Integrating simulation models to optimise nutrition and management for dairy farms: a methodology

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Introduction

Progress has been made in recent years modelling biological processes. In the case of crops and livestock the nature of the processes represented has led to the construction, at different levels of aggregation, of very similar models throughout the world. This overlapping has made model-building an expensive and time consuming activity because researchers often take on the enormous task of building new models rather than selecting and adapting the existing ones for their own purpose. Efforts have usually been directed towards representing individual units or processes within a defined system (i.e. the animal, the plant, growth, lactation). These types of models by themselves are useful but usually fail to provide the decision maker with solutions to managerial problems (Dent et al. 1994). As the dairy farming enterprise is a dynamic multi-component activity, integration of these 'individual models' together with herd and socio-economic data should provide a framework for a decision-support system.

In activities where allocation of resources plays an important role, testing different management strategies via systems simulation may not provide ideal solutions. In such cases the output of the simulations could be used as inputs in multiple criteria decision models (MCDM's) to obtain alternatives which produce the best combinations of resources (Romero & Rehman, 1989).

The objective of this project is to briefly describe a decision-support system based on systems simulation and optimisation techniques to identify viable strategies to improve nutrition and management in pasture-based milk production systems.

Modelling framework

The general dairy systems modelling framework is presented in figure 1. It consists of adapted components representing individual biological processes (grass growth, pasture-animal interface and cow models), population dynamics (stochastic herd model), management practices and the socio-economic environment (databases and surveys) and a validation element (livestock and pasture databases). These components interact so that the output of one is used as the input for another one or has an influence on it.

The simulation system consists of an adapted mechanistic grass growth model (Johnson & Thornley 1985) representing the growth, structure and chemical composition of a sward under rotational grazing with responses to N fertiliser applications, temperature and light interception throughout the year. The function of this model is to determine the effects of different grassland management options on pasture dry matter (DM) production, chemical composition and sward structure. In a rotational grazing system, the typical examples of management practices that could be examined deal with the length of the regrowth period, the amount and timing of fertiliser applications, the effects of defoliation regime on subsequent sward growth and structure and their interactions. The importance of this model being mechanistic and driven by environmental variables is that it provides a basis to study seasonal effects on pasture growth and it makes the adaptation to different grass species and different climatic regimes or latitudes a viable option.

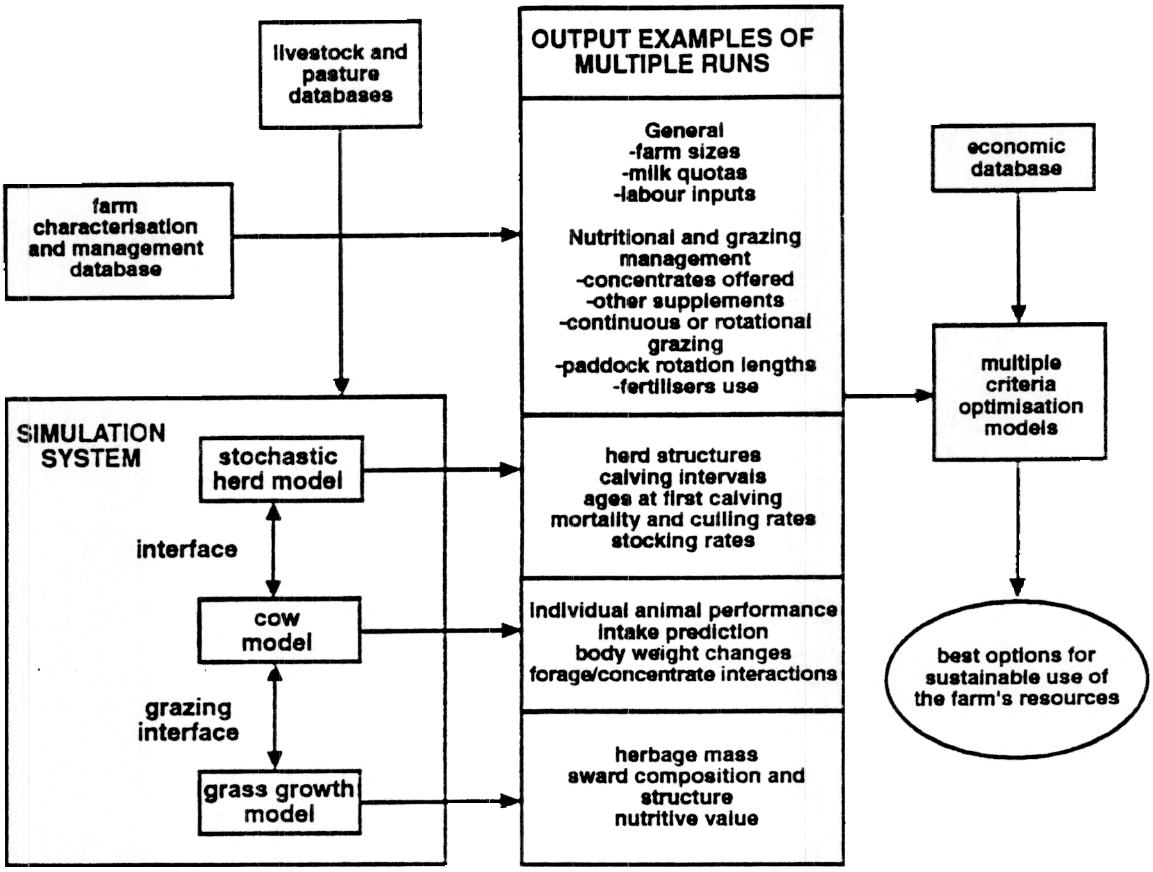

Figure 1. General dairy systems modelling framework.

The grass growth model is linked via an interface representing the grazing process and the effect of sward characteristics upon animal intake to a dairy cow model which calculates nutritional requirements (based on AFRC 1993) and digestion kinetics according to the cow's physiological state, milk production, body weight and body weight changes. The representation of the plant-animal interface is one of the most critical developments for the system because the sensitivity and accuracy of the prediction of the productive responses to nutrients by the dairy cow is largely determined by a good estimate of pasture intake. While recent systems of feeding standards (i.e. AFRC 1993) have estimated the nutritional requirements of ruminants with some degree of accuracy, they have not dealt satisfactorily with intake prediction. Most of the proposed empirical relations are descriptions of specific datasets which broadly reflect practical conditions but which are not sufficiently precise to be used in the farm management context (see Forbes 1993), especially with grazing ruminants where aspects related to the physical quantity and structure of the sward also have an influence on the amount of pasture eaten (Hodgson 1985). This interface should therefore attempt to describe the basic components of voluntary pasture intake and digestion to be able to test the effects of different grazing or supplementation strategies on the cows' productive performance.

After analysis of livestock databases including different farms from a region in study, herds are simulated by an stochastic population model. The function of this model is to provide the herd characteristics of a particular farm (i.e. number of animals, herd structures, calving intervals, culling and mortality rates) and the individual animal variables which drive the dairy cow model (i.e. body weight, milk production, physiological state) considering the random variation existing in the real systems. Its importance lies in the representation of the effects of changes in management practices on herd production and economic performance (Sorensen et al. 1992).

Data from farm surveys provide additional inputs influencing the production responses from the biological models (i.e. concentrates allowance, fertilisers use, paddock rotation lengths) and the relevant farm and management characteristics (i.e. farm size, milk quotas, young stock rearing practices) that are linked to the herd model or that constrain the system.

Validation of the simulation system against real farm data is done with animal performance and grazing databases obtained from available farm monitoring services, farm records or experiments. The important variables to validate are the outputs of each individual model, those variables with a high sensitivity to changes in management practices or those which largely determine the economic efficiency of the system. For example, herbage production, individual milk production or herd structures.

Finally, the validated outputs of alternative simulations are combined with economic data and are used as inputs in MCDM's. The dairy farm simulation system is run under different scenarios associated with changes in grass production, grazing strategy, nutritional or herd management and land use options and the MCDM's examine the different simulation runs and identify the management strategies which produce the most viable compromise between the farm's resources according to the established objectives. MCDM's have the advantage that users can assign subjective weights to represent the importance of the multiple activities in the system. Therefore if these weights represent the priorities of the decision maker (usually the farm household unit at a farm level), then better advice could be given as the resource compromise could reflect more accurately the farmer's objectives.

Although the methodology presented here is given in relation to the dairy farm, it could be adapted to other ruminant production systems (i.e. beef or dual purpose cattle, sheep, goats) which could be represented by adjusting the time steps of management events, the biological cycles, or the production objectives. The creation of this system as individual modules linked by appropriate interfaces also permits the use of each model independently if required.

Uses of the decision-support system

The system has three fundamental roles. First, as a decision-making tool for advisory purposes where the farmer together with the farm advisor can propose, test and distinguish between different management strategies involving the different sub-components of his/her farm (i.e. grass production, nutrition, herd management) while at the same time examining different land use options and their impact on the system's sustainability and profitability. One advantage of using a validated decision support system is that the typical 'what if...' questions always asked in dairy farm management can be answered without the cost, the time, the risk of failure, and sometimes long term consequences, associated with the implementation of an unsuccessful policy. Although the number of alternatives is theoretically infinite, only a small number can be validated, implemented and produce the best compromise between the resources available. The system is being tested for these purposes at present.

This decision support tool could also be used for strategic planning at the regional level. In situations where farm monitoring systems are operating, the main characteristics of the farms of a region are usually known. In such cases, the system could be expanded to represent different types of farms, and the impact of different policies on the region's use of land and resources could be tested or could be compared with other regions to provide a better specification of their problems and to prioritise their advisory and extension needs.

The system may also be integrated as a part of research activities to help in the understanding of biological and management processes and to identify factors influencing their responses. It may also help to find specific areas of research where the knowledge and information available is not sufficient to allow a formal or informal representation in the system. This would prioritise and increase the cost-effectiveness of research programmes.

A third role would be in teaching activities. Systems-oriented education is becoming increasingly important because it has been recognised that the managerial capacity of farm households is complex and does not respond only to a particular sub-component of the farming system. Therefore, students related to the agricultural or veterinary disciplines need to understand the different interactions of the system and the objectives of the farm household if at some point in their careers they are going to be involved with the farming community. A decision-support system based on simulation and optimisation techniques is an ideal complement to field practice to provide a 'test-bed' for students to assist understanding of a particular system and to expone their ideas.

Future areas of research

In the future, three areas of expertise which should be included to provide a more holistic view of the dairy farm could be epidemiology, and environmental and social science.

Although the system has been mostly directed towards grazing and nutritional management, further areas could be explored by utilising the stochastic herd model to test the effect of different replacement decisions, reproductive policies (Jalvingh et al. 1993) or youngstock rearing practices and their influence on the herd dynamics and profitability of the farming enterprise. Epidemiological models could also serve as the basis for the quantification of the impact of particular diseases (i.e. mastitis, reproductive diseases) on herd output and economic performance.

The environmental effects of livestock farming systems can be judged on the basis of the amount of pollution they cause or in changes in land use (i.e. deforestation in tropical countries). A systematic analysis of the environmental consequences of a specific management policy should be included as another objective, especially if these have long term consequences or if they put in jeopardy the existence of a particular resource or part of the system.

Also of primary importance are more studies of the farmers' behaviour in order to understand the nature and justification of the decision rules they have. This should always be pursued in order to target and provide decision-support in areas of real importance to the farming community.

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