The Ruminant Farm Systems Model: A decision-support tool for whole farm efficiency and sustainability

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Abstract

Sustainable dairy production requires methods to quantify the environmental footprint of dairy farms that can inform management decisions. Impact inventories can provide some insight for policy, but are not suitable to inform decisions at the farm level. Decision-support tools like the Ruminant Farm Systems (RuFaS) model represent farm management and estimate environmental impacts with enough detail and flexibility to compare the effect of management practices and guide farm management decisions. For example, RuFaS can be used to compare the environment impacts of reproduction protocols. The RuFaS model estimates that improving the reproductive performance of a 1,000-cow herd from a low performance to a baseline performance scenario reduces manure and enteric methane production and the emissions intensity of milk production for that herd. The expected annual enteric emissions reduction alone is equivalent to removing over 70 gas powered cars from the road for one year.

Key words: environmental footprints, decision-support tools, greenhouse gas emissions

Dairy production impacts on the environment

In the effort to increase the sustainability of U.S. dairy production, we continue to make progress along all 3 pillars of sustainability – social, economic and environmental. Dairy farms are complex agricultural system that require management of large land bases and movement of nutrients, biomass and animals. Thus, dairy production will always affect the soil, water and air in the local environment and we recognize that environmental sustainability does not equate to a dairy system with zero environmental impact. Instead, the goal of environmental sustainability is to minimize the negative environmental consequences of dairy production, both locally and globally, and, where possible, contribute to positive ecological outcomes.

However, unlike economic performance, the metrics of environmental impacts are difficult to measure. We cannot, for example, measure the nitrogen (N) and phosphorus lost through runoff from every field or put a dome over the farm to measure gas exchange. In the absence of methods for practical, accurate empirical measurements, we use mathematical models to quantify environmental impacts of dairy production. There are many approaches to building models to quantify environmental impacts that vary depending on the intended use of the metrics and the scale or level of aggregation of the estimates.

Quantifying environmental impacts

The reasons for generating estimates of environmental impacts often align with 1 of 2 objectives: 1) to create an inventory of footprints across larger geographic, political or economic scales and 2) to provide information about how management decisions affect environmental outcomes.

Inventories

Inventories of environmental footprints commonly occur at the state, national or global level, and are used to set targets for mitigation strategies, inform policy and track progress over time. For example, countries classified as Annex I countries in the United Nations (including the U.S.) have committed to conducting national inventories of greenhouse gas (GHG) emissions as part of the organization's efforts to prevent and mitigate climate change across the globe. The Environmental Protection Agency publishes an annual inventory of U.S. emissions across all sectors of the economy and natural processes to uphold our commitment to the UN.[1] In addition to collecting annual reports from participating countries, the International Panel on Climate Change (IPCC) integrates all available inventories and produces global emissions reports on a semiregular basis to track total emissions and update future climate models based on emissions trajectories and mitigation commitments.

The UN and the Environmental Protection Agency (EPA) also produce sector level reports that focus inventories on a certain activity or economic sector. For example, the Food and Agriculture Organization's (FAO) most recent report on the contributions of agriculture and food systems to greenhouse gas (GHG) emissions estimated that this sector contributed to 31% of total global anthropogenic emissions in 2019.[2] However, this global estimate masks large regional variation in agriculture's contributions to emissions that are estimated at only 21% for North American countries and as high as 72% for South American countries. Global inventories thus enable country and regional comparisons that can help intergovernmental and governmental bodies prioritize emissions or environmental impact mitigation strategies by region or country. Inventories that focus on a smaller scale can be informative as well. Companies, for example, can develop footprint inventories of their supply chain to help them identify areas of opportunity. A recent inventory of U.S. dairy production estimated the GHG emissions, reactive N loss, blue water use and fossil fuel consumption from U.S. dairy production in 6 regions across the U.S.[3] In their work, Rotz et al. attributed 43% of GHG emissions from all U.S. dairy farms to enteric emissions and 62% of the blue water use to production of purchased feed in addition to highlighting regional differences.

Irrespective of the scale or specific focus, common attributes of the methods for generating inventories are that they are retrospective analyses that represent a specific point in time; they rely on estimates of the average or representative practices usually in combination with records of total populations or production. The utility of inventories often lies in the aggregation of data and estimates and comparisons of outcomes at scales that are larger than the scale where management practices and decisions are made that will ultimately effect change through implementation of mitigation strategies.

Decision-support tools

In contrast, methods that estimate environmental footprints at the enterprise or farm level can be used to inform decisions as long as they are able to represent the system with enough detail to provide meaningful insight to the decision makers. Differences in the methodology of these decision-support tools that distinguish them from inventory models are that they are often dynamic, meaning that they represent the system over time instead of for one snapshot in time; the mathematical representations of the system aim to represent the behavior of the system through process-based, rather than empirical modeling; and they are able to estimate outcomes in the future as well as retrospective analyses.

Some examples of decision-support models that quantify environmental footprints of dairy farms include the CoolFarm Tool, COMET-Farm, and IFSM. All of these models can all, to varying degrees provide some insight into how dairy farm management practices influence environmental outcomes. However, as we continue to learn more about the sources of environmental impacts, increase our understanding of nutrient cycling within the dairy farm system, and develop new technologies to manage the animals, nutrients and land on a dairy farm, these existing tools have some limitations that prevent them from meeting the dairy industry needs for a comprehensive decision support tool. In particular, the existing models are limited in the types of management practices they can represent, especially related to animal care and management, they are either difficult to update with new practices or proprietary, and they don't always have mechanistic connections between different parts of the farm that would support a more holistic understanding of whole farm impacts by connecting downstream outcomes to management practices on each part of the farm.

The Ruminant Farm Systems Model

The Ruminant Farm Systems (RuFaS) Model is a process model of dairy farm nutrient cycling with an objective to support both scientific inquiry and farm-level decision making. Wherever possible, RuFaS draws on relationships, equations and principals from existing agricultural models and includes stakeholder-driven development decisions that differentiate our approach from extant models. An example of a methodological choice that distinguishes RuFaS from other dairy farm models is in the Animal Module that simulates each individual animal as they move through their life cycle in a dairy herd.[4] This choice allows RuFaS to compare how management decisions related to breeding, animal health and culling impact herd efficiency and thus environmental outcomes like enteric emissions and manure production. The choice to represent individual animals is one example of our general approach to build a flexible and scalable model that is capable of representing the diversity of management practices in the U.S. dairy industry.

Impacts of reproduction management on environmental outcomes

Because RuFaS simulates each individual animal in the herd and operates at a daily timestep, the model is able to connect animal management practices like breeding and reproduction programs to environmental outcomes like enteric methane emissions, feed efficiency and manure production. The flexibility offered by simulation of individual animals also allows for different breeding protocols to be applied to different groups or types of animals which is more representative of real farm management.

To demonstrate this example, I compared three different reproduction programs using the RuFaS Animal Module in a 1,000-cow herd representative of a Wisconsin dairy herd milking 2x per day.[5] The 3 reproduction scenarios are described in Table 1 and include a Baseline scenario, a Low Reproduction performance scenario, and a High Reproduction performance scenario. The turnover rate (as represented by the number of cows culled) in the Baseline scenario was around 34%. This was slightly decreased in the High Reproduction performance scenario to just under 33%. However, in the Low Reproduction performance scenario turnover rate increase substantially to around 48% as a result of an increased number of cows being culled because they were not able to get pregnant in a timely manner. The expected impacts of these reproduction management scenarios on individual animal daily milk production, annual herd milk production and whole herd dry matter intake are shown in Figure 1. Figure 2 highlights the combined effect of increased milk production and reduced feed intake on herd level feed efficiency that can be accomplished with improved reproductive performance. Further, as would be expected, manure N and phosphorous (P) excretion, follow the inverse pattern to feed efficiency with lower reproductive performance resulting higher total manure N and P excretion. The especially large increases in dry matter intake for the Low Reproduction performance scenario are mostly due to the higher demand for heifers needed to support the higher turnover rate and the higher number of heifers raised for every heifer that successfully conceives and enters the herd.

Figure 3 illustrates the connection between reproductive management and dairy's contribution to GHG emissions by estimating changes to enteric methane emissions. The Baseline scenario enteric methane emissions intensity is just below the 430 g of CO2-eq/kg FPCM that was estimated as the national average by Rotz et al.[3] Improving reproductive performance can reduce that intensity even further, and when implemented on a 1,000-cow dairy, RuFaS estimates over 138 metric tons of CO2-equivalent emissions can be avoided. This reduction is similar to taking 30 gas-powered vehicles off the road for an entire year or planting over 2,200 trees as seedlings and maintaining their growth for 10 years. Helping a herd move from the Low Reproductive efficiency scenario to the Baseline reproductive performance would have just over double that impact and be similar to taking over 75 cars off the road or planting 5,900 seedlings.

These scenario comparisons highlight the ability of the RuFaS model to connect management practices to environmental outcomes just within the Animal Module. As RuFaS development progresses, a similar level of flexibility in representation of management practices will be available across the other parts of the dairy farm system and building the connections between the modules will provide even more insight into the holistic environmental outcomes of each management decision.

Figure 1: The impact of reproduction performance on milk production and intake in a 1,000-cow Holstein herd simulated with the Ruminant Farm Systems model.

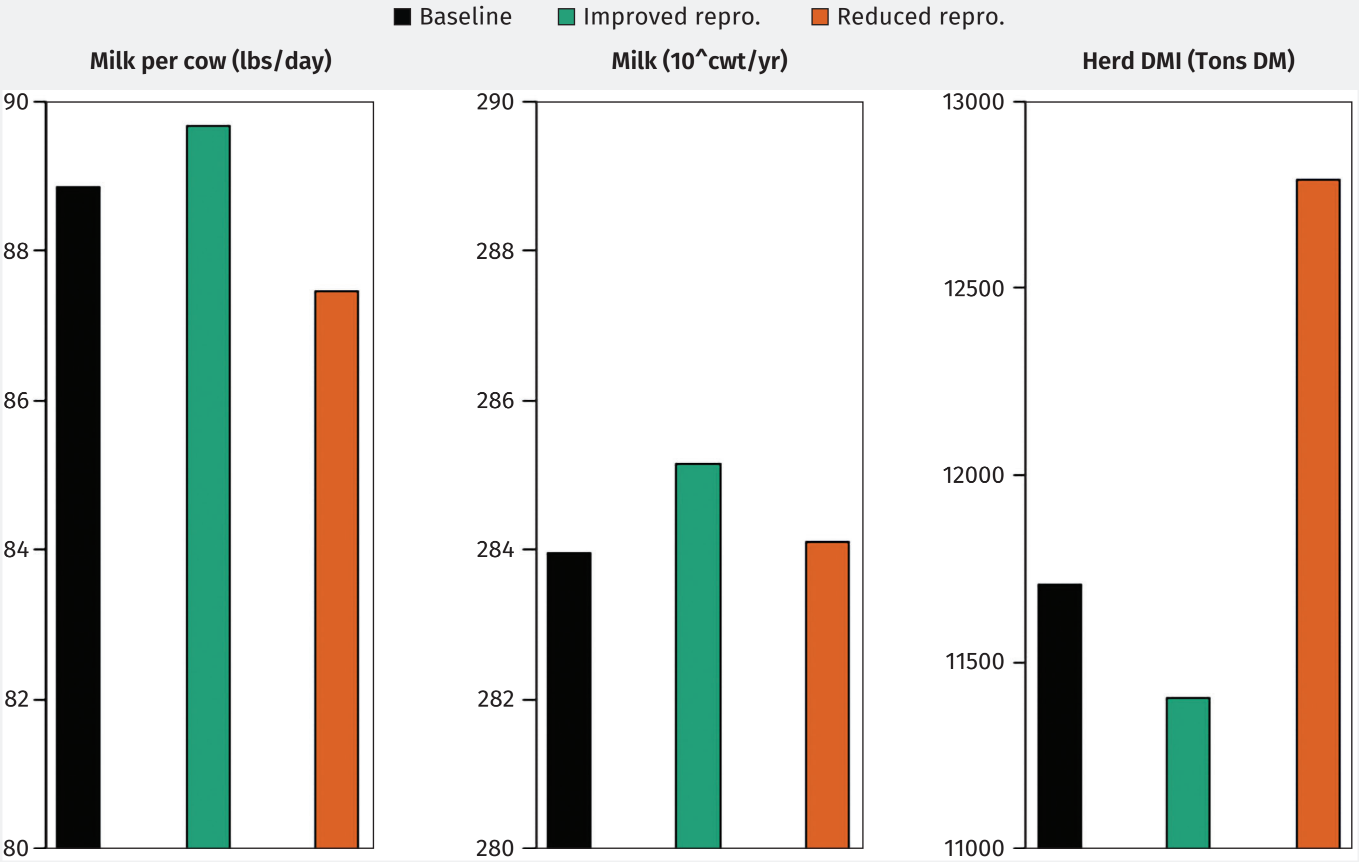


Table 1: Reproduction program scenarios.

Scenario	Heifer program	Service rate (%)	Preg./AI* (%)	Cow program (Re-Synch)	Service rate (%)	Preg./AI* (%)	VWP†
Baseline	Synch-ED	70	60	TAI (ED-TAI)	100 (60-100)	60 (45)	72
High repro. efficiency	TAI	100	60	TAI (TAI)	100 (100)	60 (55)	72
Low repro. efficiency	ED	60	60	ED-TAI (ED-TAI)	60 (60-100)	50 (50)	55-72

* Artificial insemination

† Voluntary waiting period

Figure 2: The impact of reproduction performance on feed efficiency and manure production in a 1,000-cow Holstein herd simulated with the Ruminant Farm Systems model.

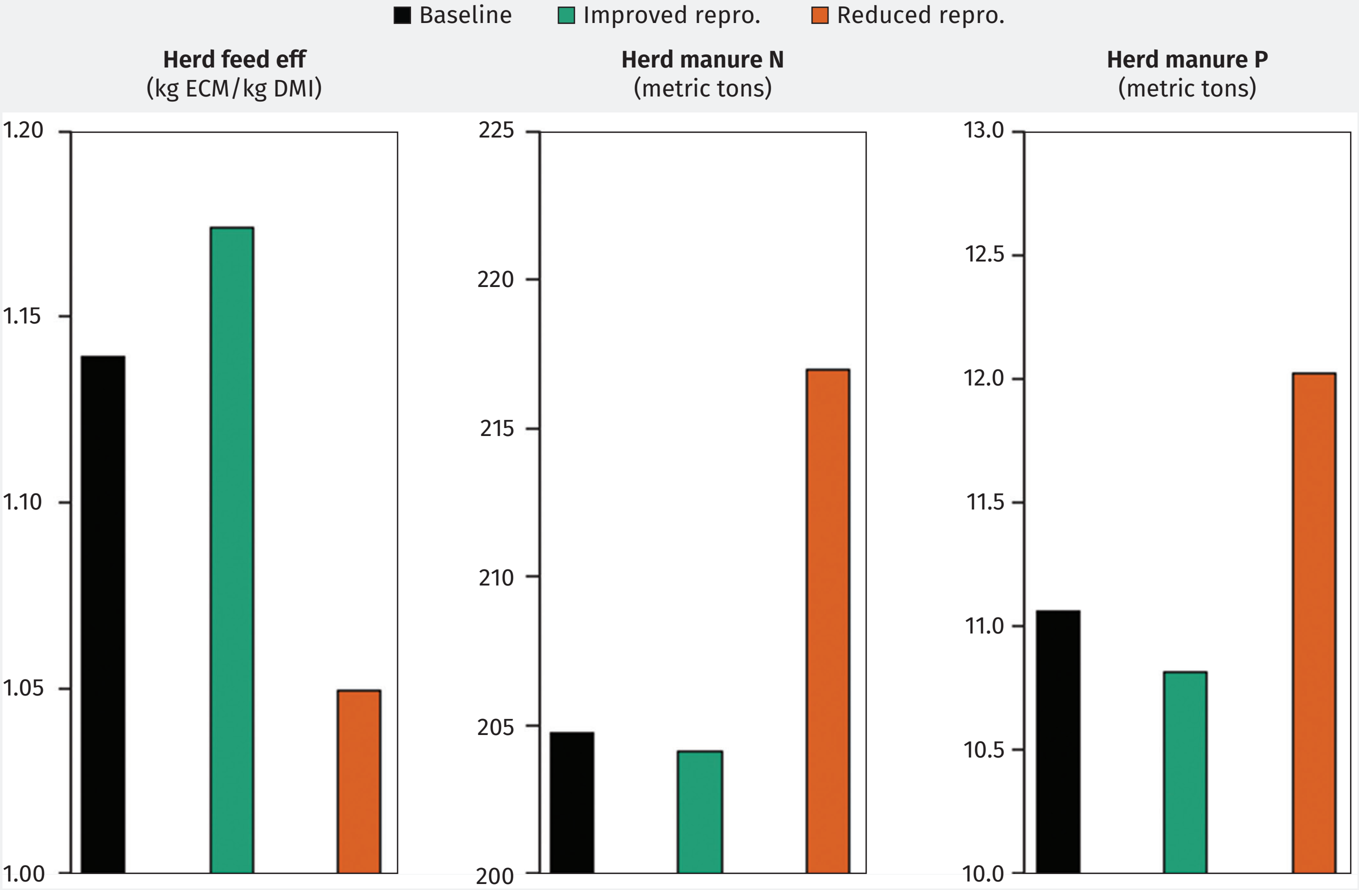
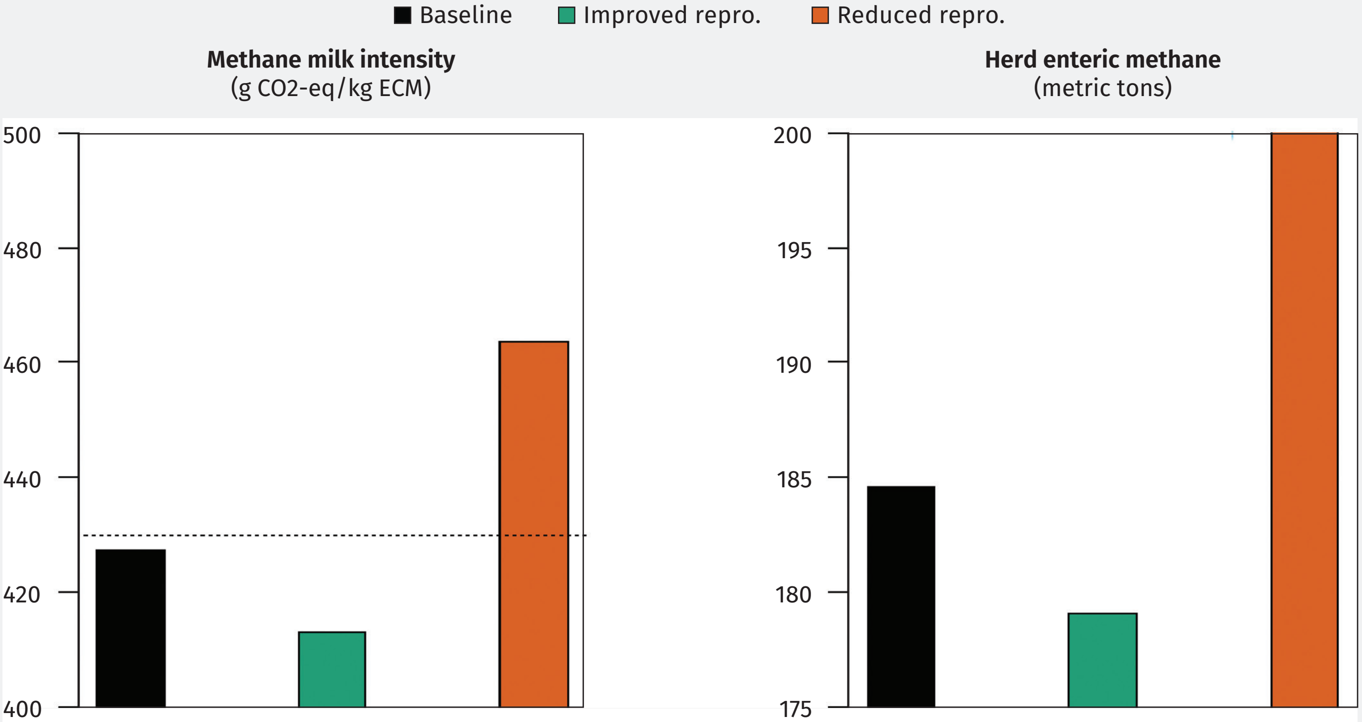


Figure 3: The impact of reproduction performance on total enteric methane productions and methane intensity in a 1,000-cow Holstein herd simulated with the Ruminant Farm Systems model.



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