

Implementation of greenhouse gas mitigation strategies on organic, grazing and conventional dairy farms

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Abstract: Greenhouse gas (GHG) emissions from dairy farms are a major concern. The objectives of this study were twofold: Compare organic, grazing and conventional farms in terms of GHG emissions and economics and assess the impact of mitigation strategies. A survey was conducted on 27 conventional farms, 30 grazing farms and 69 organic farms in Wisconsin. The data collected were used to characterize the 3 different systems scaled to the average dairy farm size (85 cows on 127 ha). The Integrated Farm System Model (IFSM) was used to simulate feeding and manure management mitigations strategies to reduce GHG emissions. Results showed that incorporation of grazing practices for lactating cows on the conventional farm led to a decrease of GHG emissions (-0.16 kg CO₂eq/kg of milk (27.6%)) and at the same time an increase in net return to management (+\$7,005/year (29.3%)) when milk production was maintained. On the grazing and the organic farms, decreasing the forage to grain ratio in the diet decreased GHG emissions when milk was increased by 5% or 10%. However, the 5% increase in milk production was not sufficient to maintain the net return on these farms. When milk was increased by 10%, net return increased on the organic farm but not on the grazing farm. Changes in manure management including the incorporation of manure into the soil the same day of application and using a 12-month covered storage pit led to a decrease in GHG emissions (-0.08 kg CO₂eq/kg of milk (13.7%)) on the conventional farm whereas GHG emissions increased slightly on the grazing (+0.04 kg CO₂ eq/kg milk (6.1%)) and on the organic farm (+0.06 kg CO₂ eq/kg milk (6.9%)). For the 3 farm systems, manure management changes led to a decrease in net return to management. Results showed that the same mitigation strategies led to different outcomes according to farm system. Simulations also demonstrate that there are some feeding and manure management mitigation strategies that are effective for reducing GHG emissions while maintaining or even improving profitability for each dairy farm system studied.

Keywords: Integrated Farm System Model, environmental stewardship, dairy production system, environmental and economic sustainability

Introduction

Greenhouse gas emissions need to be reduced in order to limit undesirable outcomes of climate change (IPCC, 1994). 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 total anthropogenic GHG emissions (FAO, 2010). Many reviews have looked at strategies to reduce GHG emissions on dairy farms (e.g., Cottle et al, 2011). 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 at the field level. Moreover, in none of these studies, the 3 main GHG (carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O)) were studied together. 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 and the effect may be different depending on the farm system. Hence, it is critical to study the farm as a whole when evaluating mitigation strategies.

Simulation is a powerful tool to study the impact of different mitigation strategies on the emission of the 3 main GHG while looking at the economic aspects within a whole farm system framework. Two areas of management are considered important for mitigation strategies. The first is feeding management because changes in it can easily be made, results are rapidly seen and feeding is a major cost on dairy farms (Eckard et al, 2010). The second area is manure management because manure is one of the major sources of GHG emissions on dairy farms (Thoma et al, 2013). The IFSM has been used to define and study management strategies in different farm systems (Stackhouse-Lawson et al, 2012; Belflower et al, 2012; Rotz et al, 2007), and it is an ideal tool to assess the combined effect of feeding and manure management strategies on GHG emissions and profitability. The objectives of this study were twofold: 1) compare Wisconsin organic, grazing and conventional farms in terms of GHG emissions and economics, and 2) assess the impact of different feeding and manure management strategies on GHG emissions and net return to management of those 3 farm systems.

Materials and methods

Integrated Farm System Model

The IFSM simulation model used in this study integrates the major biological and physical processes of a dairy farm (Rotz et al., 2011). Crop production, feed and manure management, economic performances and GHG emissions are simulated daily for a full year and can be repeated for up to 25 years in one simulation run.

Total GHG emissions within the IFSM are assessed at the whole farm level including sources and sinks of the 3 main GHG, which are CO₂, CH₄ and N₂O. Main sources and sinks of CO₂ include plant and soil respiration, plant fixation, animal respiration, manure storage, barn floor and fuel combustion (Rotz et al, 2011). Whole farm GHG emissions are divided into 7 categories. Housing facilities include emissions from the barn floor, animal respiration, and enteric fermentation when animals are housed inside. Manure storage includes emissions from the manure storage. Feed production includes emission from field applied manure and cropland. Grazing includes emission from enteric fermentation of cows grazing as well as animal respiration for the time cows spend grazing. Fuel combustion includes emissions from the consumption of fuel for feeding, handling of manure and growing and harvesting of crops. Secondary sources include emissions during manufacture of fuel, electricity, machinery, fertilizers, pesticides, plastic used in production of feed, and maintenance of animals. Soil organic carbon change from year to year is not included. Emissions of GHG are accounted at the farm gate and for all processes involved in milk production. These include, for example, meat production but not crops sold out of the farm.

The economic analysis in the IFSM is a whole farm budget where the total cost of production is compared to revenues to predict annual net return (Rotz et al, 2011). Annual fixed costs include costs for equipment, facilities and land. Annual variable costs include costs of labor (feeding, milking, animal handling and field work), resources and products. Total revenue includes revenue from milk sales, animal sales and feed sales. The economic analysis does not include tax implications or other governmental subsidies.

Surveying

An interdisciplinary and comprehensive survey instrument was developed to collect information on Wisconsin dairy farm systems. Data were collected on farm structure, labor, herd management, feeding, cropping and economics for the year 2010. Farms were selected from Wisconsin's official lists of certified milk producers and organic milk producers as well as a list of graziers compiled from extension agents from the University of Wisconsin. Dairy farms were classified across 3 different feeding systems: conventional, grazing and organic. Organic farms were those that were certified organic. Grazing farms were those using grazing as a major source of feed during the grazing season (i.e., $\geq 30\%$ of the DMI of the lactating cows was grazing) and were not certified organic. Conventional farms were defined as non-organic, non-grazing comparable farm systems.

Simulated farms and management scenarios

Data collected from the survey on 27 conventional farms, 30 grazing farms and 69 organic farms were used to characterize the 3 farm systems. In order to make a fair comparison and eliminate variation in simulation results due to difference in farm size, data from the surveys were scaled to the average Wisconsin surveyed farm in terms of land area (127 ha out of which 79 ha were owned and 48 ha were rented) and number of adult cows (85). Data presented in Table 1 used in the baseline simulations came directly from surveys. Same soil type (medium clay loam) and daily weather including minimum and maximum temperature, precipitation, and solar radiation for 25 years (1986-2010; Madison, WI) –available from official government sources– were used for the 3 simulated production systems. The 3 systems also used the same cost of diesel fuel (\$0.68/L), electricity (\$0.11/kWh), labor wage (\$11.24/h), land rental (\$215/ha), and fertilizers: nitrogen (\$1.1/kg), phosphate (\$1.199/kg), and potash (\$1.001/kg), based on local market reports. Following knowledge gained during the survey, all crop operations but grain harvests were completed by on-farm labor and alfalfa was established for 3 years with oats as a cover crop, which was harvested using a 3-cut strategy, in which first and third cuts were harvested as silage and the second as hay. Also in the 3 farm systems, young stock animals were housed in a bedded pack barn. Estimates from previous studies were used for some data not available from surveys such as some economic parameters for feed prices (Rotz et al., 2007, Rotz et al. 2008) and veterinary and breeding costs (Kriegl, 2007).

Table 1. Mean (and standard deviation) of main characteristics of simulated dairy production systems

	Conventional n=27	Grazing n=30	Organic n=69
Alfalfa, ha	47.4 (25.5)	37.7 (24.4)	45.5 (26.1)
Grass, ha	22.4 (21.2)	61.9 (36.6)	43.1 (38.4)
Corn, ha	42.6 (29.7)	16.3 (11.7)	16.8 (14.0)
Oats, ha	12.2 (7.8)	5.0 (4.9)	16.0 (8.1)
Soybeans, ha	2.4 (4.5)	6.1 (10.6)	3.6 (4.9)
First lactation cows, %	36 (11)	30 (13)	31 (11)
Milk production, kg/cow per year	9,820 (2,139)	7,256 (1,695)	6,159 (1,875)
Milk price, \$/hL	35.99 (2.05)	37.52 (2.91)	56.50 (7.64)
Grazing strategy	Older heifers and dry cows	All animals	All animals
Housing facilities	Free stall barn naturally ventilated	Tie stall barn	Tie stall barn
Manure storage	Top-loaded linen earthen basin	No storage (daily haul)	No storage (daily haul)

Conventional farm. Grass was established for 10 years with 10% White Clover and 90% Orchardgrass. Only one cut of hay was harvested from the 22.4 ha at the beginning of the grazing season. Older heifers and dry cows were grazed in this field the rest of the time. Cows were milked twice daily in a double 8 parlor. The number of heifers was 35 for the young ones (< 1 year old) and 40 for the old ones (> 1 year old). Manure was collected using a scraper with a slurry pump and stored in a 6-month storage pit. Eighty percent of the manure collected was applied to the cornfield. The remaining 20% was applied to the alfalfa field.

Three different scenarios were simulated for the conventional farm. In the first scenario, lactating cows were grazed during the grazing season. As a result, the time of labor needed for the animal grazing was increased from 2 to 6 h/week. The impact of grazing on GHG emission was assessed using the same milk production (scenario 1, Table 2) and a 5% decrease in milk production (Vibart et al, 2008) (scenario 2, Table 2). Other scenario (scenario 3, Table 2) looked at the effect of manure management. In this scenario, the manure was incorporated in the soil the same day it was spread. At that same time the 6-month storage pit was replaced by a 12-month covered tank storage to limit emissions from the manure storage. Other scenarios looked at the combination of previous scenarios (scenarios 1 and 3, and 2 and 3, Table 2).

Grazing farm. Grass was established for 5 years with 45% White Clover and 55% Orchardgrass. Two cuts of hay were harvested from the 61.9 ha and all the animals were grazed. Cows were milked twice daily using a pipeline system. The number of heifers was 34 for the young ones (< 1 year old) and 36 for the old ones (> 1 year old). Manure was collected using gutter cleaners and hauled daily (i.e., no storage manure on the farm). Fifty percent of the manure collected was applied to the cornfield, 20% to grassland, 20% to alfalfa field, and 10% to the oat field.

Three different scenarios were simulated on the grazing system. In the first scenario, the forage to grain ratio was set from high to low. A high forage to grain ratio consists of 83, 90 and 93 % of forage in the diet for the early, mid and late lactation cow, respectively. A low forage to grain ratio consists of 57, 68 and 80 % of forage in the diet for the early, mid and late lactation cow, respectively (Rotz et al, 2011). As a result, milk production was increased by 5% (Aguerre et al, 2011) (scenario 6, Table 2). A 10% increase was also simulated (Sterk et al, 2011) (scenario 7, Table 2). Other scenario looked at the effect of manure management (scenario 3, Table 2). The manure was now incorporated into the soil the same day it was spread at the same time that a 12-month covered tank was added to the farm. Other scenarios looked at the combination of previous scenarios.

Organic farm. Two hectares on the organic farm were not available for crop production due to the organic regulation for buffer zones between organic and conventional land (USDA Agricultural Marketing Service, 2013; Rotz et al., 2007). Grass was established for 5 years with 35% White Clover and 65% Orchardgrass. Two cuts of hay were harvested from the 43 ha and all of the animals were grazed. Cows were milked twice daily using a pipeline system and housed in a tie stall barn. The number of heifers was 33 for the young ones (< 1 year old) and 40 for the old ones (> 1 year old). Manure was collected using gutter cleaners and hauled daily (i.e., no storage manure on the farm). Fifty percent of the manure collected was applied on cornfield, 20% on grassland, 20% on oats, and 10% on alfalfa.

The same scenarios used on the grazing system were simulated on the organic farm (Table 2).

Results

Comparison of production systems

The 3 systems produced enough forages to feed 85 cows and their replacements. Due to higher yields, the conventional system was able to sell more forages than the grazing or the organic systems (236 vs. 192 and 94 tonne/year, respectively). However, in order to maintain a higher milk production than the 2 other systems, the conventional system needed to buy more grain (187 vs. 104 and 107 tonne/year, respectively) and more soybeans (19 tonne/year vs. grazing and organic systems selling it in quantities of 12 and 4 tonne/year, respectively).

The organic system had a high income from milk sales (Figure 1) due to a higher milk price, and an intermediate feed cost (\$149,744/year) leading to the highest net return to management (\$59,120/year, Table 2). Moreover, the variation in net return across years was the smallest for the organic system. The conventional system had an intermediate net return to management of \$23,895/year. The high milk production compared to the grazing system (9,735 vs. 7,256 kg/year) compensated for the high feed cost (\$182,124/year) in the conventional system. Although the grazing system had the lowest feed cost (\$134,133/year), it had low milk production that led to the lowest net return to management (\$14,439/year; Table 2).

On a yearly basis, the conventional farm emitted the greatest amount of kg CO₂eq/year GHG (476,623), the grazing system emitted the lowest amount (405,565), and the organic system had an intermediate level (454,780) (Table 2). However, when GHG emission was expressed in function of milk produced (CO₂eq/kg milk) the emission from the conventional system was the lowest (0.58) followed by the grazing system (0.66) and the organic system (0.74). For the 3 systems, the major sources of GHG emissions were the GHG emitted from the barn floor, the animal respiration and the enteric fermentation when animals are housed inside the barn (housing facilities). Other important sources of GHG emissions on the conventional farm included secondary sources (4.60 kg CO₂eq/cow per d), manure storage (3.93 kg CO₂eq/cow per d) and feed production (3.47 kg CO₂eq/cow per d). For the grazing and the organic farms, other important sources were feed production (4.11 kg CO₂eq/cow per d and 4.60 kg CO₂eq/cow per d, respectively) and grazing (6.75 kg CO₂eq/cow per d and 6.44 kg CO₂eq/cow per d, respectively) (Figure 2). These results are consistent with previous studies with respect to the reported GHG amounts and ranges and in the fact that the major factor affecting the amount of GHG emission per kg of milk is milk production (Gerber et al., 2011; Kristensen et al., 2011).

Table 2. Economic effects and greenhouse gas emissions for various dairy farm management changes. Bolded numbers indicate best results by row

Parameter	Unit	Scenario ¹						
		0	1	2	3	4	5	
Conventional system		0	1	2	3	4	5	
Net return	\$/cow/year	281	364	272	240	319	227	
to management	\$/tonne milk	28.9	37.3	29.1	24.6	32.7	24.3	
	\$/year	23,895	30,900	23,093	20,359	27,075	19,254	
Net GHG	kg/cow/day			15.36	11.27	10.97	13.41	10.57
10.28								
emissions	kg/kg milk	0.58	0.42	0.43	0.50	0.40	0.40	
(CO ₂ equivalent)	tonne/year	476	349	340	416	328	319	
Grazing system		0	6	7	3	9	10	
Net return	\$/cow/year	170	19	115	128	-23	73	
to management	\$/tonne milk	23.4	2.5	14.4	17.6	-3.0	9.1	
	\$/year	14,439	1,593	9,756	10,874	-1,968	6,912	
Net GHG	kg/cow/day			13.07	10.28	10.44	13.86	10.96
11.13								
emissions	kg/kg milk	0.66	0.49	0.48	0.70	0.53	0.51	
(CO ₂ equivalent)	tonne/year	406	319	324	430	340	345	
Organic system		0	6	7	3	9	10	
Net return	\$/cow/year	696	581	703	638	521	644	
to management	\$/tonne milk	112.9	89.8	103.7	103.7	80.6	95.0	
	\$/year	59,120	49,354	59,725	54,265	44,327	54,717	
Net GHG	kg/cow/day			14.66	11.36	11.51	15.65	12.19
12.35								
emissions	kg/kg milk	0.87	0.64	0.62	0.93	0.69	0.67	
(CO ₂ equivalent)	tonne/year	455	352	357	486	378	383	

¹0=Baseline or control; 1=Grazing offered to lactating cows with no decrease in milk production; 2 =Grazing offered to lactating cows with 5% decrease in milk production; 3=Incorporation of manure the same day of application and addition of a 12-month covered tank; 4=Combination of scenarios 1 and 3; 5=Combination of scenarios 2 and 3; 6=Low forage to grain ratio with a 5% increase in milk production; 7=Low forage to grain ratio with a 10% increase in milk production; 8=Combination of scenarios 6 and 3; 10=Combination of scenarios 7 and 3.

Figure 1: Feed costs and income on the simulated dairy farm systems (\$/year)

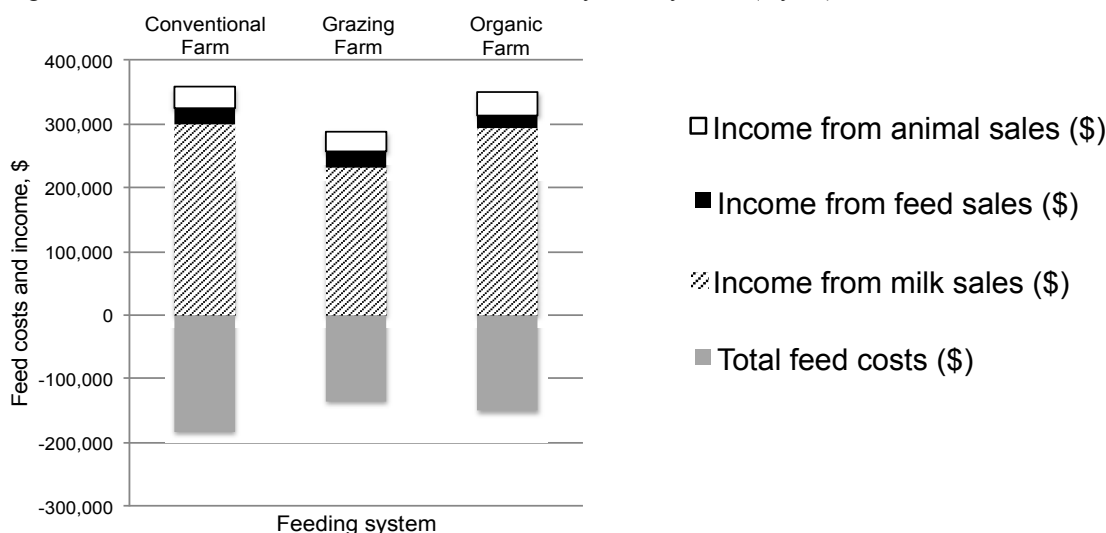
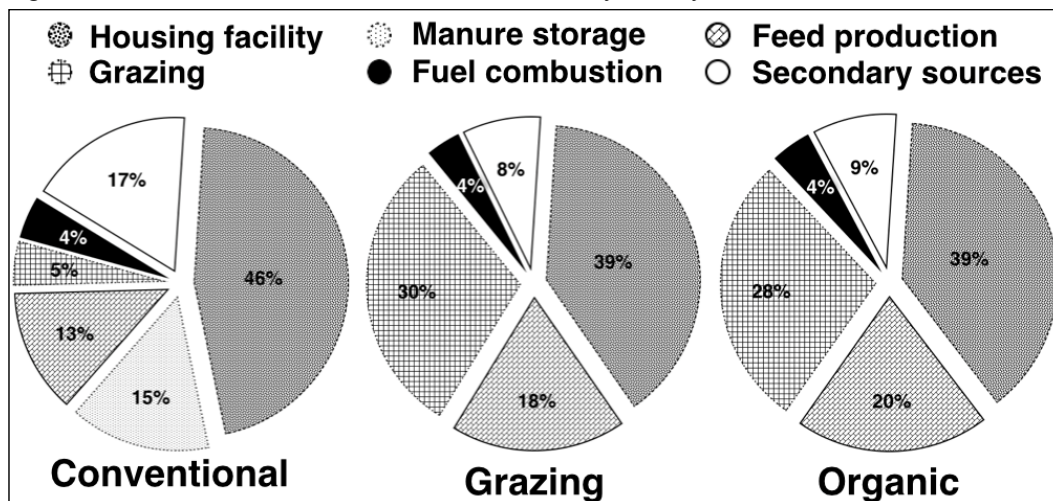


Figure 2: Sources of GHG emissions on the studied dairy farm systems



Strategies to reduce GHG emissions

Conventional farm. Scenario 1 simulated on the conventional system looked at the impact of grazing lactating cows. If the milk production was maintained at the same level, grazing lactating cows increased net return to management (+\$7,005/year) and decreased GHG emission by 27.6% (-0.16kg CO₂eq /kg of milk) (Table 2). Because lactating cows were grazing, less preserved forage was needed during the grazing season and the farmer was able to sell 33 tonne/year more forage than in the baseline scenario. This amount of forage sold contributed to an increase of \$3,684/year from feed sales. Net return to management increased also because of a decrease of \$3,856/year of total manure management cost. The time spent by the cows grazing decreased the amount of manure which needed to be stored and handled, reducing the cost of manure management. The decrease in GHG emission was possible for the same reasons. Because cows were spending time outside, GHG emission from housing facilities and manure storage decreased (-5.25 kg CO₂eq/cow per year and -2.63 kg CO₂eq/cow per year, respectively) and emission from grazing increased (+3.55 kg CO₂eq/cow per year), resulting in a net reduction in GHG emission when grazing substitute for confinement feeding during part of the year. When milk production was decreased by 5% (scenario 2), GHG emissions decreased by 26% (-0.15kg CO₂eq /kg of

milk). However, the increase in income from forage sales was compensated by the decrease in milk production and the net return to management stayed almost the same compared to the baseline scenario. Consequently, the net return to management per kg of milk was slightly better for scenario 2 compared to the baseline scenario (\$29.1 vs. \$28.9/tonne of milk, respectively).

The 12-month covered tank and the incorporation of manure the same day of application (scenario 3) led to an increase of total manure cost of \$3,398/year. For this reason, the net return to management decreased to \$20,359/year. The change in manure management was beneficial for GHG emissions, which decreased by 16% (-0.08 kg CO₂eq/kg of milk, Table 2). The decrease in emissions from the manure storage and from the field during feed production contributed to this improvement.

Scenario 4 and 5 looked at the interaction of previous scenarios simulated on the conventional system. If milk production was maintained at the same level (scenario 4), the adoption of grazing for the lactating cows and the changes in manure management led to an increase in net return to management (+\$3,180/year) and a decrease in GHG emission of 31% (-0.18 kg CO₂eq/kg milk). The change in net return was the result of the increase in income from feed sales, the decrease in total manure cost observed in scenario 1, and the increase in manure costs observed in scenario 2. The change in GHG emission was the result of a decrease in emission from the housing facilities and the manure storage. However, the overall decrease in GHG emission for scenario 4 compared to the baseline scenario did not add up to the decrease observed in scenarios 1 and 3. If milk production was reduced by 5% (9,329 kg/cow per year, scenario 5), GHG emission decreased by 0.18 kg CO₂eq/kg of milk, but net return to management was also reduced by \$4,641/year compared to the baseline scenario.

Grazing farm. Scenario 6 simulated on the grazing farm looked at the impact of changing the forage to grain ratio from high to low. This strategy did reduce GHG emission by 25.8% compared to the baseline scenario (-0.17 kg CO₂eq/kg of milk), but also reduced substantially the net return to management (-\$12,846/year or -\$151/cow per year) when milk production was increased by only 5% (Table 2). In such case, the income from the increase in milk production and the additional forage sold (92 tonne/year) did not cover the expenses needed to buy the additional grain. Feed costs increased by \$34,797/year compared to the baseline scenario. In regard to GHG emission, the increase of 2.39 kg CO₂eq/cow per year from secondary sources due to the grain purchased was offset by the reduction in emission from housing facilities (-2.28 kg CO₂eq/cow per year), grazing (-2.16 kg CO₂eq/cow per year) and feed production (-1.13 kg CO₂eq/cow per year). When milk production was increased by 10% (scenario 7), the impact of changing the forage to grain ratio was essentially the same on GHG emission and the net return was less reduced (-\$4,683/year) compared to the baseline scenario.

Adding a 12-month covered tank and incorporating the manure the same day of application (scenario 3) increased GHG emission (0.04 kg CO₂eq/kg of milk) and decreased net return to management (-\$3,565/yr) (Table 2). The reduction in net return was due to an increase of total manure cost of \$3,521/year compared to the baseline scenario. The reduction of GHG emission from feed production (-0.27 kg CO₂eq/cow per year) possible with the incorporation of manure the same day of application did not compensate for the increase in GHG emission from the manure storage (1.25 kg CO₂eq/cow per year), leading to an overall increase of 0.79 kg CO₂eq/cow per year.

When forage to grain ratio was set to low, milk production increased by 5% and a manure management change was imposed (scenario 9), net return was decreased by \$16,407/year compared to the baseline scenario due to an increase in feed cost from the grain purchased and an increase in total manure costs. When milk production increased by 10% together with a change in manure management (scenario 10), net return was decreased by \$8,247/year for the same reasons. The

overall GHG emission was reduced by 0.13 and 0.15 kg CO₂eq/kg of milk for a 5 and 10% increase in milk production, respectively (Table 2).

Organic farm. Results in the organic system followed the same trend as for the grazing system. A 5% increase in milk production and having forage to grain ratio from high to low (scenario 6) decreased the net return to management by \$9,766/year and decreased the GHG emission by 0.23 kg CO₂eq/kg of milk (Table 2). With a 10% increase in milk production and forage to grain ratio low (scenario 7), GHG emissions were reduced by 0.25kg CO₂eq/kg of milk while net return to management was still slightly increased. A 10% increase in milk production was sufficient to maintain net return compared to baseline scenario in spite of an increase in feed costs (Table 2). In scenario 3, net return to management decreased by \$4,855/yr because of an increase of total manure cost and GHG emission increased by 0.06 kg CO₂eq/kg of milk. With a 5% increase in milk production and a change in manure management (scenario 9), net return to management decreased by \$14,793/yr and GHG emissions decreased by 0.18 kg CO₂eq/kg of milk compared to the baseline scenario. With a 10% increase in milk production and a change in manure management (scenario 10), net return to management decreased by \$4,403/year and GHG emission decreased by 0.20 kg CO₂eq/kg of milk (Table 2).

Conclusions

Opportunities exist to reduce GHG emissions and maintain or even increase profitability by feeding management strategies, regardless of the type of dairy production system: conventional, grazing, or organic. In contrast, under the simulation conditions of this study, manure management changes to reduce GHG emission had a negative impact on profitability. However, the evaluation and the implementation of mitigations strategies should be based on farm system specific characteristics. Despite great strengths in modules such as crops, machinery, feed storage, or grazing, the IFSM has limitations in dairy herd management options. For instance, it assumes a fixed number of herd groups and ignores herd dynamics related to reproduction or replacement, which have important economic and environmental impacts. A sensitivity analysis including more herd-related management strategies together with uncertain factors are recommended for further study.

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