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Optimizing productivity, herd structure, environmental performance, and profitability of dairy cattle herds

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ABSTRACT

This study used the Integrated Farm System Model to simulate the whole farm performance of a representative Wisconsin dairy farm and predict its economic and environmental outputs based on 25 yr of daily local weather data (1986 to 2010). The studied farm, located in southern Wisconsin, had 100 milking cows and 100 ha of cropland with no replacement heifers kept on the farm. Sensitivity analyses were conducted to test the effect of management strategies on energy-corrected milk production (ECM; 4.0% fat and 3.5% protein), net return to management, and greenhouse gas (GHG; including biogenic CO_2) emission. The management strategies included (1) target milk production, for which the model optimized available resources to attain, and (2) herd structure, represented by the percentage of first-lactation cows. Weather conditions affected the outputs by changing the farm quantity and the quality of produced feed resources. As expected, when target milk production increased, the ECM increased positively and linearly to a certain level, and then it increased nonlinearly at a decreasing rate, constrained by available feed nutrients. Thereafter, the ECM reached the maximum potential milk production and remained flat regardless of higher target milk production input. Greenhouse gas emissions decreased between 3.4 and 7.3% at different first-lactation cow percentages. As the first-lactation cow percent increased from 15 to 45% in 5% intervals, GHG increased between 9.4 and 11.3% at different levels of target milk production. A high percentage of first-lactation cows reduced the maximum potential milk production. Net return to management had a similar changing trend as ECM. As the target milk production increased from 9,979 to 11,793 kg, the net return to management increased between 31 and 46% at different first-lactation cow percentages. Results revealed a win-win situation when increasing milk production or improving herd structure, which concurrently increased farm net return to management and decreased GHG emissions.
Key words: greenhouse gas emission, farm profitability, simulation model

INTRODUCTION

Agricultural greenhouse gases (**GHG**) constitute 8.1% of total United States GHG emissions (EPA, 2014). Livestock enteric fermentation and manure methane emission account for 34.4% of total anthropogenic CH_4 emission (EPA, 2014), and the dairy industry contributes 4% to global GHG emissions (FAO, 2010). Dairy farm GHG includes CO_2, CH_4, and N_2O from enteric fermentation, manure handling, crop production, and other processes (Rotz et al., 2010). Given these rates, dairy cattle farming faces a major challenge: to reduce GHG emissions while maintaining or increasing profitability. Crosson et al. (2011) reported that animal performance, including production and replacement decisions, influence the GHG from dairy farms. Increasing milk production through genetic and feeding improvement can decrease the per-kilogram of milk GHG (Rotz et al., 2010). Dutreuil et al. (2014) studied the economic effects of GHG-mitigation strategies, such as changing the grazing schedule, the forage ratio in diet, and manure-handling methods, and found that grazing cows in conventionally managed dairy farms would decrease GHG and increase net profit while keeping milk production constant. Likewise, Dutreuil et al. (2014) reported that increasing concentrate supplementation in grazing farms would decrease GHG emissions and increase milk production, which might increase the net profit depending on the increased amount. Additionally, adding an extra covered manure-storage facility decreased GHG emissions in conventional dairy farms because some GHG from manure was prevented from escaping to the atmosphere (Dutreuil et al., 2014). Garnsworthy et al. (2012) found that improving reproductive performance and replacement would reduce GHG emissions at the herd level by reducing the num-

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ber of replacement animals, calving interval length, and increasing the average milk production.

Due to the complex interaction of farm dynamic processes, whole farm systems need to be included in joint GHG emissions and economic studies (del Prado et al., 2010). The Integrated Farm System Model (**IFSM**; Rotz et al., 2013), which assesses the combined effect of the main dairy farm factors, is uniquely positioned to conduct this kind of study (Belflower et al., 2012; Stackhouse-Lawson et al., 2012; Dutreuil et al., 2014). The present study uses the IFSM to estimate the concurrent environmental and economic effects of 2 farm management strategies: (1) target milk production, the production goal for which the model optimizes feed allocation, and (2) the proportion of cows in first lactation, a proxy of reproduction and replacement management.

MATERIALS AND METHODS

The IFSM

The IFSM was used in our study to assess the economic and environmental output of a representative Wisconsin dairy farm. Farm performance was simulated using 25 yr of daily weather data for Madison, Wisconsin (1986–2010; Dane County Regional-Truax Field, WI; 43.13°N, 89.33°W, elevation = 259 m). The IFSM was applied to integrate crop growth, feed storage, machinery usage, and herd management to simulate farm performance with the available on-farm resources and purchased feed (Rotz et al., 2013). Daily weather data were used to estimate the annual farm-produced feed resources by simulating crop growth, tillage, and harvest. In addition, weather data were used in the manure-handling modules to estimate the manure ammonia emission as a function of temperature and wind speed. Weather data did not affect herd performance (Rotz et al., 2013). The IFSM simulates each year separately and does not consider carryover effects from one year to the next (i.e., it simulates 1 yr under historical yearly weather variability; Rotz et al., 2013).

The herd-management module inside the IFSM optimizes feed allocation by maximizing the milk production and minimizing purchased feed cost. The herd module prioritizes on-farm feed use, supplementing with purchase feed as needed.

Farm Characteristics

The representative dairy farm had 100 large milking Holstein cows (including dry cows) and 100 ha of rented cropland (43 ha of alfalfa and 57 ha of corn). The cow's average mature weight was 759 kg. The farm's topography was gently sloping. The farm soil type was medium clay loam with a soil phosphorus level of 30 to 50 mg/kg.

Alfalfa was planted and planned to have a 3-yr stand life. A yield adjustment of 90% was set to mimic the field conditions in Wisconsin. The yield adjustment factor is used to give some relative control over the simulation process to adjust the model prediction; the shorter the growth period is, the lower the adjustment factor (Rotz et al., 2013). The farm applied 20% of the total available cattle manure to the alfalfa land. A population of 11,300 plants/ha was used on the corn crop. The relative maturity index was 110 d. The grain yield adjustment was 85% and the silage yield adjustment was 100% (no adjustment). The remaining 80% of the available manure was applied to the cornfields, along with 20 kg/ha of nitrate fertilizer.

The on-farm machinery included one 47-hp (35 kW) tractor, one 87-hp (65 kW) tractor, and one 108-hp (80 kW) tractor. The 47-hp tractor was used for mowing, raking, drill seeding, and miscellaneous transporting. The 87-hp tractor was used for baling, feed mixing, silo filling, field cultivation, row crop planting, round bale loading, and pumping manure. The 108-hp tractor was used for forage chopping, manure handling, plowing, and disking. Grain harvest was custom hired. All the following tillage and planting operations were conducted only on suitable days with an upper layer soil moisture content allowing machine tractability. Alfalfa seeding started as early as April 25 and corn was planted on or after May 5. The following earliest operation dates were input, but the actual dates varied depending on weather, soil, or crop moisture conditions. Alfalfa had 4 cuttings per year: the earliest harvesting times fell around May 28, July 1, August 17, and October 15, as weather permitted. Corn was harvested for silage after September 1, for high-moisture grain after October 1, and for dried grain after October 21. The high-quality forage was stored in a 281-t of DM bunker silo, grain crop silage was stored in a similarly sized bunker, and the high-moisture grain was stored in a stave silo with 259 t of DM capacity.

The farm used a flat barn parlor and straw-bedded freestalls with natural ventilation. Cows were bred and calved year round. A loader and a mixer wagon were used to feed grain and silage. The cows were fed a low-forage diet, which maintained the minimum amount of dietary fiber (relative forage-to-grain ratio in the diet of 0.57, 0.68, and 0.80 for early, middle, and late lactation cows, respectively). Hay was provided in a self-fed hay feeder. The manure was collected and hauled using a scraper and slurry pump and then applied to the field within 2 d. Milk price was set at \$0.40 per kg, slaughter price at \$1.21 per kg, replacement heifer at \$1,500 per