CHARACTERIZING AND SIMULATING A ROTATIONAL GRAZING STRATEGY

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Abstract: The management of dairy production systems based on rotational grazing and maize-concentrate feeding requires a complex lookahead decision making procedure to elaborate a seasonal strategy that is sufficiently robust to uncertainty. In this paper, the problem is characterized rather precisely as finding for the late winter to early summer period an appropriate combination of commitments concerning the fields allocated to grazing, those kept just in case of need, the time profile of maize-concentrate distribution, the nitrogen fertilization policy and the field rotation policy. A simulation tool designed to evaluate tentative man-made strategies under given climate scenarios is described.

Keywords: strategic management, robustness to uncertainty, simulation, dairy production, rotational grazing

1 Introduction: decision support for rotational grazing

In agriculture as a production industry it is striking to see how profitability varies from one farm to the other just because of the differences in management skills of the farmers. The substantial technical evolution of agriculture as well the ongoing changes of the socio-economic context have even more sharpened this peculiarity. Consequently higher importance has been given to the abili-ty of making as wise as possible decisions both in terms of strategic choices and day-to-day management practices. Usual management aspects concerning for instance accounting, and marketing have been addressed for long time by economists and software systems developed for such purpose are now commercially available. Much less has been done on providing decision support in optimi-zing or improving the technical efficiency of agricultural production system although this could be of great benefit for particular ones such as a dairy cow farm as considered in this paper.

The farmers' difficulties in technical management are particularly acute in dairy production systems that rely as much as possible on grassland feeding resource which is used through rotational grazing and completed with maize and concentrate feeding in winter time when the herbage mass is still insufficient for grazing. In the late winter to early summer period the system must switch progressively from a fully maize-concentrate feeding to a predominantly or fully herbage-based feeding. Such a delicate transition requires a coherent and robust conditional plan (also called a strategy) in order to keep the milk production at its optimal level despite the uncontrollability of some important factors such as weather. Basically the decision problem consists in finding for the above five-month period an appropriate combination of the following main commitments: the set of fields definitely allocated to grazing, the set of fields set aside to cope with weather deviation and grazed only if necessary, the profile of maize-concentrate distribution over the whole period, the fertilization policy and the field rotation policy. A combination is appropriate if it ensures an optimal production of milk over the whole period for a sufficiently representative range of climatic conditions. This problem is a complex one because it involves a multivariable optimization: one has to decide on the above issues so that a good quantity/quality tradeoff of the available herbage is 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. Some agronomists' results, mainly coming from studies on continuous grazing, have shown that in order to have herbage of good quality it is necessary that the grazing intensity be high and regular on rotational periodicity. The problem of strategic management of a herd feeding based predominantly on rotational grazing (henceforth we shall talk simply of rotational grazing management) has to be solved once every year because the stock of maize at the start of the period varies from one year to the other and the size and characteristics of the herd may change too. From an economical point of view, it is important to solve the problem properly because the herbage resource is much cheaper than the maize-concentrate one.

The management of rotational grazing is a difficult problem for farmers because they lack sufficient capabilities of predicting the dynamics of growth and quality of grass and because the problem intrinsically involves a complex planning dimension in which several fields have to be dealt with concurrently given that the elaboration of the resource grass and the process of its use strongly interfere. For all these reasons we have setup a project for constructing a decision support tool that could provide help in constructing a rotational grazing strategy for the period considered. So far the project has concentrated on a preliminary step that consisted in clarifying the understanding of what a strategy might be and how it could be characterized and represented concretely. Simultaneously we have started to develop a software enabling us to simulate the application of such a strategy on a particular configuration of the production system under an assumed climatic scenario.

With respect to most of the simulation tools developed in the agricultural domain the one developed in this project is rather novel[1] on its ability to reproduce the continuous interaction between a decision system and a biophysical system. The first infers what should be done on the basis of the chosen strategy, the perceivable state of the biophysical system and observed data about the external environment (the climate). The biophysical systems reproduce the dynamics of the herbage production, animal intake and milk production under the influence of the external environment and the farmer's actions. The usually reported simulation systems (e.g. Topp & Doyle, 1996) only have a biophysical component or have a rather crude decision system that simply applies a pre-specified sequence of actions rather than a strategy (i.e. a conditional plan).

2 A model of the biophysical system

The dairy production system can be seen as a biophysical system guided by a decision system (discussed in the next section). The biophysical system, which is sketched here (see Duru *et al.* 1996 for a complete description), represents through empirical laws structured on a daily basis the dynamics of several interactive subsystems dealing with herbage production, cow intake and milk production. The driving variables include, for climate, the average daily temperature and average incident solar radiation and, for management interventions, the nitrogen level, grazing operation, cutting operation and amount of maize-concentrate[2] feeding.

The pasture is divided into a certain number of fields having different sizes but producing the same kind of forage crop. The herbage production submodel comprises four state variables: leaf area index (LAI), nitrogen index (NI), dry matter (DM in g/m^2), and average digestibility (also refereed to as quality) of the sward (AD in %). The dynamics of NI is represented by piecewise linear function linking the levels corresponding to fertilization operations. For a given field at a given date, the LAI, DM and AD may vary slightly differently depending on whether the last completed operation was a cutting or a grazing or whether the current day is within a grazing operation. In the first case, the model reproduces the growth and senescence processes. The LAI is initially 0 and depends on temperature and NI, growth (newly created DM) depends on LAI and solar energy and senescence applies to a proportion of dry matter that has reached a certain age expressed in degree-days. The AD variable decreases with age (again expressed in degree-days) rather slowly before 200 degree-days and faster afterwards; between 200 and 600 degree-days a loss of 12% of average digestibility is

[1] Although not widely published there has however been other simulors of this kind developed at INRA, including DECIBLE and ANSYL (Gibon *et al.*, 1989).

[2] So far, only maize feeding is modeled but adding concentrate feeding is not conceptually different.

assumed. After a grazing operation the only change to made concern the LAI which must be computed with respect to residual LAI at the end of the grazing operation and the AD which is obtained by combining the average digestibility of the dry matter created since the end of the grazing operation and the diminishing impact of the average digestibi-lity of the dry matter that remained after the grazing of the field. During a grazing operation the computation of the DM must incorporate the amount grazed by the herd. The LAI is assumed to be proportional to the remaining DM and the AD is kept at the value it has when the grazing operation started. The latter assumption is acceptable because a grazing operation lasts three days at most. The average digestibility describes the field as a whole but the average digestibility of the cow intake depends on the depth of the sward that is grazed; the upper part of the sward is more digestible therefore the average digestibility of animal intake decreases every day during a grazing operation on a given field. The model uses a function describing the variation of digestibility along the herbage dry matter scale, thus enabling us to represent its variation along the depth axis. The physical properties and the spatial distribution of forage within the field are assumed to be homogeneous over each field (even during or after a grazing operation).

The intake process is controlled by three factors: the dry matter availability, the physiological limit on intake and the physical ability of the cows to consume feed. The actual intake on a given day is determined by the most limiting of these factors. It is assumed that the cows do not graze very close to the ground and most specifically do not graze below a dry matter of $120g/m^2$. The herd is represented by a set dairy cows that are assumed identical with respect to production characteristics (genetic type, age, weight, start of lactation,...). Since the herd may partially be fed with maize and concentrate the availability of dry matter is the sum of the maize-concentrate complement and herbage dry matter above the $120g/m^2$ threshold. The physiological limit of intake is determined by the daily metabolizable energy requirements required by a cow which includes the part needed for maintenance and the part devoted to milk production. The required energy of maintenance depends only on whether or not the turnout to herbage has already occur-red. The part of energy that corresponds to the maximal potential milk production has its highest value during the first 40 days after calving and then decreases every day at a constant rate. The physical ability of the cow to consume feed is determined by its average digestibility which, for herbage, is computed as the integral of the digestibility variation function between the states describing the dry matter before and after grazing, divided by the difference between these two states. The amount of herbage dry matter intake is the maximum value compatible with the diges-tibility constraint and the energy requirement not fulfilled by the maize-concentrate complement.

The milk production is simply calculated on the basis of energy available for milk production that comes from the overall energy intake minus the amount required for maintenance.

3 Characterizing and simulating a strategy

In many production system (e.g. cash cropping) it is rather easy, even for farmers, to formulate the strategy of technical management that they intend to follow. This is usually not the case for rotational grazing partly because the management problem is much more complex and also because it has not been studied extensively by agronomers.

Basically a management strategy for an agricultural production system is a temporal structure that specifies, according to global objectives and constraints, a coherent sequence of states and actions that ensures the reach of the objective under a reasonable hypothesis concerning the uncontrollable variables (i.e. the climate): this could be called a nominal plan. A strategy must also incorporate the necessary elements to adapt the nominal plan in case a significant deviation with respect to the normally anticipated evolution of the production system has occurred.

On this basis we have crafted a framework for expressing a rotational grazing strategy. Essentially the late-winter to early-summer period has been divided into a sequence of four episodes corresponding to end-of-winter (before turnout to grass), early-spring (before the deadline for the first grazing on a field), full-spring (before the fields cut for silage become usable for grazing) and remaining sub-period. Within each episode we have identified a specific set of activities to consider and the constraints on these activities (e.g. priority among conflicting activities, precedence). An activity expresses under what conditions and how, depending of the current situation, a particular type of action (e.g. maize feeding) should be performed. In order to insure sufficient robustness of a strategy, the decision-making components of each episode includes rules of adaptation of the activities and constraints. These rules are used to monitor the important deviations of the biophysical system (due to the climate) and specify the required modifications on the originally intended course of actions. For instance, the grazing activity in the third episode specifies for any day the set of candidate fields to be considered for grazing for the rest of the episode and the criteria to chose one among those presently qualified for a grazing operation. The set of candidate fields is augmented (resp. reduced) by one field among those set aside as buffer fields whenever a shortage (resp. a excess) of herbage is anticipated. The way of selecting the field to graze on a particular day may be defined by a hierarchy of criteria specifying, for example, that the preference goes to field grazed the previous day, then (if the preceding criterion is not sufficiently discriminatory) to a field not initially belonging to the buffer set and finally to the one ranking first on dry matter quantity.

The daily application of such a strategy amounts to find out what is the current episode, check if some adaptations are necessary, trigger the activities that are applicable and, finally, execute them in the right order with instances corresponding to the current context. For example, at the end of the second episode a cutting activity is planned to make some field grazable again in the next one ; it applies to all fields that have not been grazed at least once (including those set aside as buffer) and that will never be otherwise due to the poor quality of herbage on them.

The process of supporting the strategy elaboration task by using a simulation-based approach that works as follows. A man-made strategy is provided and then simulations of its application in various climatic conditions are run. If the outputs meet acceptably the objectives with sufficient certainty (i.e. with a certainty above the lower bound specified by the farmer as its risk attitude), then an appropriate (sufficiently robust) strategy has been found. Otherwise a different one should be formulated and the simulation process restarted until a satisfactory solution is reached.

4 Conclusion

The simulator briefly described here is still under development; the software design relies on an object-oriented representation with the C++ programming language. Clearly the most interesting aspect of such a tool is in the coupling of a decision process and a biophysical system, allowing us to perform virtual experimentation of the functioning of the dairy production system without oversimplifying its decision-making component that in reality plays a key role. At the conceptual level some fundamental strutural aspects underlying the concept of strategy have been identified but further work is required in order to define a general language supporting a rigorous and intelligible representation of strategies.

The complexity of the production system precludes yet the possibility of elaborating a strategy by an automatic configuration program, however, we plan to study the possibility of providing more help than what the present simulator can do. An idea would be to perform a generation on the basis of a cruder model, simple enough to lend itself to a kind of reversal process enabling the determination of a strategy on the basis of desired features, possible futures and results of previous runs of the simulator presented in this paper.

5 References

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