J. Dairy Sci. 101:1–20
https://doi.org/10.3168/jds.2017-13536

Symposium review: Uncertainties in enteric methane inventories, measurement techniques, and prediction models[1]

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ABSTRACT

Ruminant production systems are important contributors to anthropogenic methane (CH_4) emissions, but there are large uncertainties in national and global livestock CH_4 inventories. Sources of uncertainty in enteric CH_4 emissions include animal inventories, feed dry matter intake (DMI), ingredient and chemical composition of the diets, and CH_4 emission factors. There is also significant uncertainty associated with enteric CH_4 measurements. The most widely used techniques are respiration chambers, the sulfur hexafluoride (SF_6) tracer technique, and the automated head-chamber system (GreenFeed; C-Lock Inc., Rapid City, SD). All 3 methods have been successfully used in a large number of experiments with dairy or beef cattle in various environmental conditions, although studies that compare techniques have reported inconsistent results. Although different types of models have been developed to predict enteric CH_4 emissions, relatively simple empirical (statistical) models have been commonly used for inventory purposes because of their broad applicability and ease of use compared with more detailed empirical and process-based mechanistic models. However, extant empirical models used to predict enteric CH_4 emissions suffer from narrow spatial focus, limited observations, and limitations of the statistical technique used. Therefore, prediction models must be developed from robust data sets that can only be generated through collaboration of scientists across the world. To achieve high prediction accuracy, these data sets should encompass a wide range of diets and production systems within regions and globally. Overall, enteric CH_4 prediction models are based on various animal or feed character-

Received July 20, 2017.
Accepted March 25, 2018.
[1]Presented as part of the Production, Management, and the Environment Symposium: Greenhouse Gas Emissions from Dairy Operations at the ADSA Annual Meeting in Pittsburgh, Pennsylvania, in June 2017.
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istic inputs but are dominated by DMI in one form or another. As a result, accurate prediction of DMI is essential for accurate prediction of livestock CH_4 emissions. Analysis of a large data set of individual dairy cattle data showed that simplified enteric CH_4 prediction models based on DMI alone or DMI and limited feed- or animal-related inputs can predict average CH_4 emission with a similar accuracy to more complex empirical models. These simplified models can be reliably used for emission inventory purposes.

Key words: enteric methane, uncertainty, prediction model, livestock

INTRODUCTION

The livestock sector is a significant source of anthropogenic greenhouse gas (**GHG**) emissions. In the United States, emissions from livestock production contributed an estimated 48% of the 2015 agricultural GHG emissions (US EPA, 2017). In Europe (EU-28), 59% of estimated agricultural GHG emissions were from livestock in 2015 (http://ec.europa.eu/eurostat/web/agriculture/data/database; accessed December 5, 2017). Methane (CH_4) and nitrous oxide are the 2 most important GHG from agricultural activities. Methane, a potent short-lived (12.2-yr lifetime; Myhre et al., 2013) GHG, is emitted from livestock operations through enteric fermentation in the animal's gastrointestinal tract (reticulo-rumen and hindgut) and similar methanogenic processes in manure. Globally, enteric CH_4 emissions make up about one-fifth of the 10 to 12 Gt CO_2-equivalent/yr GHG emissions from the Agriculture, Forestry, and Other Land Use sector (IPCC, 2014). There are, however, large uncertainties associated with estimating GHG emissions from livestock (or any other source), which has led to discrepancies between top-down (i.e., based on atmospheric measurements) and bottom-up (based on national or regional activity data and emission factors for different CH_4 sources) and among bottom-up CH_4 emission inventories (Miller et al., 2013; Hristov et al., 2014, 2017; Wecht et al., 2014; Maasakkers et al., 2016). These uncertainties may be related to uncertainties in changes in CH_4 sinks (Rigby et al., 2017), or to uncertainties in changes in CH_4 sources. As an example, a recent bottom-up inventory analysis, based mostly on national inventory reports, suggested that global livestock CH_4 emissions are 11% greater than estimates based on Intergovernmental Panel on Climate Change (**IPCC**) emission factors (Wolf et al., 2017). As an 11% difference is well within the uncertainty bounds for livestock CH_4 inventories (Hristov et al., 2017; US EPA, 2017), conclusions from such analyses have to be interpreted with caution. Therefore, the objective of this paper was to review uncertainties and discrepancies in CH_4 inventories as related to livestock emissions, enteric CH_4 measurement methods, and DMI and CH_4 prediction models. The review and data presented here are an integral part of the GLOBAL NETWORK project and the Feed and Nutrition Network (http://animalscience.psu.edu/fnn/current-research/global-network-for-enteric-methane-mitigation; accessed December 4, 2017) within the Livestock Research Group of the Global Research Alliance for Agricultural Greenhouse Gases (www.globalresearchalliance.org; accessed December 4, 2017).

UNCERTAINTIES IN ATMOSPHERIC METHANE CONCENTRATIONS AND ATTRIBUTION TO LIVESTOCK SOURCES

Globally, atmospheric mixing ratio of CH_4 (the number of moles of CH_4 per mole of air) was relatively stable between 1999 and 2006 but have increased continuously since 2006 at a rate of 4 to 12 nmol/mol per year (https://www.esrl.noaa.gov/gmd/ccgg/trends_ch4/#global_growth; accessed June 16, 2017). There is no consensus about the major drivers for this increase and, in addition, there is considerable disagreement regarding the contribution of livestock to global CH_4 emissions. Reports based on isotopic composition of CH_4 in the atmosphere, ice cores, and archived air, or combined data from bottom-up and top-down methodologies suggested that post-2006 increases in CH_4 emissions are predominantly caused by increases in microbial CH_4 (Nisbet et al., 2016; Saunois et al., 2016; Schaefer et al., 2016). Microbial, or biogenic, CH_4 is generated by methanogenic archaea and can be from wetlands and agricultural activities, mainly livestock production and rice cultivation (Stolper et al., 2015). The atmospheric mixing ratio of CH_4 is a function of emissions and sinks. The major sink for atmospheric CH_4 is oxidation by hydroxyl radicals (OH), occurring mostly in the troposphere, which accounts for approximately 90% of the global CH_4 sink (Kirschke et al., 2013). Because of the short lifetime of OH, direct observations of atmospheric OH mixing ratio are difficult to accomplish (Rigby et al., 2017). Therefore, the increase in atmospheric CH_4 cannot be reliably attributed to an overall increase in emissions. The analysis by Rigby et al. (2017) pointed to "significant OH-related uncertainties" in the atmospheric CH_4 budget and concluded that it is impossible to implicate global CH_4 emission changes as the primary driver for recent trends in atmospheric CH_4 mixing ratio.

If there was an increase in atmospheric CH_4 mixing ratio and the increase was caused by agricultural sources, specifically livestock emissions, the trends in atmospheric CH_4 should correspond to dynamics in global