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Predicting manure volatile solid output of lactating dairy cows

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ABSTRACT

Organic matter (OM) in livestock manure consisting of biodegradable and nonbiodegradable fractions is known as volatile solids (VS). According to the Intergovernmental Panel on Climate Change (IPCC) Tier 2 guidelines, methane produced by stored manure is determined based on VS. However, only biodegradable OM generates methane production. Therefore, estimates of biodegradable VS (dVS; dVS = VS − lignin) would yield better estimates of methane emissions from manure. The objective of the study was to develop mathematical models for estimating VS and dVS outputs of lactating dairy cows. Dry matter intake, dietary nutrient contents, milk yield and composition, body weight, and days in milk were used as potential predictor variables. Multicollinearity, model simplicity, and random study effects were taken into account during model development that used 857 VS and dVS measurements made on individual cows (kg/cow per day) from 43 metabolic trials conducted at the USDA Energy and Metabolism laboratory in Beltsville, Maryland. The new models and the IPCC Tier 2 model were evaluated with an independent data set including 209 VS and dVS measurements (kg/cow per day) from 2 metabolic trials conducted at the University of California, Davis. Organic matter intake (kg/d) and dietary crude protein and neutral detergent fiber contents (% of dry matter) were significantly associated with VS. A new model including these variables fitted best to data. When evaluated with independent data, the new model had a root mean squared prediction error as a percentage of average observed value (RMSPE) of 12.5%. Mean and slope biases were negligible at <1% of total prediction bias. When energy digestibility of the diet was assumed to be 67%, the IPCC Tier 2 model had a RMSPE of 13.7% and a notable mean bias for VS to be overpredicted by 0.4 kg/cow per day. A separate model including OM intake as well as dietary crude protein and neutral detergent fiber contents as predictor variables fitted best to dVS data and performed well on independent data (RMSPE = 12.7%). The Cornell Net Carbohydrate and Protein System model relying on fat-corrected milk yield and body weight more successfully predicted dry matter intake (DMI; RMSPE = 14.1%) than the simplified (RMSPE = 16.9%) and comprehensive (RMSPE = 23.4%) models to predict DMI in IPCC Tier 2 methodology. New models and the IPCC Tier 2 model using DMI from the Cornell Net Carbohydrate and Protein System model predicted VS (RMSPE = 17.7–19.4%) and dVS (RMSPE = 20%) well with small systematic bias (<10% of total bias). The present study offers empirical models that can accurately predict VS and dVS of dairy cows using routinely available data in dairy farms and thereby assist in efficiently determining methane emissions from stored manure.
Key words: dairy cow, manure, prediction model, volatile solid

INTRODUCTION

Despite a growing number of policies to reduce climate change, global emissions of greenhouse gases (**GHG**) have increased to unprecedented levels. Livestock manure management systems (**MMS**) are significant sources of GHG, particularly in regions where industrialized livestock farming takes place (Masse et al., 2008). For instance, MMS in the Americas and Europe account for 15 to 25% of total agriculture GHG emissions compared with 7 to 11% in Africa and Asia (Tubiello et al., 2013). Methane (CH_4) is the main GHG emitted, particularly from liquid-based MMS, common in North America. In the United States, on average 43% of total dairy cattle CH_4 emissions comes from MMS (Owen and Silver, 2015). Jayasundara et al. (2016) indicated the possibility of mitigating MMS emissions in Canadian dairy farms by up to 50%. Therefore, CH_4

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from MMS is a primary target of programs and policies aiming at mitigating GHG emissions from agriculture. Quantifying CH_4 emissions from MMS is important in establishing national inventories and assessing the effect of mitigation programs (e.g., anaerobic digestors). Because measurement of CH_4 emissions is expensive and labor intensive, mathematical models can be used successfully to predict the emissions.

The Intergovernmental Panel on Climate Change (**IPCC**) Tier 2 methodology is widely used to estimate CH_4 emission factors (kg of CH_4/animal per year) of given MMS and relies primarily on OM or volatile solid (**VS**) output (kg/cow per day) and the maximum CH_4 producing potential of the manure ($\mathbf{B_0}$; kg of CH_4/kg of VS). In IPCC Tier 2 methodology, VS is determined with a model requiring information such as gross energy (**GE**) intake (MJ/d) and dietary energy digestibility (**DE**; %), which are not routinely available at commercial farms. Therefore, default constants or population averages are generally used for those factors. The use of constant values can have considerable effect on the accuracy of VS estimates because factors, such as DE, are highly variable across diets (e.g., 49–81% in Hanigan et al., 2013). Alternatively, models including variables routinely measured on farms and that have significant relationships with OM digestibility or DE could be able to predict VS more efficiently and accurately. Nutrient composition of diets is routinely available in the majority of commercial dairy farms in the United States and has previously been shown to affect OM digestibility (Broderick et al., 2001; Colmenero and Broderick, 2006). Biodegradable VS (**dVS**; dVS = VS − fecal lignin output) undergoing anaerobic digestion produce CH_4 during manure storage (Petersen et al., 2016). Lignin is fully resistant to anaerobic digestion and increases the resistance of cellulose in lignocellulosic materials. Lignin content of VS could be as high as 14% and vary significantly [e.g., coefficient of variation (**CV**) >30%] across different diets (Hindrichsen et al., 2006). Therefore, CH_4 emissions from MMS determined with dVS would be more representative than those based on VS.

Dry matter intake is the most important information required by models predicting fresh manure nutrient output of dairy cows (Appuhamy et al., 2014), including the IPCC Tier 2 model. However, accurate measurements of feed intake of individual cows are challenging to obtain in most commercial farms (Vallimont et al., 2010). The IPCC Tier 2 methodology includes a separate set of models to predict DMI if actual feed intake measurements are not available. Other extant models for predicting DMI of lactating dairy cows are available. Appuhamy et al. (2016) evaluated several of those models, including the Cornell Net Carbohydrate and Protein System (**CNCPS**) model (Fox et al., 1992) and National Research Council model (NRC, 2001), using measured DMI of cows in North America and Europe. These models include variables such as dietary nutrient composition, milk yield and composition, week of lactation, and BW. Information on these variables is usually available in commercial farms or can be estimated with narrow uncertainty. The CNCPS model including fat-corrected milk and BW as predictor variables performed best and had small prediction error, which was only 8% of the average DMI of cows in the United States and Canada. Consequently, Appuhamy et al. (2016) demonstrated the possibility of accurately determining enteric CH_4 from North American cows using DMI estimated with the CNCPS model. The objectives of the present study were to (1) develop models to predict VS and dVS of lactating dairy cows using data routinely available in dairy farms and (2) evaluate the performance of these new models and the IPCC Tier 2 model using measured or estimated DMI by challenging them on an independent data set.

MATERIALS AND METHODS

Data for Model Development

A total of 857 measured fecal OM (**FOM**; kg/d) and urinary carbon (**UC**; kg/d) outputs of individual cows, as well as related DMI and dietary nutrient composition, milk yield and milk composition, DIM, BW, and age, were obtained from 43 energy balance trials conducted at the former Energy Metabolism Unit (**EMU**) at USDA Beltsville from 1962 to 1995. In each energy balance trial, feces and urine outputs of individual cows were measured daily over 5 to 7 d using a total collection method while animals were housed in respiration chambers for measurements of CH_4 and carbon dioxide production and oxygen consumption. Cows were catheterized to measure total urine volume in all trials (Wilkerson et al., 1997). Nutrient concentrations in diets, feces, and urine were measured with daily-collected samples composited over the trial period. Therefore, feed intake, milk yield, and manure output measurements were averaged over each trial period to be in line with the nutrient concentrations. All the trials used a total of 254 lactating Holstein cows, 226 of which were used in multiple trials and thus provided multiple manure output and other related measurements.

The forage content of the experimental diets varied from 0 to 100% with a mean of 53% of DM. Eighty percent of the diets included alfalfa hay or alfalfa silage. Almost half of those diets also included corn silage. Ground corn, soybean meal, and ground barley and oats were included in 71, 61, and 32% of the diets, respectively. Dried feed and fecal samples were analyzed