	n	R^2	RMSE[b]
1	Intercept	0.12440	161	0.8284	44.26
	DMI	<0.0001			
	ADFI	0.00220			
	FpDM	0.00550			
	DMIpBW	0.01310			
	ADF	0.11540			
2	Intercept	0.54000	161	0.8257	44.47
	DMI	<0.0001			
	ADFI	0.00190			
	FpDM	0.01480			
	DMIpBW	0.02820			
3	Intercept	0.91900	220	0.7836	47.79
	DMI	<0.0001			
	FpDM	<0.0001			
	DMIpBW	<0.0001			
4	Intercept	0.01680	220	0.7652	49.67
	DMI	<0.0001			
	FpDM	<0.0001			
5	Intercept	0.64920	161	0.8202	45.02
	DMI	<0.0001			
	FpDM	0.03480			
	DMIpBW	0.00130			
6	Intercept	0.00620	161	0.8128	45.94
	DMI	<0.0001			
	FpDM	0.00440			
	ADF	0.04560			

[a]DMI: Dry Matter Intake, ADFI: Acid Detergent Fiber Intake, FpDM: Forage as a Percentage of Dietary DM, DMIpBW: DMI as a percentage of BW, ADF: Acid Detergent Fiber; [b]RMSE: Root Mean Square Error

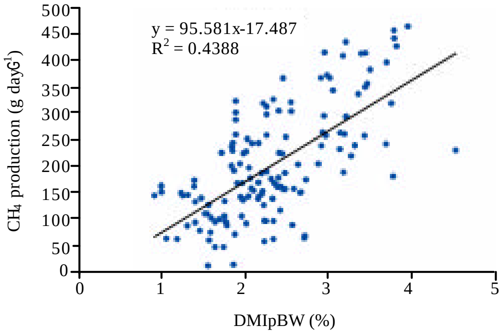

Fig. 4: Relationship of CH_4 production (g day^{-1}) with dry matter intake as a percentage of body weight (DMIpBW, %)

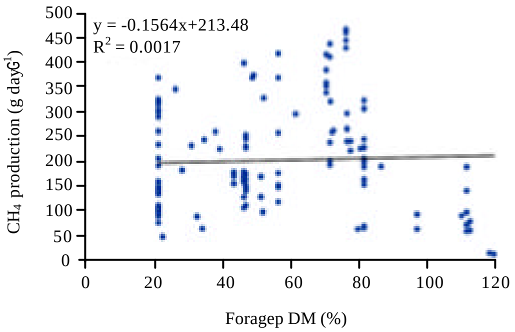

Fig. 5: Relationship of CH_4 production (g day^{-1}) with the amount of forage as a percentage of dietary dry matter (forageDM, %)

researchers obtained -24.27 (±17.76)+13.93 (±1.68) DMI (kg) + 0.57 (±0.20) FpDM (%) + 8.43 (±4.16) NDFI (kg) (n = 145, -2 Res log likelihood = 1434.9) for predicting methane production (g).

Using a simple linear regression, the best equation was CH_4 (g) = −18.53 (±14.90) + 11.89 (±1.50) DMI (kg)+ 0.49 (±0.18) FpDM (%) + 14.19 (±3.77) NDF intake (kg) (R^2 = 0.84, root mean square error = 42.25) even though other possible equations were also derived (Table 3 and Fig. 6). Although, DMI and NDFI are inherently correlated, a single variable was not sufficient to explain the variations in methane production of cattle. When both DMI and NDFI were present in the model type of animal or method of methane measurement was no longer significant. This implies that DMI, NDFI and FpDM can successfully account for the differences in methane production among different stages or types of animals and among different methods (i.e., chamber, SF6 and hood methods).

Table 3: Coefficient of determination of the linear models to predict ruminal methane production with different input variables

Variables	R^2	Variable	R^2	Variable	R^2
DMI	0.7674	DMI, NDFI	0.8307	DMI, FpDM, NDFI	0.8391
NDFI	0.7493	DMI, FpDM	0.8229	DMI, DMIpBW, NDFI	0.8318
BW	0.4782	DMI, NDF	0.8149	BW, DMI, NDFI	0.8313
DMIpBW	0.4388	NDF, NDFI	0.8106	DMI, NDF, NDFI	0.8307
FpDM	0.0017	BW, NDFI	0.7742	BW, DMI, FpDM	0.8295
NDF	0.0000	DMIpBW, NDFI	0.7717	DMI, DMIpBW, FpDM	0.8294
-	-	BW, DMI	0.7704	DMI, FpDM, NDF	0.8260
-	-	DMI, DMIpBW	0.7697	FpDM, NDF, NDFI	0.8218

DMI: Dry Matter Intake, NDFI: Neutral Detergent Fiber Intake, BW: Body Weight, DMIpBW: DMI as a percentage of BW, FpDM: Forage as a Percentage of Dietary DM, NDF: Neutral Detergent Fiber Fig. 1. Relationship of CH_4 production with Dry Matter Intake (DMI)

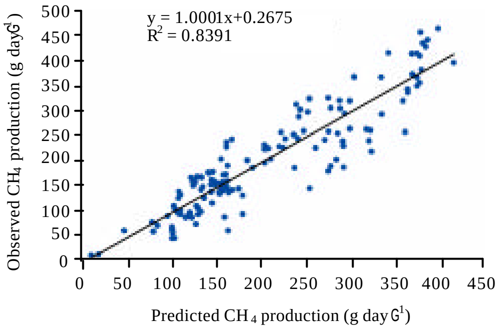

Fig. 6: Regression of observed CH_4 production against predicted values.

CONCLUSION

The results from this study suggest that methane production from cattle can be predicted accurately with DMI and NDFI. More research however is needed to improve accuracy of the model predictions.

ACKNOWLEDGEMENT

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