The Human Side of Agricultural Production Management – the Missing Focus in Simulation Approaches

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EXTENDED ABSTRACT

Agricultural production decision-making is becoming more complex. This is due, in part, to the increased competition caused by the globalization of agriculture, the need to adopt more sustainable farming practices and the increasing rate and volume of information exchange. Predicting the behavior of production systems is critically important for sustainability issues that concern profitability, environment soundness and consistency with society interests. This raises an important systems research demand for innovation in agricultural production management.

Computer based simulation is one of the most commonly used tools utilized to aid in the design and evaluation of production management policies. Simulation approaches have traditionally focused on the agronomic and technological aspects of the production processes, e.g. crop or animal responses to farming operations. There is a growing recognition by the scientific community that principles from the biological, physical, management and social sciences must be integrated to understand and predict the behavior of agro-ecosystems under the various dimensions that are relevant for design purpose. The prevailing simulation models used by the agronomists and farming systems researchers largely abstract from the spatial, temporal and resource boundedness aspects of agricultural production systems. Consequently they offer limited help in explaining system performances and their sensitivity to external events and management behavior.

How then can we develop a more useful simulation approach to understand and predict the behavior of agricultural production systems? Using biophysical models based on scientific knowledge of soil, crop and animal functioning is definitely necessary but may not be sufficient. The paper argues in favor of a more realistic, explicit, systemic representation of the production management behavior that includes the following features:

- decision-making is driven by a management policy that is specific to the farmer's material conditions and constraints, his understanding or belief about the biophysical functioning of his system and his personal expertise about relevant decision indicators;
- since the technical operations usually interact (utilize the same resource pool and have synergic or conflicting effects), they should not be dealt with separately;
- the decision-making process is both reactive (response to endogenous and exogenous events) and anticipatory (goal-oriented);
- decision-making deals primarily with the issue of dynamic work scheduling and resource allocation;
- the simulated decision process must reflect the way uncertainty and multiple goals are dealt with to select actions in situ.

Basically we advocate for a modeling and simulation approach that recognizes the central role of humans in the functioning of agricultural production systems. Besides the biophysical aspect, the model should pay particular attention to the manager's decision making process and to the aspects of implementation of the actions decided.

After having recalled the rationale behind this study, the paper reviews the notion of agricultural production management and outlines the objective and scope of the advocated approach. The main section presents the salient features that the model should possess. Finally some difficulties that might be encountered with the practical use of such an approach are pointed out.

1. INTRODUCTION

Farming involves the input of resources (seed, fertilizer, pesticides, time, labor, etc.) to natural systems driven toward the harvesting of outputs for sale (biomass, grains, livestock, etc.). The complex interaction between natural and man-controlled processes is at the very heart of agricultural production. As a production manager the farmer makes decision about the timing, combination and implementation of technical operations (tilling, planting, fertilizing, irrigating, spraying, harvesting, feeding animals, etc.) in hope of achieving his objectives. The farming business is risky because the outputs of operations are subject to hardly predictable events of nature (weather, disease, etc.) and because it depends on changing economical factors (market demand, fluctuation of prices, etc.).

Internationalization of markets, shifts in consumer demands and requirements, rapid evolution of technologies are among the recently emerging factors that make competitiveness much harder to achieve and maintain in the agricultural production industry. The performances of farms operating in similar physical and economic environments are often very different (Poppe and van Meijl, 2004). Research shows that the difference is due to the farm manager's decision-making aptitude and ability to properly weigh up a wide range of factors. Good management depends essentially on the manager's technical, conceptual and diagnostic skills as well as his ability to properly interact with external actors such as advisors, cooperative boards, industrial suppliers or local authorities.

In addition, the sustainability of farming systems and practices has come under scrutiny internationally, and is increasingly an issue in policy development and market positioning. In response to environmental concerns, farmers must reassess previously acceptable farming practices and are looking for economically viable alternatives. For instance, agrichemical use and animal welfare practices are frequently pinpointed. Soil erosion, water pollution and invasion of pests and weeds are also demanding changes to current agricultural management practices. There is no simple answer to this.

The competitiveness pressure, the concern for environmentally acceptable practices, and farm workers' aspiration for better working conditions make farm production management a more complex task and, consequently, renew the demand in farm management research. Clearly the important questions of production management dealing with risk control, changes (new practices, products and techniques), and more stringent resource allocation problems require innovative approaches that recognize and focus on the holistic, dynamic and human dimension of farm systems. This paper argues in favor of a simulation-based approach that focuses on the dynamic functioning of an agricultural production system, tending especially accounting for the farmer's management behavior and its interaction with the biophysical components of the system and the external environment. In this paper we shall focus on aspects pertaining to the technical management of the production process, thus leaving aside other aspects such as budgeting and marketing for instance. At this tactical level, management is seen as a continual decision-making process. Decision making studies in cognitive science and artificial intelligence (Simon, 1996) have significantly influenced the present work through their focus on modeling human decision behavior as a problem solving and information processing process.

The paper is organized as follows. The next section reviews the notion of agricultural production management. Section 3 brings in the objective and scope of the advocated simulation approach. Section 4 presents the salient features that the model needs. Section 5 points out some current limits of the approach.

2. AGRICULTURAL PRODUCTION MANAGEMENT

As defined by Dillon (1980), farm management is the process by which resources and situations are manipulated over time by the manager of the farm system in trying, with less than full information, to achieve his or her goals. Little attention has been paid to the managerial practices of farmers. See (Aubry *et al.*, 1998; Papy, 2000) for analyses reflecting essentially the thought of the French community on farming systems. What kinds of activities does a manager perform and what are the distinguishing characteristics of this managerial work? The diverse functions involved in dealing with the technical aspect of production include:

- organizing: configuring the production system resources both material (land, machine) and human (hiring, role assignment);
- planning: setting goals and formulating accordingly an outline of activities to be done along the production period and methods for their execution with respect to the various production constraints;
- information and knowledge handling: decision making is based on the ability to handle information and knowledge (what has to be

acquired and stored, when to acquire it or recall it, how to use it in decision making: either directly or through decision-relevant synthetic indicators). The manager must therefore have event monitoring activities, looking at the environment for opportunities, disturbances or potential threats and initiating/ devising the proper reaction, e.g. changing intended actions (if wind is strong then postpone spraying). In order to make informed decisions he also needs to forecast the likely evolution of the system in response to a course of actions. This requires to master the biophysical causality and the specifics of his production system.

- determining actions and commanding:
  - identifying possible courses of action in face of current or anticipated situation (essentially in the biophysical domain) and constraints (availability and compatibility of resources, compatibility of activities);
  - selecting actions in function of different criteria such as risk and cost/benefit considerations, continuity and harmonization of activities, urgency (having some activities finished or state achieved before a deadline, having particular resources released by a date);
  - issuing instructions to cause operation implementation to happen in a specific context-dependent manner.

In his management task the farmer has to deal with several interactive dynamics concerning the biophysical components, the environment of the system of interest (external events) and the unfolding of the technical actions resulting from the decision he has made. The farmer has to combine planned and reactive behaviors in order to organize the work in function of known and exploitable regularities and adapt to contingencies as they occur. Therefore the tight coupling between sensing and decision making in a timely manner is of primary importance. Managing an agricultural production process is a dynamic process in which plan revision and execution must be interleaved because the external environment changes dynamically beyond the control of the farmers and because relevant aspects are revealed incrementally. Moreover the biological and time dependent nature of agricultural production, which is partly dictated by uncontrollable conditions (e.g. precipitation, solar radiation, diseases, etc.) implies a management attitude characterized by personal preferences and rather subjective judgment of the farmer. Because the farmer can never be sure of the outcomes of his today's decisions the best he can do is to make those decisions which, he thinks, will best achieve his goals in function of his assessment of the current situation, his own prediction capabilities and his preferences.

3. A SIMULATION APPROCH

As pointed out by Malcolm (cited by Ronan, 2002):

> "The major reason for the limited relevance of a good deal of academic work in farm management to (actual) farm management is probably to be found in the methodology. The basic production model leaves out most of the really important things for farm management, viz., the technology, the human element, the risk, the dynamics and time".

This diagnosis summarizes very well our main motivation in adopting a dynamic decision-centered simulation approach to study managerial performance in farm production. The simulation model under consideration should reproduce the functioning of a production system constituted by a set of enterprises that share some resources; the whole farm system is therefore the usual target of such an investigation. The model includes the human actors, in particular the farm manager, and the decision-making and action execution processes. The overall purpose of studying production management activities from the standpoint of their profitability together with environmental and social soundness justifies a farm level modeling. Indeed, the questions of determining actions, allocating resources and implementing them would lose relevance at a smaller scale. The natural, operational and economical phenomena of interest originate or take place at this level.

Simulation to explore management possibilities in agricultural enterprises has gained popularity among professionals and researchers in the last two decades (McCown et al., 2002). The developed tools have traditionally focused on the agronomic and technological aspects of the production processes, e.g. crop or animal responses to farming operations. The underlying simulation models largely abstract from the spatial, temporal and resource restriction aspects of agricultural production management. There is a growing recognition by the scientific community that biological and physical knowledge should be integrated with management and social sciences to understand and predict the behavior of agro-ecosystems under the various dimensions of interest. The descriptive approach advocated here stresses on the realistic modeling of the operational context faced by the manager in his production system. The model should make explicit what is planned, how to adapt to what might happen and, more generally, any information and knowledge used in the decision process (its inputs) and for analysis purpose (economical and environmental outputs in particular).

Naturalistic decision making (Zsambok and Klein, 1997) is a school of thought that deals with this kind of decision problems. It aims at describing the way experienced people actually make decisions in operational settings that evolve over time. It offers an insightful perspective to understand this process in situation where information may be ambiguous and uncertain, and where the goals change over time as in agriculture.

Most of the theories on decision making in an organization do not go beyond the act of choice among given alternatives, making the decision an end in itself rather than a means to accomplish objectives within a dynamic partly controllable process. The process of generating the alternatives should also be accounted for by the model. Moreover, the real value of a decision becomes apparent only after implementation, which must therefore also be simulated. Implementation should not be neglected and is far from straightforward because the effects depend on the actual situation (biophysical conditions, availability of resources).

A model of production management behavior should enable to study the impact of changes on all parts of the production process. For example, the incorporation of new technology often implies a reorganization of the production process. When some activities are inserted, canceled, modified or coordinated differently with others, the model must be able to represent how this will affect the resource use, economic performance and other consequences of interest in time and space.

The main purpose of such an investigation is to gain a better understanding of the interactions and interrelations that occur throughout the production period among the human actors (decision makers and operating agents), the biophysical entities (e.g. fields, crops, livestock) and the events in the environment (e.g. climatic circumstances). Simulation provides the framework to bring together the many relationships of a production system and the timing of events. It enables to conduct various kinds of investigation (economical, environmental, technical feasibility) and facilitates the elaboration of plausible conjecture and expectations about the behavior of hypothetical configuration (both material and managerial) of farm systems. Simulation tells how the system behaves in response to the application of tactical decisions. By coalescence of multiyear analyses this means can be used to evaluate the impact of strategic (periodic) decisions such as enterprise type, land and machinery acquisition, labor change, intensification or extensification. In such exploratory approaches, interpretations of the behavior of a system inform potential revision and redesign of that system. Commonly accepted practices or the knowledge put into the model may raise questions and call for modification of these practices or generate new understanding of the system functioning.

Dynamic simulation brings greater realism about interdependency of processes and risks over time. It helps making sense of the complex resource allocation questions in production management and ease communication about it. It enables one to avoid the common flaw of looking only to static balances, and average or most likely outcomes. Through virtual experimentation sessions simulation can help in eliciting and transmitting practical and scientific knowledge, offering therefore a tool to support interactive learning of stakeholders (farmers and extension services).

4. MODELING FEATURES NEEDED

4.1. A Systemic Representation

At the fore of the advocated approach is a systemic view of the encompassing object to be simulated and a holistic understanding of the entities, relationships and phenomena that operate at farm level. A system is an organized unitary whole consisting of a set of interrelated components or subsystems, each of which is related directly or indirectly to every other component of the system. System performance must therefore be judged not simply in terms of how each part works separately, but also in terms of how the parts fit together, and of how the system relates to its environment and to other systems in that environment. A farm system involves at least a biophysical system (composed of land, crops, livestock, etc.), a decision system (the manager) and an operating system that implements the decisions using various resources (input, labor, machinery, etc.). Simulation concerns not merely the interactions of biophysical components but also the making of choices by people in the system and the execution of the decided technical operations on the biophysical system.

The systemic approach to model-building emphasizes system structure and promotes explicit descriptions of structural and causal relationships. The resulting model, verifiable to some extent by common sense and technical expertise, represents an operational statement about how the world (system and its environment) works. The modeler can capture the highly complex, non-linear feedback relationships that exist in any control problem and in any biological system. Understanding feedback is critical for explaining and rationally altering the system behavior.

4.2. Management Strategy

A prerequisite for such a modeling undertaking is to have a comprehensive view of the decision process and to identify and define some basic concepts enabling to describe and model this human part of agricultural production systems. The decision making behavior of farmers in production management has been the subject of different kinds of investigation but the mental process that intervene between stimuli and response and by which that behavior is exhibited is still largely unknown. Nevertheless the concept of management strategy is often used as a means to express beforehand what determines the farmer's management behavior. These management strategies do not pretend to reproduce closely what is happening in the manager's head. More modestly they attempt to enable the derivation of what the farmer does depending on the current state of affairs. Informally a management strategy can be seen as a manually elaborated construct that specifies a kind of flexible plan coming with its context-responsive adaptations and the necessary implementation details to constrain in situ the stepwise determination and execution of the actions.

Due to evolving and unpredictable circumstances the plans should be flexible with respect to the temporal organization of the constituting activities. The commitments to particular activities are delayed until run-time conditions are known. In particular, what and when something can be executed is strongly constrained by the availability of resources and state-dependent requirements on the operations suggested by the plan.

4.3. Anticipatory Behavior

Anticipatory behavior (Bergez et al., 2004) refers to decision behavior that is influenced not only by the past and present but also by some dated expectations or predictions about the future, such as events, intended actions, or future states that may result from performing some actions or merely from natural evolution. Failure to anticipate can be extremely harmful in agriculture, which deals with hardly reversible processes.

The pieces of information about the future may be certain in some cases but are uncertain in most common cases of anticipatory decision making, especially in agricultural production management. To anticipate means to get useful information about what lies ahead or to take action responding to something before it happens. It relies on prediction or forecasting means or on a mental representation abstracted from past experience. Building and maintaining a management strategy is a form of anticipatory behavior that sets up intentions structured on the time line and tells how to adjust them in response to specific contingencies. Another form is at work when it comes to decide the next actions to execute.

Action-oriented decision making focuses on evaluating and approving a set of actions (see Section 4.6), the implementation of which may extend over a significant period of time. It combines on a continuous basis perception-response driven behavior and more complex cognitive behaviors including consideration about the future, either relevant events (opportunities, constraints, threats), intended future actions or goals. It is therefore both reactive and anticipatory.

Anticipation in action-oriented decision making is also central in deciding to delay the execution of an action if, after projection, it appears better to do so (i.e. less risky or worthier).

4.4. Goals

The future evolution of the production system is often evaluated with respect to intermediate desirable or undesirable states: things to be striven for or avoided. Behavior is guided by the consequences likely to result from the selection of a given alternative. The choice of the manager relies on a certain mental representation he has about the relationship between goals and actions done in a particular context. Based upon experience, a decision maker believes that an alternative action will result in achieving acceptably well one or several desired objectives (see Section 4.6). Biophysical causality is the primary source of the prediction made by agricultural managers (in some cases of deficient knowledge, predictions might however be closer to wishful thinking). Goals remain implicit when sufficient experience has been accumulated. Appropriate action can then be determined directly on the basis of current state and prediction of relevant phenomena such as weather forecasts.

Consequently, the simulation of a purposive system such as a farm necessitates a representation of manager's prediction capabilities and of goals formation and revision. Goal are multiple, multi-attribute, hierarchically structured, concurrent and of different types. The fact that the goals change is inherent to the pervading uncertainty of the production business. The nature and extent of this modification is specific to the manager's perception of where relevance lies and of his attitude with respect to risk.

4.5. Resources

As pointed out by Dillon (1980), resource management is the essence of farm management. Basically a resource is something required by an activity to be executable. Typically the activity performers, the machinery involved and the various inputs (seeds, fertilizer, water, fuel) are resources. In some cases, the location of an activity may be considered as a resource if, for instance, it prevents other activities from taking place at the same location. Time may also be a resource when the duration of availability of labor conditions the scheduling of an activity. A resource is possibly constrained with respect to the maximum number of operations simultaneously supported and the maximum number of resources of the other types that can be exploited simultaneously with it. A resource can be either consumable (usable only once), reusable after it has been released, or even reproducible (as grass in a dairy enterprise). Its availability may depend on a qualitative state (e.g. ready or not ready) or a numerical capacity (amount of fuel in the tank). The availability of a resource is constrained by *availability constraints*. An availability constraint specifies the conditions enabling its usage and consumption. Such constraints might be temporal constraints (time window of availability), capacity-related constraints (the amount available) or other state-related constraints (phonological stage of a crop).

Investigating resource allocation means looking at resource bottlenecks and inefficient utilization that have a significant impact on the system performance. Simulation must include the process of dynamic allocation that takes place repetitively as part of the action-oriented decision making. At any time, the management strategy can tell what activities are deemed appropriate and the resource allocation must determine among them the combinations that are feasible from the resource availability point of view.

4.6. Trade-off Reasoning

The scarcity of resources and the existence of several possibilities at branching point of the plan make it necessary to make continual choice among the competing alternatives of action. This is where trade-off considerations involving weighing of the alternatives with respect to goals and expectations become active.

Selection of a set of actions among some candidates requires the manager to figure out the implications of performing these actions for the future. The actions have to be examined with respect to the desirability and undesirability of the likely resulting states at some point in time. This involves matching the expected outcomes with the goals. The obtained values of desirability (pros) and/or undesirability (cons) of each action have to be combined taking into account the importance of each source in relation to the others (i.e. the compensatory effect between good and bad evaluations). This evaluation process can also used to assess the pertinence of executing an action immediately or later.

5. CURRENT LIMITS

Using the simulation approach as an analysis and demonstrating tool lies in using representative and/or real whole farm cases. Besides the still pending knowledge representation issues that lies ahead (see conclusion section), modeling these cases may be quite time consuming and difficult because the acquisition process concerns the specifics of the biophysical systems, the cognitive idiosyncrasies of the manager (decision indicators, organizational logic, prediction patterns, goal structure and preferences). It is not easy to elaborate a revealing set of scenarios encapsulating significant combinations of events and external conditions both sequential and simultaneous.

Classically, validation of a model involves experiments comparing model behavior against actual measurements. Obviously the more variables and parameters in the model, the less tractable is the validation process. Validation becomes increasingly difficult for an agricultural production model that is expected to provide realistic estimates of different dynamic aspects varying over a period of several months. The extent of variation of most input variables (weather and management) is large and precludes any systematic exploration. Consequently it is impossible for this kind of simulation model to be validated over its entire domain of application (Sargeant, 1999). Moreover records from the observation of the natural system (the production system and weather) are scarce and incomplete with respect to the set of aspects listed above and the time frame of interest. Although these data might be used to perform standard statistical validations of some parts of the model there is no assurance that the assembled model will necessarily behave acceptably well. Some errors may be introduced through linking model components at a higher level. The various parts of the model may be unequally checked and some interactions may not be predictable. Hence, the standard approach is a subjective one in which knowledgeable people in the domain are provided with simulations of cases familiar to them and asked if the model behavior is consistent and reasonably accurate. The validation consists then in checking that the results of simulation are in agreement with those expected by the knowledgeable people involved in the validation process.

The farm management simulation model outlined in this paper is certainly quite complex. It is still an open question whether this approach could scale up to address problems that take place beyond the farm gate. For instance, adding up such models to study environmental impacts of agricultural practices at watershed level may likely be a too fine-grained approach.

6. CONCLUSIONS

This paper has argued in favor of a simulation model including the human components of a production system. Since opportunities, threats and even resources are not fixed, the management strategy devised to support tactical decisions must be flexible, open-ended and responsive to changing circumstances. A management strategy roughly sets up an envelope of courses of action. To be faithful to the reality of a management problem and bring new investigation capabilities, simulation has to reproduce the process by which a management strategy interpretation yields successive commitments to action in compliance with the management principles it embeds and the actual situation encountered.

Many dynamic simulation models have been developed with the intent to aid farmer in decision making. Most of these models focus on physical and biological processes and consider decision making as a reflex (rule-based) procedure. Moreover they addresses only superficially the goal-oriented and resource management aspects that lies at the core of farm production systems. Going beyond these approaches requires a richer modeling of the production management process. This paper has only sketched some of the basic needs and issues that need to be addressed. So far no full implementation of the presented principles exists (see Martin-Clouaire and Rellier (2003) for a preliminary attempt).

The subfield of artificial intelligence concerned with agent modeling (Wooldbridge, 2002; Morley and Myers, 2004; Smith et al., 2005) provides a set of inspiring and useful formalisms for representing such knowledge structures and afferent processing mechanisms. However difficult knowledge representation issues have not received satisfactory solution at this stage. These include in particular the processing of concurrent goals in an ongoing action deliberation process that takes place in an uncertain environment.

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