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Modeling greenhouse gas emissions from dairy farms[1]

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ABSTRACT

Dairy farms have been identified as an important source of greenhouse gas emissions. Within the farm, important emissions include enteric CH_4 from the animals, CH_4 and N_2O from manure in housing facilities during long-term storage and during field application, and N_2O from nitrification and denitrification processes in the soil used to produce feed crops and pasture. Models using a wide range in level of detail have been developed to represent or predict these emissions. They include constant emission factors, variable process-related emission factors, empirical or statistical models, mechanistic process simulations, and life cycle assessment. To fully represent farm emissions, models representing the various emission sources must be integrated to capture the combined effects and interactions of all important components. Farm models have been developed using relationships across the full scale of detail, from constant emission factors to detailed mechanistic simulations. Simpler models, based upon emission factors and empirical relationships, tend to provide better tools for decision support, whereas more complex farm simulations provide better tools for research and education. To look beyond the farm boundaries, life cycle assessment provides an environmental accounting tool for quantifying and evaluating emissions over the full cycle, from producing the resources used on the farm through processing, distribution, consumption, and waste handling of the milk and dairy products produced. Models are useful for improving our understanding of farm processes and their interacting effects on greenhouse gas emissions. Through better understanding, they assist in the development and evaluation of mitigation strategies for reducing emissions and improving overall sustainability of dairy farms.

Key words: greenhouse gas, model, dairy, methane, carbon footprint

INTRODUCTION

Greenhouse gas (**GHG**) emissions have gained international attention due to their effect on global climate. There are many sources of GHG emissions, with agriculture estimated to contribute about 11% of all global emissions (Smith et al., 2014) and 8.4% of US emissions (EPA, 2017). Livestock have received extra attention for their contribution to GHG emissions along with other environmental impacts (Steinfeld et al., 2006). Globally, cattle are estimated to produce 5,335 Mt of CO_2 equivalents (**CO_2e**) per year, which is about 11% of all human-induced GHG emissions (Smith et al., 2014). Within the United States, cattle are estimated to produce 212 Mt of CO_2e per year, or 3.4% of total GHG emissions, with dairy cattle responsible for 83.5 Mt of CO_2e, or 1.3% of the US total (EPA, 2017).

Dairy farms are a major contributor to the total GHG emissions over the life cycle of milk and other dairy products. In an evaluation of GHG emissions from the national supply chain of fluid milk, Thoma et al. (2013) found that 72% of the emissions occurred in processes prior to the milk leaving the farm. Thus, it is important to know farm emission sources and to understand the processes creating those emissions. Knowing more about these emission sources and the processes involved leads to opportunities for mitigation.

Important sources of GHG emissions from dairy farms include CH_4 and N_2O from enteric fermentation, manure storage and handling, and crop and pasture land (Figure 1). Anthropogenic CO_2 emissions from fossil fuel combustion and the decomposition of lime applied to crop and pasture land also contribute. Nitrous oxide emissions include both direct emissions from the farm and indirect emissions from ammonia and nitrates leaving the farm that may ultimately transform into N_2O in other ecosystems. Although these are often treated as independent sources, interactions do occur, which affect the overall emission.

Much effort has been given to measuring GHG emissions from each important source on dairy farms, but monitoring and simultaneously quantifying all emis-

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sions from a given farm or production system is essentially impossible and prohibitively expensive. Thus, some type of model is required to quantify and evaluate GHG emissions from dairy production systems. Models can range from relatively simple emission factors to very detailed process-level simulations. All model forms have appropriate applications; an emission factor provides a quick assessment, but to fully understand the emission processes and their interactions a detailed process model is needed. The objective of the current study was to review the more important models used to evaluate GHG emissions from dairy farms across this full continuum of modeling approaches.

MODELING GHG SOURCES

Across the continuum of model complexity, models can be categorized as (1) emission factors, (2) process-driven emission factors, (3) empirical or statistical relationships, and (4) mechanistic process simulation. The simplest emission factors consist of 1 value to represent the production system. For example, the GHG emission for US dairy farms could be defined as 8,000 kg of CO_2e/cow. Although crude, this would provide a very general number that may be appropriate for certain applications. More often, factors are used to quantify the important individual processes of a dairy farm. When they represent the underlying process, they can be classified as process-driven emission factors. The IPCC (2006a) has defined these as tier 2 factors; an example is when enteric CH_4 is represented as a function of gross energy intake of the animal. A similar, but usually more detailed model, is an empirical relationship where a process is described as a function of multiple factors. This may be a purely statistical model based upon measured data without much understanding of the underlying process or a relationship developed to represent the process using linear or nonlinear functions. The most detailed model is a more mechanistic process simulation that uses multiple relationships to represent the dynamics within the process. Examples of the various types of models will be discussed for each of the important sources of GHG emission on a dairy farm.

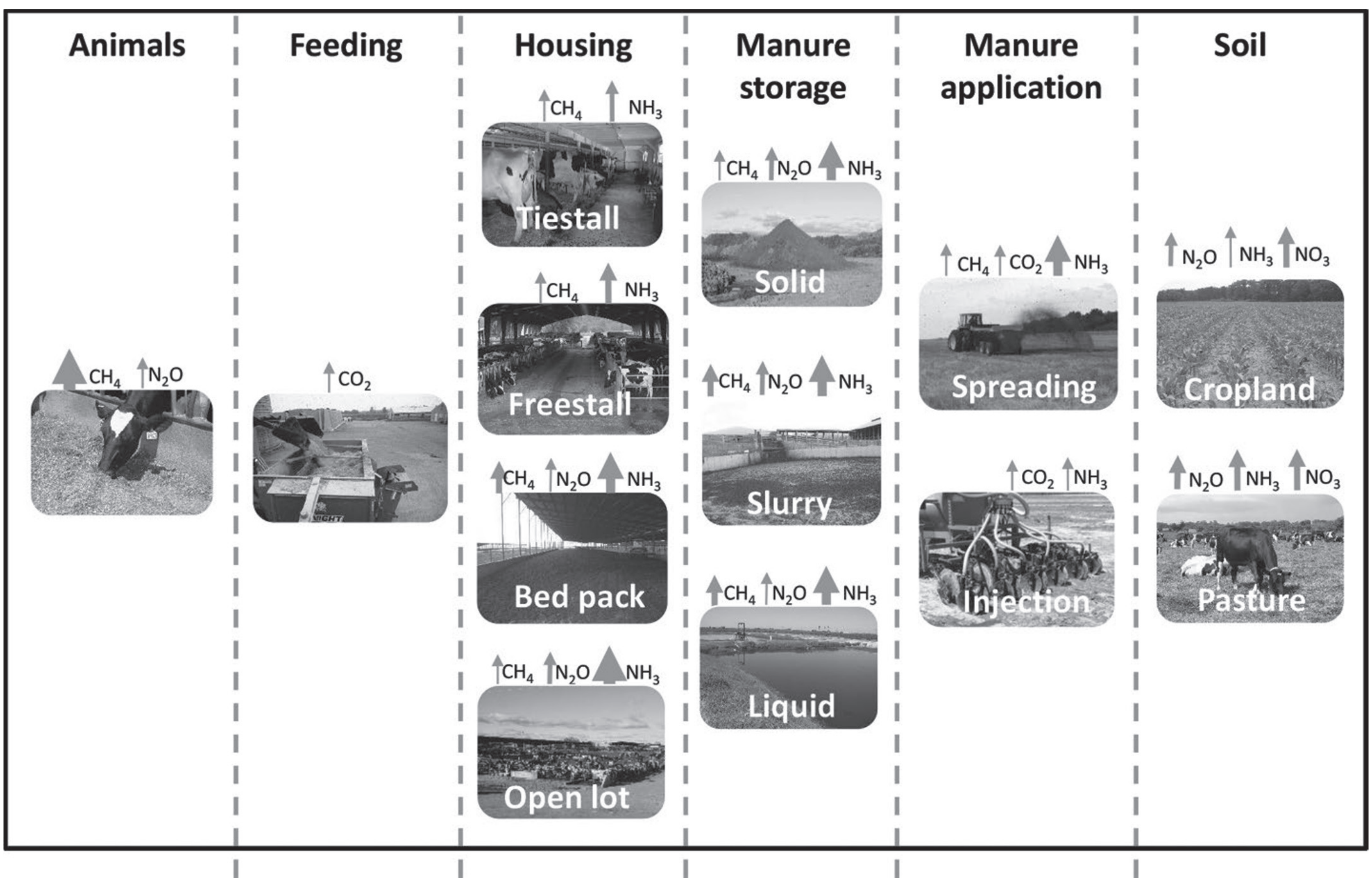

Figure 1. Important direct and indirect greenhouse gas sources and relative amounts (differently sized arrows) emitted from dairy farms. Color version available online.