

# SEPATOU: a Decision Support System for the Management of Rotational Grazing in a Dairy Production

M.-J. Cros, F. Garcia, R. Martin-Clouaire  
Unité de Biométrie et Intelligence Artificielle  
INRA, BP 27, Auzeville,  
31326 Castanet Tolosan cx  
FRANCE  
{cros, fgarcia, rmc}@toulouse.inra.fr

**Abstract:** The paper presents the simulator SEPATOU that can reproduce the day-to-day dynamics of two interactive systems: the decision system representing the dairy farmer's management behavior and the biophysical system that encompasses the herbage production, consumption and transformation into milk. The activities to be managed concern the type and amount of conserved feed, where to fertilize and how much, the choice of fields to cut and, most importantly, what field to graze next. Typically, SEPATOU is designed to be used by extension services and farming system scientists. It provides a flexible environment through which learning about a satisfying management strategy of a given dairy production system can take place by iterating simulation and evaluation of tentative ones.

## 1) Introduction

A growing movement has emerged during the past two decades to promote sustainable and more socially acceptable agriculture. Pasture-based dairy systems certainly share this concern. However, in order to ensure profitability, such a type of production requires quite good organization, planning and operating capabilities on the side of the farmer. An important research effort has been done to acquire scientific knowledge on how the sward reacts to environmental conditions and practices and on how the animals respond to feeding diets. The challenge is now to integrate this body of information into a form that enables to address the full complexity of the dairy enterprise management task. Modern computer technology and, in particular, decision support systems, offer great potentialities for such an investigation.

At the core of the decision support approach that we are developing lies an explicit and rigorous modeling of the management strategy that underlies a dairy farmer's decision making behavior (real or hypothetical). The aim of the SEPATOU system we have developed is then to compare tentative strategies (so as to select the best one), by simulating the application of any of them throughout the production season and under different hypothetical weather conditions. SEPATOU is a discrete event simulator that reproduces the day-to-day dynamics of the strategy dependent decision making of the farmer and the response of the controlled biophysical system for which models of grass growth, animal consumption and milk production are used. The relative worth of a strategy can be assessed by analyzing the effects on the biophysical system and their variability across the representative range of possible conditions that is considered.

The paper introduces the decision problem and the simulation approach that is used as the basis of decision support. The main components of the production system that need to be modeled are sketched. The general architecture and functioning of the SEPATOU simulator is explained and illustrations of the user interface, which plays a crucial role in any decision support system, are provided. Finally, the important issue of validation of such a decision support system is discussed.

## **2) The decision problem**

Many dairy production systems rely strongly on a grassland feeding resource that is exploited through rotational grazing (moving animals from pasture to pasture) and completed by conserved feed (maize silage, concentrate and hay) especially in winter times when the herbage mass is still insufficient. The late winter to early summer period is a particularly crucial phase in which the diet must switch progressively from a fully maize-concentrate feeding to a predominantly or fully herbage-based feeding. The general objective of the farmer is to keep the milk production at its optimal level over the whole production period, despite the uncontrollable fluctuations of some important factors such as weather. In that order, it is necessary for the farmer to apply a coherent strategy, defined as a set of planned tasks that incorporates provision to adapt to stochastic fluctuations of the weather (Sebillote and Soler, 1988). Such a strategy aims primarily at ensuring appropriate grassland resource and coordinating its use by intensive rotational grazing on a set of fields, this primary feed being possibly completed by conserved feed under some conditions and at particular times. Hence, a fully specified strategy enables to generate what actions to perform in any situation along the production period.

The main difficulty in this management problem stems from the fact that the herbage production process interacts strongly with its concomitant use through grazing. For rotational grazing to be successful, the herbage supply must constantly match the demand as closely as possible. This requires anticipation (i.e. planning) as well as timely adjustments of the intended decision trajectory in order to cope with uncontrollable factors. The underlying control problem is a complex one because it involves a multivariable optimization. An appropriate quantity/quality tradeoff of the available herbage should be maintained along the considered period given that the maize distribution profile can only be non-increasing and the grass growth rate is partially controllable by the fertilization but also partially uncontrollable due to the climatic influence. Too much herbage can be as big a problem as too little. It has been shown that in order to have herbage of good quality it is necessary that the grazing intensity be high and regular on rotational periodicity. For rotational grazing to be successful, the turnout time and the timing of rotations must be carefully chosen in function of the pasture state. The rotational grazing management problem may change from one year to the other because the stock of maize available may be significantly different and the size and characteristics of the herd may vary too.

## **3) Simulation of the production system dynamics: principle and modeling needs**

The main objective of the SEPATOU software is to provide a flexible environment through which learning about a satisfying management strategy of a given dairy production system can take place. The intended users of SEPATOU are farming system researchers and extension services agents that aim at advising on the decision-making behaviors appropriate to a particular goal and a particular production context defined by specific characteristics and constraints. SEPATOU provides a representation framework in which the users can make explicit the management strategy to be applied along the production period considered in the analysis. SEPATOU is equipped with a so-called biophysical model (Cros *et al*, 1999) made of two components corresponding to the herbage production on each pasture and the animal component that contains the cow intake process and the transformation of a feeding diet into milk. At the core of SEPATOU lies a discrete event simulation mechanism that reproduces the day-to-day dynamics of two interactive processes: first, the decision making process that itself results from the application of the management strategy under the current conditions

(biophysical and exogenous) and, second, the biophysical system that responds to both the actions ensuing from the decision process and the external factors such as the weather or particular events. By simulating the application of a strategy on a range of hypothetical factors it is possible to assess its robustness (its ability to give acceptable results in almost all the situations that might be encountered). Actually, only the most feasible events are dealt with since it is impossible to consider all contingencies that might have an impact on the production system (e.g. meteoric events). The worth of a strategy can be evaluated with respect to a particular risk attitude and with respect to the criteria that are chosen by the user as the expression of the subjective global objective of the farmer (see Figure 1).

The creation of an integrated farm control DSS for investigating the planning and implementation of technical activities is quite original although other similar attempts start to emerge. Beside its scope, the main novelty of the SEPATOU project lies in the elaboration of a representation framework in which management strategies can be expressed rigorously and intelligibly. The main strategic commitments embedded in a strategy concern: the set of fields allocated to grazing, the set of fields set aside to cope with weather deviation and grazed in case of necessity, the profiles of conserved feed distribution over the whole period, the fertilization policy, the cutting policy and the field rotation policy. Altogether these choices specify in a coherent way what to do every day depending on the current state of the production system and on various contingencies. The period considered in the management task covers the interval starting at the beginning of February and finishing at the end of the summer. The starting of this time window corresponds to the change of the sward from the vegetative to reproductive stage, time at which the first fertilization operation may have to be performed.

The corner stone of the SEPATOU strategy representation is constituted by a set of planning rules for the different tasks to manage including, in particular, maize-concentrate feeding, grazing field selection and fertilization. A planning rule specifies the event that causes its firing and the set of decisions attached to the temporal window in which they apply. Some planning rules are also used to specify required adaptation of the decisions conditionally to the occurrence of some events (e.g. climatic deviations). The decisions are general prescriptions (e.g. the set of grazable fields, the desirable diet of the herd in terms of maize, concentrate and herbage portions). From these prescriptions specific context dependent actions can be generated each time it is necessary (every day typically) by applying so-called action rules. Besides planning and acting rules, a management strategy also contains two other components: first, the indicators that are events to be monitored and which are driving plan execution and adaptation and, second, the interpretation functions that map observed states (from the biophysical system or external environment) into concise pieces of information that are used in the decision making process and/or its analysis.

A formal language (called LnU) has been defined to represent, using a fairly intelligible syntax, the planning and acting rules, the indicators and the interpretation functions of a strategy. Figure 2 gives an example of planning rule for the grazing task. It specifies the set of fields to graze and the grazing mode (day and night or day only) in two successive periods (from turnout till the end of the first rotation and from this later date till July 1<sup>st</sup>). See Cros *et al.* (1998) for more on the strategy representation and the simulation-based DSS approach.

#### **4) The SEPATOU software**

The first step in using the simulator is to initialize the production system by describing the various components of the biophysical system (the fields, the herd and the stocks of maize

silage and hay) and the strategy (planning and acting rules, indicators and interpretation functions). The user must also provide a set of climatic years taken from a database or constructed by using a weather generator that is incorporated in the simulator (Racsko *et al.*, 1991). Using a set of climatic years is necessary in order to be able to realize significant statistics on the results of simulations. At last, the user has to specify the desired outputs of simulations. Possible outputs include decision variable traces, chronicles of actions, time series of state variables, temporal occurrence of events, values of interpretation functions over time and statistics over the simulated years. A user friendly editor has been developed for easing the entering and modification of all these pieces of information (see Figure 2 and 3). Any particular production configuration of the biophysical system or management strategy can be recorded and reloaded at will.

The second step encompasses a pre-processing phase and the running of the simulations. The pre-processing consists in parsing and then translating the strategy from the language specifically developed for strategy representation (LnU) into the C++ programming language in which the simulator is implemented. The translated strategy must then be compiled and linked with the code of the simulation mechanism. At this stage the simulations can be run. The discrete event simulator is designed to work as follows. Every day it is checked whether a noticeable event has occurred and, if so the plans attached to the activities are eventually created or adapted, using planning rules. By using actions rules the general instructions specified in the plans are then transformed into executable actions that depend on the current situation of the biophysical system (more precisely on the decision maker perception of the current situation), the external environment and the current date. The changes that the actions cause on the biophysical system are then computed, resulting in a milk production realized during this day and an updating of the biophysical state that correspond at this point to the situation at the beginning of the next day. The simulator considers then the next day and performs similar processing. The iterations are pursued until the end of the simulated period. To give an idea of execution time, the simulation of one strategy application under 500 climatic years takes between one and five minutes on a 300 MHz Pentium II processor depending on the amount of outputs that user has requested (and that must be written in files).

In the third step, the user can visualize the outputs of simulations. A set of display capabilities, are provided for helping analyze the results. The time series of any user-selected variable along a set of simulated years can be visualized in tabular form or graphic form (in case of numerical data). Other types of display are also possible as shown, for example, in Figure 4 and 5. Figure 4 shows the diet composition along one particular year (in kg of dry matter of maize, concentrates, hay and grass) both day-by-day and globally over the simulated period. Figure 5 shows a plot of the chronicle of the executed actions concerning rotations, silage cutting, hay cutting and fertilization on each pasture. To help between-years variation analysis some basic statistical tools are also available. By using these analysis tools the user can evaluate the strategy, pinpoint the causes of undesirable behaviors and from this build a new strategy by attempting to correct the previously tested one. The user can then start a simulation of this new strategy. A set of information recording possibilities is offered to store cases (farm configurations and strategies) and simulation results for bookkeeping purpose.

SEPATOU uses state-of-the-art point and click interface written with Tcl/Tk. The Tcl scripting language and Tk toolkit, used with the Tix and BLT extensions, provide a powerful (now widely used) programming environment for building graphical user interface. The translator is programmed with the tools *flex* (fast lexical analyzer generator) and *bison* (parser generator). The core of the simulator (including the biophysical model) has been written with gnu C++.

Presently SEPATOU runs on a Linux platform. Since all the development tools used exist under different platforms (especially Windows), the portability of the software on different platforms should not be a major problem. Currently, SEPATOU is available in French only.

## **5) On the system validation**

SEPATOU is currently undergoing a validation and evaluation process that is briefly described in this section. Although very important to a DSS project success very few model-based systems have been examined with respect to this aspect and no formal methodology is available so far (Borenstein, 1998). We intend to pursue the following three steps:

- i) checking that the biophysical model and decision-making mechanism are correctly implemented;
- ii) qualitative validation of the dynamic behavior of the dairy production system model by assessing to what extent the results of simulations are coherent with the expectation of experts;
- iii) assessment of the overall value of SEPATOU as a decision making aid.

The checkings of the first step have to be performed many times during the implementation (normally every time a change is made). This step should, in principle, be conceived as a software engineering validation process. In practice, this is hardly possible because the specifications evolve as a result of the second step realization that must be interwoven with the first one. This situation is quite common in research model development. The first step helped improve the interface of the software by identifying needs of display tools.

For addressing the second step, we have defined a set of contrasted case studies, that is, a set of pairs, each composed of a dairy system configuration and a management strategy. We then intend to confront the results of simulation of each case with the judgment of farming systems scientists and extension service specialists that are sufficiently familiar with grazing systems to identify any wrong behavior of the simulated production system and pinpoint the causes. In addition, we plan to examine the sensitivity of the simulated system behavior to small changes in the strategies and configurations. The idea behind it is that generally small changes should not result in a qualitatively different behavior. It is likely that this second step will bring improvement of the biophysical model, and also improvement of the strategies considered for testing. It will not be possible to precisely assess the reliability of the numerical predictions since we do not have quantitative data to compare with. The validation process should at least provide insight on the capability of the simulator to rank correctly a set of candidate strategies.

In the last step we would like to get an appreciation from the users about the ease of use of the software, the appropriateness of the strategy representation language, the acceptability of the simplification hypotheses and, above all, whether the use of SEPATOU brings any significant decision making support. Some of the questions that we would like to address include :

- to what extent can the software be thought provocative on the management issues ?
- are better strategies really and often obtained by the interactive use of the system ?
- are there other potential users that could benefit from the software (e.g. students) ?

## **6) Conclusion**

So far the complexity of dairy production systems has precluded the use of optimization techniques for decision making. The simulation approach adopted for the SEPATOU system forces to fully specify candidate management strategies and enables their evaluation through

the use of the simulator. Simulation enables to perform virtual experimentation under various and repeatable conditions which would of course be impossible in real world experiments. Each strategy (hopefully) conveys a coherent anticipatory and adaptive decision trajectory that drives the enterprise production toward an intended objective and reduces as much as possible the impact of the fluctuations of the uncontrollable factors. The SEPATOU software used in a trial and error approach constitutes a decision support system designed for elaboration of a satisfactory strategy. The software should also enable to verify the soundness of classical advice such as “too much herbage does not allow a good use of herbage” or “the first cycle of pasture has great consequences on the management of pasture”, or also “start pasture as soon as possible”, depending on the configuration that is considered.

Presently SEPATOU is undergoing a thorough validation process addressing the issues raised in the previous section. Whatever the conclusions might be the research project from which the system evolved has already generated fruitful questioning among the potential users by providing structure in the decision making process and by focussing modeling efforts on the most relevant aspects. One of the most rewarding aspects of the project is the chance for scientists and extension service to interact.

After the validation and evaluation phase, the possible extensions of the project could consist in removing some of restrictive hypotheses. Hence it could be pertinent to take into account :

- the heterogeneity of herd by distinguishing different populations depending on age and calving date,
- that management decisions are constrained by resource availability within the farm enterprise and conflict with other activities,
- animal health consideration (e.g. mastitis) in management decisions.

Similar attempt at modeling and simulating management strategies have been reported for other kinds of agricultural production (see for examples Olesen *et al.*, 1997; Rellier *et al.*, 1998). Developing a generic platform for such decision making investigation seems worth considering. Another line of further research along the use of production system simulation would be to incorporate machine learning techniques to provide some decision optimization capabilities in the spirit of Attonaty *et al.* (1997).

## References

Attonaty J.-M., Chatelin M.-H., Garcia F. (1997). Using extended machine learning and simulation technics to design crop management strategies. First European Conf. For Information Technology in Agriculture. June 15-18, Copenhagen, DK.

Borenstein D. (1998) Towards a practical method to validate decision support systems. *Decision Support Systems*, 23, 227-239.

Cros M.-J., Duru M., Garcia F., Martin-Clouaire R. (1998). Uncovering and evaluating management strategies : a grazing system case study. On EFITA web site: <http://www.efita.org/> in EFITA papers section.

Cros M.-J., Duru M., Garcia F., Martin-Clouaire R. (1999). Gestion du pâturage tournant : modèle biotechnique pour l'aide à la définition de stratégies. Internal report of Unité de Biométrie et Intelligence Artificielle, INRA, Auzeville. Submitted.

Olesen J.E., Pedersen L., Christensen S., Secher B.J.M., Petersen J. (1997). An integrated decision support system for management of winter wheat. First European Conf. For Information Technology in Agriculture. June 15-18, Copenhagen, DK.

Racsko P., Szeidl L., Semenov M. (1991). A serial approach to local stochastic weather models. *Ecological Modelling*, 57, 27-41.

Rellier J.-P., Martin-Clouaire R., Navarrete M., Jeannequin B., Gary C., Montbroussous B, Tchamitchian M., Baille A. (1998). Modeling and simulating decision making for greenhouse tomato production: the CONserto project. *Acta Horticulturae*, 456, 485-492.

Sebillote M., Soler L.-G. (1988). Le concept de modèle général et la compréhension du comportement de l'agriculteur. *C. R. Académie d'Agriculture Française*, 74, 59-70.

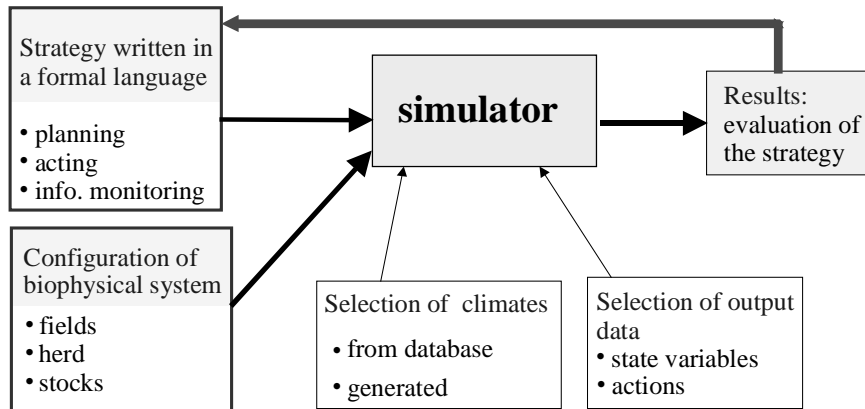


Figure 1. Simulation as a DSS approach for learning strategies

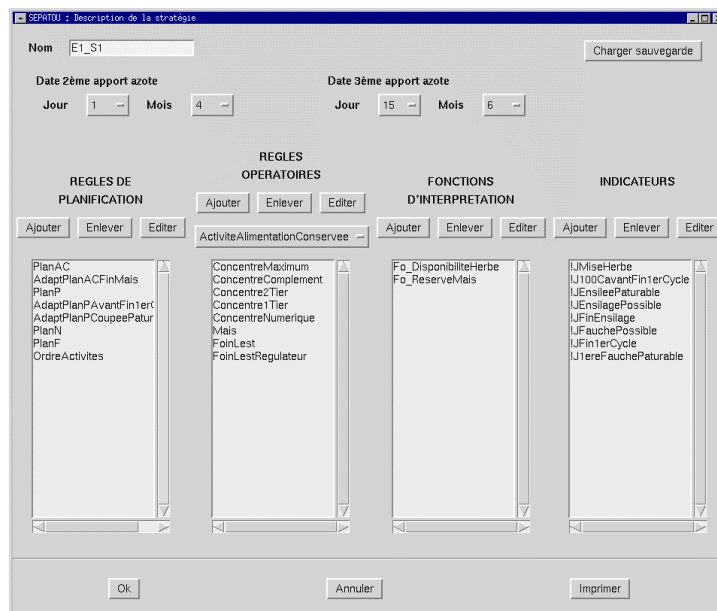


Figure 2. Main window of the strategy editor

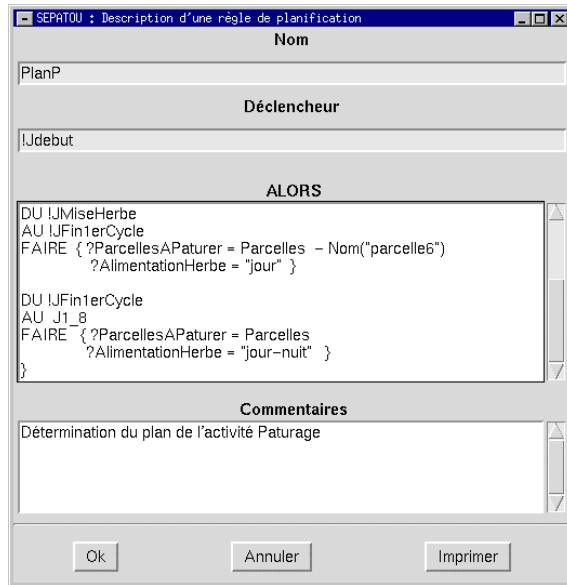


Figure 3. Window of the planning rule editor

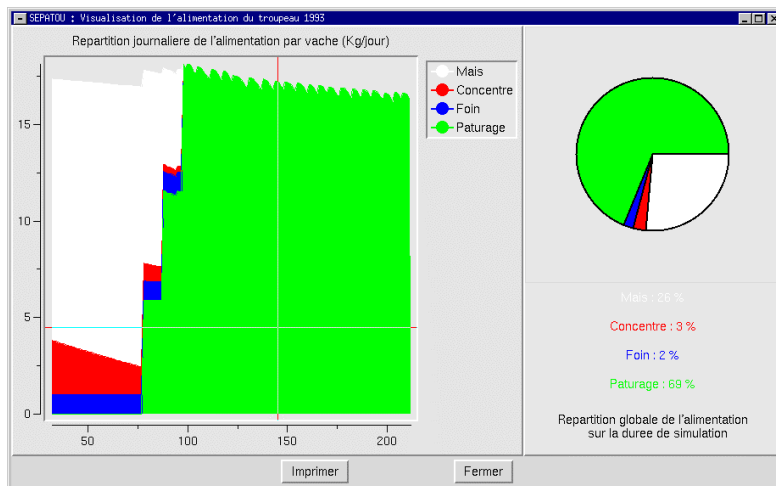


Figure 4. Output of the diet composition over a 220 day period



Figure 5. A window for inspecting the chronicle of actions