Agriculture, Ecosystems and Environment 215 (2016) 89–99

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Development of statistical models for prediction of enteric methane emission from goats using nutrient composition and intake variables

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ARTICLE INFO

Article history:
Received 10 April 2015
Received in revised form 9 August 2015
Accepted 16 September 2015
Available online 25 September 2015

Keyword:
Goat
Methane emission
Statistical model
Dietary variable

ABSTRACT

The objective of this study was to develop linear and nonlinear statistical models for prediction of enteric methane emission (EME; MJ/day) from goats. Dietary nutrient composition (g/kg), intake of nutrients (kg/day) and energy (MJ/day), digestibility (g/kg) of energy and organic matter (OM) were used as predictors of methane production. A database from 42 publications, which included 211 mean observations of EME measured on 978 goats, was constructed to develop EME prediction models. Observations containing anti-methanogenic compounds and outliers were removed before statistical analyses. The simple linear equation that predicted EME with high precision and accuracy was: EME = $0.242_{(\pm 0.073)} + 0.0511_{(\pm 0.0073)}$ × digestible energy intake, adjusted $R^2 = 0.83$ with root mean square prediction error (RMSPE) of 30.3% of which 97% is from random error and regression bias of 2.85%. Multiple regression equations that had slightly better precision and accuracy than simple prediction equations were EME = $-1.04_{(\pm 0.271)} + 2.21_{(\pm 0.395)}$ × neutral detergent fiber intake − $2.42_{(\pm 1.10)}$ × ether extract (EE) intake + $1.456_{(\pm 0.323)}$ × nonfiber carbohydrate intake + $0.0208_{(\pm 0.0039)}$ × OM digestibility at maintenance level of feeding (OMDm) – $0.513_{(\pm 0.137)}$ × feeding level (FL), adjusted $R^2 = 0.82$ [RMSPE = 30.3% with 98.3% random error and 1.24% regression bias] and EME = $-0.885_{(\pm 0.154)} + 0.809_{(\pm 0.0867)}$ × dry matter intake – $0.397_{(\pm 0.0494)}$ × FL + $0.0198_{(\pm 0.0022)}$ × OMDm + $2.04_{(\pm 0.234)}$ × acid detergent fiber intake – $8.54_{(\pm 0.548)}$ × EE intake, adjusted $R^2 = 0.88$ [RMSPE = 36.3% with 99.1% random error and <0.01% regression bias]. Among the nonlinear equations developed, Mitscherlich model [EME = $1.721_{(\pm 0.151)}$ × {1 – exp($-0.0721_{(\pm 0.0092)}$ × metabolizable energy intake)}; adjusted $R^2 = 0.79$; RMSPE = 31.2% with 96.9% random error and 2.94% regression bias] performed better than simple linear and other nonlinear models, but the predictability and goodness of fits of the equation did not improve compared with the multiple regression models. Application of the current prediction equations developed by Food and Agricultural Organization and Intergovernmental Panel on Climate Change overestimated EME from goats, and had low accuracy and precision. Therefore, the equations developed in this study will be useful for national methane inventory preparation, and for a better understanding of dietary factors influencing EME from goats.

1. Introduction

Microbial fermentation process of feeds in the rumen normally results in production of methane, which results in an energy loss of up to 15% of the digestible energy intake depending upon chemical composition of feeds and shares a major fraction of total greenhouse gas (GHG) emissions from livestock production systems (Steinfeld et al., 2006; Patra 2012; 2014a). Enteric methane emission (EME) from livestock contributes approximately 38.6% of total agricultural emissions (FAOSTAT, 2014). Although a major portion of the EME arises from cattle (73.8%) and buffalo (11.3%) in 2010, the world goat population of about 1.01 billion (FAOSTAT, 2014) produces approximately 4.61 million tonnes of enteric methane representing 4.9% of total EME from livestock (Patra, 2014a). Moreover, EME from goats are expected to grow in the years ahead due to enhanced growth of goat population and growing demands of milk and meat (Steinfeld et al., 2006; Patra, 2014a). Development of EME prediction models is, therefore, required to precisely estimate methane emissions from goats.

A number of statistical models have been developed, based on database organized from different studies, to estimate EME and understand the various dietary factors that affect rumen fermentation process in cattle (e.g., Kriss, 1930; Axelsson, 1949; Mills et al., 2003; Kebreab et al., 2008), buffalo (e.g., Patra, 2014b) and sheep (e.g., Blaxter and Clapperton, 1965; Pelchen and Peters, 1998). Statistical models predict EME from nutrient intake, composition,

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http://dx.doi.org/10.1016/j.agee.2015.09.018
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feeding levels and digestibility directly (Blaxter and Clapperton, 1965; Moe and Tyrrell, 1979; Mills et al., 2003; Kebreab et al., 2008; Ellis et al., 2009; Ramin and Huhtanen, 2013; Moraes et al., 2014; Patra, 2014b). These models had been useful to calculate EME without undertaking extensive and costly experiments. In addition, EME prediction models are needed for better estimates of methane emissions in national and global GHG inventories and development of strategies and environmental policies for emission reductions (Intergovernmental Panel on Climate Change (IPCC, 2006). The IPCC (2006) and Food and Agricultural Organization (FAO, 2010) had developed methodologies to estimate EME with the use of methane emissions factors (Ym; i.e. the proportion of the gross energy (GE) intake which is lost as methane). However, Ym does not directly represent variations in methane emissions determined by the ruminal fermentation of distinct carbohydrates, and thus the usefulness of Ym based models in predicting EME and evaluating dietary methane mitigation options is limited (Moraes et al., 2014). Furthermore, the low predictive ability of the Ym approach may introduce considerable inaccuracy in preparation of GHG inventories (Ellis et al., 2010; Patra, 2014b). In this context, although there are several statistical models for predicting EME from cattle, buffalo and sheep, there is no model for predicting EME in goats developed from a large database emanated from different countries. Development of equations for predicting EME from a large database specifically from goats may improve predictive ability of enteric methane production under wide range of feeding situations. Therefore, the objective of this study was to develop statistical models to predict enteric methane production from goats using commonly measured dietary composition and nutrient intake variables.

2. Materials and methods

2.1. Construction of database

A database containing 211 treatment mean data from 42 published studies (Appendix 1) was constructed for development of prediction models of enteric methane production from goats. The studies report data on description of the animals, chemical composition of diets, feed intake, digestibility and in vivo methane production from goats. Methane production was measured using the sulphur hexafluoride technique ($n = 3$), respiration chamber ($n = 194$) and open circuit mask system ($n = 14$). Treatments ($n = 9$) with feed additives with antimethanogenic properties (fumaric acid, tannins, bromochloromethane and plant phytochemicals) were excluded from final database before statistical analyses.

The investigated animal factors (explanatory variables) were body weight (BW), intakes of dry matter (DM), individual nutrients, gross energy (GE) and metabolizable energy (ME), organic matter (OM) and GE digestibility, diet chemical composition [(ether extract (EE), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL), non-fibrous carbohydrate (NFC)], forage proportion and feeding level (FL), which were used for regression equation development. Chemical composition of diets was recorded from the published values given in each paper. When some composition data were missing, tabulated values (Feedipedia, 2014) were used for calculating chemical composition of diets.

When GE intake (MJ/day) was not reported in the published papers, it was estimated from DM intake and GE concentration (MJ/kg DM) calculated from chemical composition of diets (Jentsch et al., 2003):

$$\text{GE intake (MJ/day)} = \text{DM intake (kg/day)} \times \left[\frac{\{23.6 \times \text{CP (g/kg)} + 39.8 \times \text{EE (g/kg)} + 17.3 \times \text{NFC (g/kg)} + 18.9 \times \text{NDF (g/kg)}\}}{1000}\right] \quad (1)$$

The FL as a multiple of maintenance was estimated by dividing the ME intake by the maintenance ME requirement for goats (AFRC, 1998):

$$\text{FL} = \frac{\text{ME intake (MJ/d)}}{[0.438 \times (\text{BW(kg)}^{0.75})]} \quad (2)$$

Digestibility of OM was estimated from DM digestibility when a study did not report OM digestibility using the equation derived from the data in this study. When either GE or OM digestibility was not reported, they were estimated using prediction equations derived from the current data set as follows:

$$\text{OM digestibility (g/kg)} = 53.1(\pm 15.5) + 0.934(\pm 0.0255) \times \text{GE digestibility (g/kg)} \ (\text{RMSE} = 21.8;\ n = 110) \quad (3)$$

$$\text{GE digestibility (g/kg)} = -6.58(\pm 15.3) + 0.987(\pm 0.022) \times \text{OM digestibility (g/kg)} \ (\text{RMSE} = 25.1\ \ n = 110) \quad (4)$$

$$\text{GE digestibility (g/kg)} = 3.33(\pm 19.1) + 1.00(\pm 0.029) \times \text{DM digestibility (g/kg)} \ (\text{RMSE} = 37.8; n = 109) \quad (5)$$

Digestibility at a maintenance level of feeding (OMDm, g/kg) is the most consistent assessment of digestibility of feeds (Ramin and Huhtanen, 2013), which was used a predictor methane production in this study. Because digestibility was determined at actual level of intake, actual OM digestibility was adjusted to OMDm using the relationship between DM intake/BW and OM digestibility (1.83 per 1 g/kg of DM intake/BW; Ramin and Huhtanen, 2013) with the following equation:

$$\text{OMDm(g/kg)} = \text{OM digestibility(g/kg)} + 1.83 \times \left(\frac{\text{DM intake}}{\text{BW}}\ \text{(g/kg)}\ \text{at actual level} - \frac{\text{DM inatke}}{\text{BW}}\ \text{(g/kg)}\ \text{at maintenance level}\right) \quad (6)$$

DM intake/BW (g/kg) at maintenance level was calculated from the following relationship observed in this study:

$$\frac{\text{DM intake}}{\text{BW}}\ \text{(g/kg)} = 7.64(\pm 1.43) + 12.0(\pm 0.61) \times \text{FL}\ (\text{RMSE} = 3.13; n = 159) \quad (7)$$

where FL = 1 is the maintenance level feeding.

Since all variables were not available across all observations in the data set, the number of observations used for development of prediction equations varied between explanatory and response variables depending on the regressor variables available. Data reported in differing units of measure were transformed to the