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Enteric Methane Emissions from Dairy Cows: Accounting Techniques

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Introduction

Methane is a colorless and odorless gas released into the atmosphere from many sources, including the digestive tract of ruminant animals. Enteric methane is the term used to refer to the emission of methane associated with this digestive physiology. Compared to single-stomach animals (poultry and swine), ruminants (cattle, sheep, and goats) have complex digestive systems with compartments that ferment feed. Enteric methane is one of the many products of the fermentation process, and it is produced in much larger quantities in large ruminant animals like cattle than in other species. Enteric methane emissions contribute more than 50% of the total greenhouse gas (GHG) emissions from U.S. dairy farms, making them the most significant source of GHG emissions on the farmstead.

Aside from the impact on climate change, enteric methane from dairy cows represents a carbon (i.e., energy) source that has not been used to produce milk or meat. For many years nutritionists have viewed methane as the "cost to pay" for using cattle to convert rations high in fiber that are inedible for humans into high-quality animal protein (e.g., milk and meat) that is edible for humans. Methane represents an inefficiency, as the energy it contains is not converted to useful products. Reducing enteric methane losses could increase the efficiency of feed conversion, which is an important profitability indicator on many dairy farms and simultaneously reduces environmental impacts.

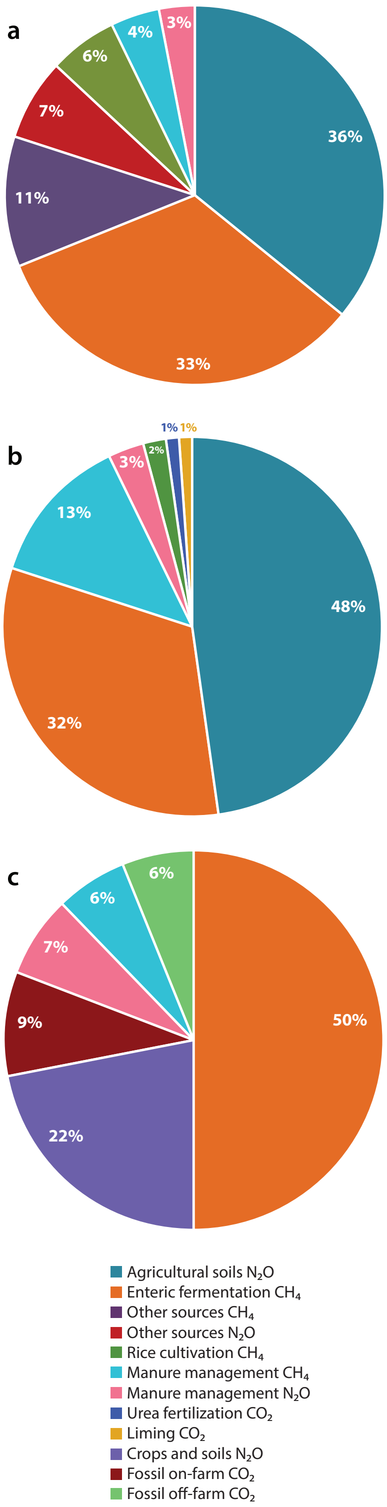

Figure 1. a) Global agriculture GHG emissions (from IPCC 2014), b) U.S. agriculture GHG emissions (from USEPA 2012), and c) dairy farm GHG emissions (from Aguirre-Villegas et al. 2015).

Methane as a Greenhouse Gas (GHG)

Methane is considered a GHG because it traps infrared radiation in the atmosphere causing an increase in air temperature. Once emitted, methane remains in the atmosphere for an average of 12 years. This is a shorter period than carbon dioxide, but methane traps 28-34 times more solar radiation than carbon dioxide. Thus, any amount (e.g., 1 lb or 1 kg) of methane in the atmosphere has 28-34 times the effect of the same amount (1 lb or 1 kg) of carbon dioxide, or 28-34 times its warming potential (Myhre et al. 2013).

Enteric methane is an important contributor to global GHG emissions, representing 4.3% of global GHG emissions and 27% of global methane emissions (IPCC 2014; USEPA 2012). Enteric methane is even more important for agricultural emissions, as it represents 33% and 32% of global and U.S. agricultural GHG emissions, respectively (Figures 1a and 1b). Nearly 24% of global GHG emissions and 9% of U.S. GHG emissions come from agriculture (IPCC 2014; USEPA 2012). At the farm level, enteric methane can represent 50% of GHG emissions (Aguirre-Villegas et al. 2015), highlighting the significance of enteric methane on dairy farms to total GHG emissions (Figure 1c).

Factors Affecting Enteric Methane Estimations

The cow's rumen is an anaerobic (lacking oxygen) environment where a multitude of microorganisms degrade and ferment feed. As microbes ferment the feed, they grow and generate volatile fatty acids (acetic acid, propionic acid, and butyric acid) and methane through a series of complex metabolic pathways. The same process takes place in the cecum, which is part of the large intestine. Overall, a high-producing cow consuming and fermenting a large amount of feed can emit as much as 500 g of methane per day (Aguerre et al. 2011). Approximately 95% of enteric methane is released through the nose and mouth, and 5% is released through flatulence. As a result, factors affecting enteric methane emissions include changes in metabolic pathways, types of microorganisms and their growth rate, feed type and amount of feed the animal eats. Recent research indicates that cows with higher feed efficiency (ability to convert feed to milk) might have lower methane emissions (Belflower et al. 2012).

When assessing the impact of enteric methane emissions, the mode of expression has a large impact on the results and interpretations. There are many indicators of emission. For example, studies evaluating GHG emissions from dairy farms usually express enteric methane emissions per unit of milk produced. This makes sense, as milk is the main economically valuable product of a dairy farm. Some enteric methane emission estimates for U.S. dairy systems are 0.4-0.5 kg of carbon dioxide equivalents per kilogram of milk (Aguirre-Villegas et al. 2015; Thoma et al. 2013). Lowering enteric methane per unit of milk can be achieved by increasing milk production and keeping all other factors constant (including the actual amount of methane emitted per day). However, if emissions were expressed on a per-cow or a per-acre-of-farmland basis, an increase in milk production would have a different impact on these emission indicators. Therefore, careful examination of the accounting methods is critical when interpreting results.

Measuring and Predicting Enteric Methane Emissions

Enteric methane emissions can be measured and predicted. Measurement techniques can be conducted with the animal itself (called in vivo) or in the laboratory (in vitro). In vivo techniques measure emissions from one cow or from many cows. The most precise and accurate method to measure enteric methane emissions is the respiration chamber, where animals are housed within an airflow-controlled chamber. Emissions are determined using the amount of air flowing through the chamber and the concentration of gas in the air going in and coming out of the chamber (Aguerre, Wattiaux, and Powell 2012). One concern with this method is animal behavior. A narrow and confined environment may affect emission data, as the animal is not in its natural habitat (Haque, Cornou, and Madsen 2014). The high precision of this technique is also reflected in the high cost.

Other in vivo techniques include placing a tracer gas, such as sulfur hexafluoride (SF_6) in the rumen through a permeation capsule containing the gas. With this technique, the rate of release of the tracer gas is known and samples are taken to measure the concentration of methane and the tracer gas (Wang 2014). Other techniques use mobile measuring devices to collect methane samples as the cow feeds (also called spot sampling) (Danielsson 2016). These devices have been used successfully to determine emissions of cows in a freestall barn or in pasture.

In vitro measurement techniques are much cheaper, as they are conducted in the laboratory where the conditions of the rumen are simulated. The reduced costs allow for evaluation of more samples and treatments using in vitro techniques. In vitro measurements are commonly used to determine the effect of specific feed or to screen compounds (synthetic or organic) that may be good candidates for further research. Unfortunately, in many cases in vitro results are not generalizable to in vivo conditions, as the laboratory does not completely replicate what happens in the cow's rumen.

In addition to measuring enteric methane emissions, predicting emissions via models can be useful. Models can predict enteric methane emissions based on the biochemistry of the fermentation in the rumen (mechanistic models) or based on the nutrients in the animals' feed using statistical methods (statistical or empirical models) (Wang 2014). Mechanistic models are more accurate than empirical models, but they are also much more complex and require significant information about diets, microbial community, and animal characteristics. The advantage of empirical models is that they do not rely on biological information, which is often hard to collect, but rather predict methane emissions based on more accessible information (e.g., dry matter intake). However, these models are restricted to the specified parameters and conditions that were used to develop them, limiting their applicability to different farm practices.

Among the most important of the fermentation models are the COWPOLL model (Kebreab et al. 2004) and the MOLLY model (Baldwin 1995). These statistical models that focus on feed nutrients are developed from experimental data (Table 1). The Intergovernmental Panel on Climate Change (IPCC) has also developed widely used enteric emissions models

Table 1. Statistical models used to predict enteric methane emissions.

$$CH_4 = \frac{GE * \frac{Y_m}{100} * 365}{55.65}$$

DESCRIPTION	CH_4 = methane emissions (kg CH_4/head/yr) GE = gross energy intake (MJ/head/day) Y_m = methane conversion factor (6.5% for dairy cows) 55.65 = energy content of methane (MJ/kg CH_4)
SOURCE	*(IPCC 2006), Tier 2*

$$CH_4 = 0.341 + 0.511 * NFC + 1.74 * HC + 2.652 * CEL$$

DESCRIPTION	CH_4 = methane emissions (MJ/day) NFC = diet non-fiber carbohydrate concentration (kg/day) HC = hemicellulose (kg/day) CEL = cellulose (kg/day)
SOURCE	*(Moe and Tyrrell 1979)*

$$CH_4 = 45.98 - (45.98\, e^{-1 * [(-0.0011 * \frac{\text{starch}}{\text{ADF}}) + 0.0045 * \text{ME intake}]})$$

DESCRIPTION	CH_4 = methane emissions (MJ/day) ADF = acid detergent fiber intake (kg/day) Starch = starch intake (kg/day) ME = metabolizable energy intake (MJ/day)
SOURCE	*(Mills et al. 2003)*[a]

$$CH_4 = 1.28 * dcp - 0.31 * dcf + 1.31 * dst + 1.16 * dsu + 2.40 * NFR$$

DESCRIPTION	CH_4 = methane emissions (kJ) dcp = digestible crude protein (g) dcf = digestible crude fat (g) dst = digestible starch (g) dsu = digestible sugar (g) NFR = digestible N free residuals (g)
SOURCE	*(Jentsch et al. 2007)*

$$CH_4 = 2.72 + 0.0937 * MEI + 4.31 * CEL - 6.49 * HC - 7.44 * Fat$$

DESCRIPTION	CH_4 = methane emissions (MJ/day) MEI = metabolizable energy intake (MJ/day) CEL = cellulose (kg/day) HC = hemicellulose (kg/day)
SOURCE	*(Ellis et al. 2009)*[a]

$$CH_4 = 62(\pm 5.5) + 25.0(\pm 0.54) * DMI$$

DESCRIPTION	CH_4 = methane emissions (l/day) DMI = dry matter intake (kg/day)
SOURCE	*(Ramin and Huhtanen 2013)*

[a] Additional equations for the prediction of enteric methane emissions are available in the cited work

with three levels of complexity based on the data available for computation. The first level (Tier 1) is the simplest and gives an average emission factor by region of the world. For example, the yearly default emission factor for a dairy cow in North America is 128 kg of methane (350 grams per day). The second level (Tier 2) relates enteric methane to gross energy intake, and the third level (Tier 3) is the most complex, incorporating several more variables. These statistical models are generally used by researchers to advise GHG emission mitigation strategies. The use of one over the other will depend on the available data.

Aside from these models, there are larger tools and studies that incorporate these equations to estimate farm-level GHG emissions. Some of these tools include the Integrated Farm System Model (IFSM) (Rotz et al. 2015) and the Cornell Net Carbohydrate Protein System (CNCPS) (Van Amburgh et al. 2015). These models are useful in evaluating the impacts of a management change throughout the dairy system. Larger studies use life cycle assessment (LCA) methodologies, which explore the use of all input resources to include all potential impacts during milk production (Thoma et al. 2013; Rotz, Montes, and Chianese 2010; Belflower et al. 2012; Liang and Cabrera 2015).

Summary

Enteric methane emissions are a byproduct of the digestion process of ruminant animals, including dairy cattle. During a dairy cow's digestion process, approximately 95% of methane that is formed is expelled through the nose and mouth. Enteric methane is the most significant source of GHG emissions at the dairy farm level, as it can contribute 50% of the farm's total GHG emissions. Methane loss also represents an inefficient process, as it reduces the conversion of feed to useful products like milk and meat.

Enteric methane emissions can be measured and predicted with models. Measurement techniques can be conducted within the animal itself (in vivo) or in the laboratory (in vitro). In vivo techniques are more precise in measuring enteric methane emissions but are also more expensive. In vitro measurements are much cheaper, as they are conducted in the laboratory, but they are also less precise. Enteric methane emissions can be predicted using mechanistic and empirical models. Mechanistic models can predict enteric methane emissions based on the biochemistry of the fermentation in the rumen but are complex and require significant information about the microbial community. Empirical models use statistical methods to predict emissions based on the nutrients in the feed, which is more accessible information than the data used by mechanistic models. The use of one over the other will depend on the available data. Careful examination of the accounting methods is critical when examining enteric methane emissions, as the methods have a large impact on the results.

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