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Feeding strategies and manure management for cost-effective mitigation of greenhouse gas emissions from dairy farms in Wisconsin

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ABSTRACT

Greenhouse gas (GHG) emissions from dairy farms are a major concern. Our objectives were to assess the effect of mitigation strategies on GHG emissions and net return to management on 3 distinct farm production systems of Wisconsin. A survey was conducted on 27 conventional farms, 30 grazing farms, and 69 organic farms. The data collected were used to characterize 3 feeding systems scaled to the average farm (85 cows and 127 ha). The Integrated Farm System Model was used to simulate the economic and environmental impacts of altering feeding and manure management in those 3 farms. Results showed that incorporation of grazing practices for lactating cows in the conventional farm led to a 27.6% decrease in total GHG emissions [−0.16 kg of CO_2 equivalents (CO_2eq)/kg of energy corrected milk (ECM)] and a 29.3% increase in net return to management (+$7,005/yr) when milk production was assumed constant. For the grazing and organic farms, decreasing the forage-to-concentrate ratio in the diet decreased GHG emissions when milk production was increased by 5 or 10%. The 5% increase in milk production was not sufficient to maintain the net return; however, the 10% increase in milk production increased net return in the organic farm but not on the grazing farm. A 13.7% decrease in GHG emissions (−0.08 kg of CO_2eq/kg of ECM) was observed on the conventional farm when incorporating manure the day of application and adding a 12-mo covered storage unit. However, those same changes led to a 6.1% (+0.04 kg of CO_2eq/kg of ECM) and a 6.9% (+0.06 kg of CO_2eq/kg of ECM) increase in GHG emissions in the grazing and the organic farms, respectively. For the 3 farms, manure management changes led to a decrease in net return to management. Simulation results suggested that the same feeding and manure management mitigation strategies led to different outcomes depending on the farm system, and furthermore, effective mitigation strategies were used to reduce GHG emissions while maintaining profitability within each farm.

Key words: Integrated Farm System Model, environmental stewardship, feeding system, environmental and economic sustainability

INTRODUCTION

Greenhouse gas (**GHG**) emissions need to be reduced to limit undesirable outcomes of climate change (IPCC, 1994), such as the rise in sea level, extensive species losses, and economic losses due to extreme weather. Livestock operations are one of the largest sources of agricultural GHG emissions (EPA, 2009), and milk production is considered to be responsible for 4% of global anthropogenic emissions of GHG (FAO, 2010). An important challenge for a state such as Wisconsin, which ranks second in the United States with 14% of national milk production (USDA/NASS, 2013), is to reduce emissions of GHG while remaining economically competitive.

The 3 main GHG are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), and their emissions are usually expressed on a CO_2-equivalent (**CO_2eq**) basis to represent their global-warming potential in the atmosphere. Methane and N_2O have global-warming potentials 25 and 298 times of that of CO_2, respectively (IPCC, 2007). Sources of CO_2 on the dairy farm include plant respiration, animal respiration, and microbial respiration in the soil and manure. Carbon dioxide can also be assimilated on the farm via carbon fixation (Rotz et al., 2011a). Methane sources include enteric fermentation, manure storage, field application of manure, and feces deposited on pasture or on the barn floor (Rotz et al., 2011a). Sources of N_2O on the farm include soil and manure through the processes of nitrification and denitrification (Rotz et al., 2011a). In total, enteric fermentation, feed production, and manure management typically account for 35, 32, and 26% of GHG at the farm scale, respectively. The rest of the emissions come from fuel and electricity consumption (Thoma et al., 2013).

Many reviews have looked at strategies to reduce GHG emissions from dairy farms (Cottle et al., 2011;

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Rafiu et al., 2012). However, these reviews did not include the economics of the mitigation strategies, did not differentiate type of dairy-farm system, and limited the boundaries of the system at either the cow, housing, manure storage, or field level. Moreover, none of aforementioned studies included the 3 GHG. Yet, the decrease in GHG emissions in one area of the farm may not necessarily lead to a reduction in GHG emissions for the whole farm or the CO_2eq per kilogram of milk produced on the farm. Furthermore, the effects of a mitigation strategy may depend upon the farm system. Hence, it is critical to study the farm as a whole when evaluating mitigation strategies.

Simulation is a powerful tool to integrate, in a single study, the effect of management practices on both GHG emissions and economic outcomes within a whole farm system framework. In this study, 2 areas of management were targeted for mitigation strategies. First, feeding management was selected because of its effect on enteric CH_4 emission (Aguerre et al., 2011), and it is often the single-most important cost in milk production on dairy farms (Eckard et al., 2010). Furthermore, changes in this area can easily be made with readily observable effects. The second area targeted was manure management because manure is a major source of GHG emissions on dairy farms (Sommer et al., 2000; Chadwick et al., 2011; Thoma et al., 2013). The Integrated Farm System Model (**IFSM**) has been used to define and study management strategies in different farm systems (Rotz et al., 2007; Belflower et al., 2012; Stackhouse-Lawson et al., 2012), and it is a useful tool to assess simultaneously the combined effect of feeding and manure management strategies on GHG emissions and profitability. The objectives of this work were (1) to compare Wisconsin organic, grazing, and conventional farms in terms of simulated GHG emissions and economics using survey data and the IFSM, and (2) to assess the potential effect of different feeding and manure management strategies on simulated GHG emissions and net return to management of those 3 farm systems.

MATERIALS AND METHODS

IFSM

The IFSM is a simulation model that integrates the major biological and physical processes of a dairy farm and assesses economic performances given a set of management practices (Rotz et al., 2011a). Crop production, feed and manure management, and environmental impact were simulated on a daily time step over 25 yr of daily weather conditions including minimum and maximum temperature, precipitation, and solar radiation as recorded in Madison, Wisconsin. To avoid the possible confounding effect of soil type, medium clay loam was used as a default for all simulations conducted in this study.

Simulation of GHG Emissions. Total GHG emissions are assessed at the whole-farm level including sources and sinks of CO_2, CH_4, and N_2O. Main sources and sinks of CO_2 include plant and soil respiration, plant fixation, animal respiration, manure storage, barn-floor manure, and fuel combustion (Rotz et al., 2011a). Carbon dioxide emitted by plant and soil respiration is assessed using functions from DAYCENT (2007), which are incorporated in the IFSM. Carbon dioxide emitted by animal respiration is a function of total DMI (Kirchgessner et al., 1991). Emissions of CO_2 from the barn floor are calculated based on ambient temperature and manure-covered area using the following equation: $E_{CO2} = \max(0.0,\ 0.0065 + 0.0192t) \times A_{barn}$, where E_{CO2} = daily rate of CO_2 emission from barn floor, kg of CO_2/d; t = ambient temperature in the barn, °C; and A_{barn} = floor area covered by manure, m^2.

A coefficient of 2.637 kg of CO_2/L is used to calculate emission from fuel combustion. For uncovered and covered manure storages, average emission rates of 0.04 kg of CO_2/m^3 per day and 0.008 kg of CO_2/m^3 per day are used, respectively. Main sources of CH_4 emission include enteric fermentation, barn floor, manure storage, field application, and feces deposited on pasture. An equation developed by Mills et al. (2003) is used to assess CH_4 emission from enteric fermentation based on dietary composition, management practices, and animal type and size. The model from Sommer et al. (2004) based on volatile solids (organic compounds of animal or plant origin), temperature, and storage time is used to calculate emission from manure storage. Methane emission from the barn floor is a function of ambient temperature. For bedded-pack barns, an adaptation of the tier-2 approach of IPCC (2006) is used to account for higher emission rates compared with a daily-cleaned barn floor. Methane emission from the field is accounted for up to 11 d after manure application and is a function of the concentration of volatile fatty acids in the soil. A factor of 0.086 g of CH_4/kg of feces is used to evaluate CH_4 emission from manure deposited on pasture. Main sources of N_2O include barn floor and manure storage. The emission of N_2O occurring during the nitrification-denitrification process is modeled using functions from DAYCENT (2007), which are incorporated in the IFSM model. Nitrous oxide emitted from barn floors is calculated based on the tier-2 approach of the IPCC (2006) for bedded pack and dry lot. Emission of N_2O is set to zero for facilities where manure is removed on a daily basis. For an uncovered slurry-storage tank where