Ruminant Farm Systems Model: Development Progress and Applications

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Model Background

Simulation models are a tool that can guide policy, support farm decisions, and evaluate novel technologies. Models can estimate multiple outcomes that result from of management changes or adoption of new technologies and provide a more robust, systematic evaluation than isolated research experiments. Examples of whole-farm models for dairy production include the Integrated Farm Systems Model (Rotz et al., 2013), DairyMod (Johnson et al., 2008), DyNoFlo (Cabrera et al., 2006), and SIMS(DAIRY) (Del Prado et al., 2011). However, wide-scale industry adoption of these models has not occurred due to limitations in model applications for current and future scenario analysis. Existing model structure and code bases prevent model adaptation or development of features like data integration and novel management scenarios that would encourage widespread. Thus, we are developing a new farm simulation model that can adapt to changing technologies and support sustainable dairy production (Kebreab et al., 2019).

The Ruminant Farm Systems Model (RuFaS, Figure 1) applies modern computer coding practices centered around clarity and adaptability to respond to evolving technologies in the dairy industry. RuFaS embraces the key characteristics for next-generation agricultural systems models described by Jones et al. (2017) so that it can be adaptable as new technology arises, be interoperable with other software and models, and meets user needs by continuous interaction with stakeholders during the development process.

Our development team includes scientists from 5 universities and several USDA-ARS stations who represent a range of disciplines. Rather than relying on research scientists to fill the role of translating their model equations and algorithms into computer code, we work closely with computer scientists to develop the modular codebase. We emphasize thorough documentation at all steps of model development. The scientists develop detailed pseudocode that provide heuristic descriptions of the model processes, literature references, and the mathematical equations. Similarly, the computer scientists provide in-code comments that describe the flow of information and references to equation numbers from the pseudocode to link the computer code directly to the scientific documentation.

The Ruminant Farm System (RuFaS) model is based on a foundation of four biophysical modules (animal, manure handling, crop + soil, and feed storage) that represent the main components of a dairy farm as shown in Figure 1. The simulation inputs include the desired length of the simulation, herd characteristics, manure management strategy, crop characteristics, and other elements of farm management. We use a tiered file structure for inputs that separates inputs that designate whole farm and simulation structure from inputs specific to each of the modules with increasing level of detail associated with inputs at lower tiers. Model outputs are exported to CSV files, graphic images, and an SQL database. The model uses a daily time-step and is programmed in Python, an adaptable and easy to read computer programming language.

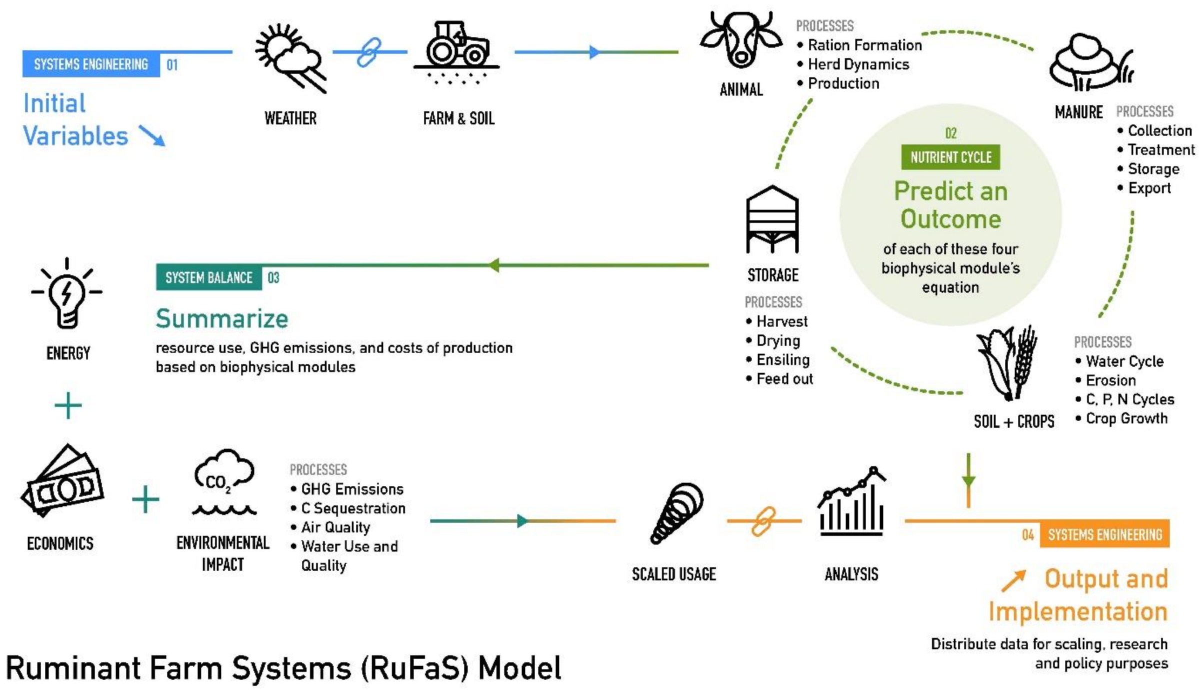

Figure 1. Conceptual diagram of the Ruminant Farm Systems model

Progress Updates

Model Inputs and Management Options

Through the model inputs, the user defines the farm management and environment for each simulation scenario. At the farm level, the user specifies the target lactating cow number, the replacement rate and growing herd size, the housing type and size, purchased and growing feeds, field number and size, and provides the weather (temperature, solar radiation, precipitation) during the simulation period. At the herd level, the user can specify the breed and reproduction protocols. The model primarily uses the Wood's lactation curve to estimate the baseline milk production for each cow on each day of lactation and this baseline production can be adjusted to fit desired farm or total lactation production by modifying the lactation curve parameters. Other animal characteristics that can be modified by the user include parameters that define the bodyweight distribution, reproductive efficiency, and probability of disease.

The model user defines a manure management strategy for each animal pen to provide the flexibility to represent different manure compositions and handling methods based on the animal group. The method and frequency of manure collection, treatment and processing methods, and storage length and type are all set by the user for each pen or group of pens.

The Crop and Soil Module has similar flexibility to represent a range of crop production practices. The user can specify any number of fields, each with its own size, soil properties, crop rotation, and tillage, fertilization, planting, and harvest practices. Crop growth in RuFaS is based on the methods used in the Soil and Water Assessment Tool (Neitsch et al., 2011) and currently has the ability to simulate corn, alfalfa, soybeans, rye, winter wheat, meadow fescue, and beets.

The feed storage module is much simpler than the rest of the model in its current state and provides only empirical estimates of forage composition change, emissions, and leachate for silage and hay storage. This module estimates changes in forage composition during storage once per season which is the only part of the model that does not function on a daily timestep.

Nutrient Cycling and Outputs

RuFaS simulates transformation, export, and loss of biomass, agriculturally significant elements (N, P, and K) and H_2O as they cycle through the 4 modules that represent a dairy farm. The Feed Storage module tracks the composition and inventory of farm grown feeds. This information is passed to the Animal Module and used, in combination with purchased feeds, by the automated, least-cost diet formulation algorithms to simulate feed delivery each day. The diet formulation algorithms are currently based on the NRC (2001) Nutrient Requirements for Dairy Cattle though we hope to update them soon. The Animal Module uses a Monte Carlo stochastic framework to simulate each individual animal as they move through their lifecycle on the farm which is represented by 5 distinct animal classes. Detailed descriptions of the ration formulation methods and the life events simulated by the Animal Module are provided in our recent publication (Hansen et al., 2021). The simulated intake, diet composition and characteristics of each individual animal drive the estimates for partitioning of the diet N, P, and K into milk, body mass, and manure to maintain a mass balance of these important elements at the animal level. Manure organic matter and enteric methane emissions are also estimated. Daily production of manure from each animal is summed per pen and the total manure mass and composition (DM content, volatile solids, degradable volatile solids, N, K, P, soluble P, and ammonia concentration) are passed to the Manure Module.

The Manure Module first simulates ammonia emissions from the barn floor after excretion and before cleaning and then combines the bedding, flush water, and parlor cleaning water into a simulated reception pit. Currently the model can represent both flushing and scraping cleaning systems from tie stall and free stall pens. Compost bedded-pack barns and dry-lot housing systems are still in development. After the reception pit, the model simulates movement of the combined manure and wastewater to either long term storage or for processing. Current options for manure processing include mechanical solid-liquid separation and anaerobic digestion. Manure emissions and composition change are estimated at each daily step during manure handling, processing, and storage.

On the days when the Crop and Soil Module simulates manure application to fields, the Manure Module passes information about the amount and composition of the manure in storage and subtracts the mass of the simulated manure application from the stored quantities. The Crop and Soil Module then simulates daily biogeochemical nutrient and water transformation, crop uptake, and loss from the soil profile based on a combination of the SWAT (Neitsch et al., 2011), SurPhos (Vadas, 2009) and DayCent (Del Grosso et al., 2011) models. Crop growth rate and composition is based on solar radiation, temperature, and water and N availability. At harvest, above ground crop biomass is partitioned into crop residue that remains on the field and that which is transferred to the Feed Storage Module to inventory management, completing the dairy farm nutrient cycle.

Model Applications

One of the features that sets RuFaS apart from other farm simulation models is the objective for the model to be used for both research and as a decision support tool for the dairy industry. The detailed documentation and use of Python language will facilitate research use by empowering future scientists to understand, modify, and update the model as part of their research program. For industry applications, the flexibility built into the model structure and multiple options for each management decision will support the industry need to estimate current environmental footprints and to inform sustainable decision making.

For example, one type of management decision that RuFaS could support is determination of the reproduction protocols. A recent case study compared two different synchronization protocols (5dCoSynch and OvSynch56) under two different voluntary waiting periods. By including these options in a farm system model, RuFaS is able to provide estimates of the impact of these decisions on the expected feed consumption, enteric methane production, and manure production. For example, in a preliminary comparison, we found that a shorter voluntary waiting period reduced the enteric methane intensity of milk production but that the improved conception rate of the OvSynch56 protocol, did not appear to reduce the methane intensity in comparison to the 5dCoSynch protocol.

Farm system impacts of diet changes or improvements in feed efficiency are another example of an application of RuFaS to inform management decisions. In the case study we presented in Hansen et al. (2021) we demonstrate that RuFaS is able to compare changes in feed efficiency by assigning a stochastic residual feed intake (RFI, kg/d) value to individual animals. As expected, improved efficiency and reduced RFI decreased enteric methane and manure production. However, the percent decrease in both enteric methane and manure emissions were not equivalent to the percent increase in feed efficiency due to non-linearities in the system. Thus, RuFaS can provide estimates of expected environmental benefits from nutrition and breeding programs to improve feed efficiency that account for interactions between the diet, animals, herd dynamics, and downstream farm management choices.

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