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Nordic dairy cow model Karoline in predicting methane emissions: 2. Model evaluation

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ABSTRACT

Models are widely used to predict methane (CH_4) emissions, and can be used to develop mitigation options and policies. The objective of the current study was to evaluate the performance of the Nordic dairy cow model Karoline in predicting CH_4 emissions. Karoline is a dynamic, deterministic and mechanistic simulation model that describes the digestion and metabolism of nutrients, and production in a dairy cow. The model was evaluated against observed data from studies reporting CH_4 emissions from respiration chamber studies. The dataset included a total of 184 treatment means from 31 published papers. The dietary and animal characteristics used for the model evaluation represent the typical range of diets fed to dairy cattle. When analyzed with a fixed model regression, there was a good relationship between predicted and observed CH_4 emissions measured from respiration chamber studies with a small root mean square error of prediction (R^2=0.93, RMSPE=10.1% of the observed mean). The mean bias was small (1.9%) but statistically significant, and there was no slope bias. Most of the error was due to random variation (96.4%), whereas the contributions of mean and slope bias were small. By considering study as the random effect in the model (mixed model regression analysis), the fit improved to R^2= 0.98 and RMSPE decreased to 6.1% of the observed mean. The influence of some input variables such as total dry matter intake, proportion of concentrate, dietary concentrations of crude protein, neutral detergent fiber and ether extract, and organic digestibility (OMD) on the residuals (observed–predicted) of CH_4 emissions were not significant. The residuals of both CH_4 emissions and OMD were significantly related to each other, indicating the Karoline model requires accurate estimates of digestion kinetic parameters as input variables. When the laboratory was used as a class variable in the model, the residuals of CH_4 emissions were significantly different both between the laboratories and also between experiments within individual laboratories. It is concluded that the Nordic dairy cow model Karoline is a useful tool in predicting CH_4 emissions and understanding the system behavior. The model can also be used in developing mitigation strategies for the national inventories of CH_4 emissions.

1. Introduction

Within the agriculture sector, livestock methane (CH_4) emission contributes about 51% of total agricultural CH_4 emission in which the agricultural sector contributes about 60% of the total anthropogenic emissions of CH_4 (Wuebbles and Hayhoe, 2002;). The CH_4 gas is about 25 times more effective in trapping heat in the atmosphere than carbon dioxide (IPCC, 2007; McAllister et al., 2011). In the recent IPCC (2013) report the factor was increased to 34. In addition to contribution to greenhouse gas emissions, CH_4 represents an energy loss to the host animal ranging from

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2% to 12% of the gross energy (GE) intake depending on diet composition and intake level (Johnson and Johnson, 1995).

There have been several attempts to develop mathematical models predicting CH_4 emissions. The simplest of models developed to predict CH_4 emissions used empirical relationships between dry matter intake (DMI) and CH_4 emissions (Kriss, 1930; Axelsson, 1949). More complicated empirical models consist of nutrient intake, diet composition and feeding level (e.g. Blaxter and Clapperton, 1965; Yan et al., 2000; Jentsch et al., 2007). Methane emissions have also been quantified using dynamic and mechanistic models as described by Mills et al. (2001) using the model of Dijkstra et al. (1992) and by Benchaar et al. (1998) using the model of Baldwin (1995). Mechanistic modes simulate CH_4 emissions using mathematical descriptions of ruminal fermentation biochemistry; therefore, they can be helpful in understanding the mechanisms and factors influencing CH_4 emissions. A recent evaluation (Huhtanen and Ramin, 2012) using a synthetic dataset developed by Monte Carlo simulation suggested that the dynamic, deterministic and mechanistic Nordic dairy cow model Karoline (Danfaer et al., 2006a) has a potential to predict CH_4 emissions. In a companion paper (Huhtanen et al., in press) modifications of digestion and methane modules and sensitivity analysis were described. The objective of the current study was to evaluate the performance of the revised Karoline model in predicting CH_4 emissions against observed data from respiration chamber studies conducted in growing and lactating cattle.

2. Materials and methods

Karoline is a simulation model of a lactating dairy cow consisting of two sub-models: nutrient digestion and metabolism of absorbed nutrients (Danfaer et al., 2006a). The sub-model predicting CH_4 emissions in the Karoline model is based on the amounts of substrates fermented and fermentation stoichiometric balances (Sveinbjörnsson et al., 2006).

2.1. Dataset used for model evaluation

Acquisition of the dataset used for evaluation of the Karoline model in predicting CH_4 emissions is described in more detail by Ramin and Huhtanen (2013). Only the published data on CH_4 emissions determined using respiration chamber was collected. Only the studies conducted in dairy cows and growing cattle were chosen from the original dataset (Appendix). A brief description of the dietary and animal variables in the dataset is given in Table 1. The number of treatment means used for the model evaluation was 184 originating from 31 published papers from the 1960s to 2013 (see Appendix). Prerequisites for a study to be included in the dataset were that, in addition to measured CH_4 emissions, feed intake, diet digestibility and adequate diet composition data [e.g. ingredients and concentrations of crude protein (CP) and ether extract (EE)], were reported. Revisions of the Karoline model (Huhtanen et al., in press) were completely independent of the model evaluation dataset.

2.2. Estimation of fibre and protein parameters

Since the Karoline model requires chemical feed fractions and parameters of digestion kinetics, these had to be estimated from the available data in the papers or derived from the literature. Because of the high sensitivity of digestibility parameters on CH_4 emissions (Huhtanen et al., in press), a special emphasis was given to the digestion kinetic variables.

When reported, digestion kinetic variables were derived from *in vivo* or *in vitro* digestibility of forages. For the mixed diets, organic matter digestibility (OMD) of forages was calculated as a difference using tabulated digestibility coefficients for the concentrate ingredients (MTT, 2013). To estimate digestibility at the maintenance level, the reported digestibility values were first corrected for the feeding level effects according to the equation of Huhtanen et al. (2009). When the concentration of indigestible neutral detergent fiber (iNDF) in forages was not reported, it was estimated from OMD using empirical relationships derived from the forage dataset of Huhtanen et al. (2006a). Potentially digestible NDF (pdNDF) was calculated as NDF – iNDF. The digestibility of pdNDF (pdNDFD) was calculated as digested NDF/pdNDF. Digested NDF was calculated from digestible OM assuming that metabolic and endogenous fecal OM was 100 g/kg DMI (Weisbjerg et al., 2004; Huhtanen et al., 2006a). The digestion rate (k_d) of pdNDF was calculated as described by Huhtanen et al. (2006b)

$$k_d\mathrm{pdNDF}_{(1/h)} = \left\{ -\left(k_p + k_r\right) + \left[\left(k_p + k_r\right)^2 + 4 \times \mathrm{pdNDFD}_{(kg/kg)} \times k_r k_p / (1 - \mathrm{pdNDFD}) \right]^{0.5} \right\} / 2 \quad (1)$$

where k_p (1/h) is the fractional rate of passage and k_r (1/h) is the fractional rate of release from the non-escapable pool to the escapable pool. Values of 0.05 and 0.033 for k_r and k_p, respectively, are based on the total rumen residence time of 50 h (20 h + 30 h in rumen non-escapable and escapable pools) at the maintenance level of intake. Because details of maize silages were not reported, we used a value of 0.30/h of starch k_d for maize and barley silages based on the Cornell Net Carbohydrate and Protein System feed table (CNCPS; Fox et al., 2004; Tylutki et al., 2008). The k_d values of starch for the concentrate ingredients were derived from the CNCPS feed table (Fox et al., 2004; Tylutki et al., 2008) and the *in vitro* gas production results of Stevnebø et al. (2009).

For the concentrate ingredients, iNDF concentrations were based on data from 12-d ruminal *in situ* incubation conducted at MTT Agrifood Research Finland, or when the data was not available, iNDF was calculated as 2.4 × lignin (Sniffen et al., 1992; Tylutki et al., 2008). Digestion rates of pdNDF for concentrate ingredients were determined by the automated *in vitro* gas production system using isolated NDF or, when not available, from the CNCPS feed table (Fox et al., 2004; Tylutki et al., 2008).