Cognitive tools to support learning about farming system management: a case study in grazing systems

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Abstract. The complex challenge of farm management has prompted a search for ways in which scientific knowledge can be acquired and combined with practical know-how and experience to enhance the adaptability, profitability and environmental soundness of agricultural systems. Cognitive tools offer a kind of model-based learning support that facilitates and stimulates critical thinking about the functioning of agricultural production processes and the ways to control them in various and changing situations. The purpose of this paper is to delineate, illustrate and analyse the concept of cognitive tool together with the learning processes and conditions in which such tools are used. We review three such tools built to help understand, improve, adapt or design grazing management practices in pasture-based livestock farms. For each of them we examine the knowledge content of the tool, the way it is represented, the kind of use and the nature of the support it provides to its users.

Additional keywords model; learning; grazing systems; production management; biophysical processes

Introduction

Internationalisation of markets, fluctuation of selling prices, increased energy costs, shifts in consumer demands, climate change, rapid evolution of technologies and greater concerns for environmentally-friendly production are among the rising factors that make the competitiveness of the agricultural production industry much harder to achieve and maintain. Unlike the relatively stable context of the past decades, farmers and their advisors must now strive for a dynamic competitive advantage that requires a good understanding of their production processes so as to choose and control them under varying constraints and toward specific objectives. Consequently, increasing importance has been placed on the ability of making the wisest decisions possible about the configuration of production systems as well as their day-to-day technical management, especially through the determination of potential sources of improvement or adaptation to a changing context. Indeed, management capacity is seen as the fourth production factor in addition to the traditional land, labour and capital factors.

Agronomic research has an active role to assist extension agents, consultants and farmers. A number of decision support systems (DSS) have been developed for this purpose. In the broadest sense, DSSs are any method by which information can be transmitted, shared or structured to help their users to reach a decision (Stone and Hochman 2004). In agriculture, DSSs are typically based on computer models of biophysical systems, derived either from a statistical- and/or process-based analysis of factors, either uncontrollable (e.g. weather) or controllable through management actions, affecting outcomes such as crop yield, resources consumed or economical performance. They are designed to support a specific set of decisions through interactive information analysis, prediction and decision-making procedures. While there is an increasing interest in developing computer-based DSSs, several authors have pointed out that their use by or with farmers remains very low (Matthews 2002; Stone and Hochman 2004; Ascough et al. 2005). According to McCown et al. (2009)
the main reason for this paradox is that DSSs are too normative and usually take little account of farmers’ management peculiarities, consequently having little relevance to real-world situations. The values and preferences of decision makers are hardly considered. The spatio-temporal dimension of the decision problems are overlooked, leaving aside issues that need to be addressed at the farm level and beyond just the present situation. There needs to be a compromise between short- and medium-term concerns, coordination of the various technical activities etc. Moreover, integrating economic, social and environmental criteria is another challenge that adds to the limitations of DSS if they remain prescriptive. Thus, using lessons drawn from agricultural (McCown et al. 2009; Jakku and Thorburn 2010) and non-agricultural domains (March 2006), we believe that in most cases the underlying models are more appropriate for discovery or investigative learning rather than for decision making. Currently there is a great variety of means coming from educational research, called cognitive tools (Reeves 1999) or mind tools (Jonassen 2000) that can provide support for learning with models and sometimes by modelling. In agriculture, as shown in this paper, such tools can be used as intellectual companions helping to make sense of problems, facilitate critical thinking about the behaviour of the biophysical system and ways to control it.

In this paper, we provide a generic characterization of cognitive tools that encompasses a large range of such tools as well as the learning processes and conditions (issues addressed, people involved, background knowledge mobilised) in which their might be used. We visit three such tools built in our research laboratories to help understand, improve, adapt or design grazing management practices in pasture-based livestock farms. For each of them, we examine the knowledge content of the tool, how this knowledge is represented, what is implemented as a computer model, the kinds of use and users, and the nature of the support provided to the beneficiaries that might be farmers, advisers as well as researchers. We show that the purpose of the tool induces very different configurations with respect to these features. The process of construction of these tools is outside the scope of this paper.

The paper is organized as follows. We first present the conceptual framework underlying the notion of cognitive tool. Any such a tool needs to be used within a well-defined and focused problem space; for this reason, we outline in the subsequent section the grazing-systems background knowledge that is expected for working with the three cognitive tools that are presented in the following section. In the last but one section, we draw some lessons by examining the tools with respect to modelling requirements, the type of users and the kind of investigation the tools can support. The last section synthesizes the main aspects drawn from our experience with cognitive tools and attempts to envision their likely evolution in the close future.

**What is a cognitive tool and how does it support learning?**

In the literature (Jonassen 2000) cognitive tools refer to learning with a technological support designed to facilitate and stimulate cognitive processing. Each tool is focused on the system that is the target of the learning project. In this paper the target system is a pasture-based livestock production system. A cognitive tool includes a kind of model of this system, i.e. a more or less abstract representation of the system or part of it. This representation might take different forms depending on the purpose of the tool: it can be a dynamic simulation model, a database or a visual knowledge representation medium (either computer or non-computer based). In the grazing management domain, this knowledge might be based on biophysical principles, technical expertise with farming practices, or local knowledge gained through involvement in real production situations. This knowledge...
constitutes the primary source of information to make predictions and interpret situations. Thanks to feedback from using it the learner can discover inductively new useful relationships between practices and biophysical behaviour.

The ability of a cognitive tool to support learning about a problem is a function of the nature of the problem, the way it is represented in the tool, the way it is presented to the learner, and a host of individual differences affecting the learning process. The type and degree of detail of knowledge contained in a tool is likely to be different from what is put into another tool, depending on whether the problem is prediction, pattern identification or diagnosis for instance. The dynamic aspect of the system may or may not be modelled and the on-farm management policies may be explicitly represented or left out of the tool. The variables and processes taken into account depend on the intended scope and the focus of the learning program. For instance, there is no need to incorporate variables characterizing the labour resource if labour management is not among the issues to be addressed.

Other discriminating features between cognitive tools include:

- the nature and amount of information required in order to use the tool (biophysical system parameters, weather scenarios);
- the number of exploration paths to be looked into (e.g. a simulation model may require numerous runs to figure out the effect of stochastic factors on system behaviour);
- the means of communicating information (maps, static graphs, time series, chronologies of actions, text, databases).

The actors involved in the learning process can be primary learners (i.e. farmers), intermediate agents (advisors, experts or researchers) and necessarily a coordinator. Lessons drawn from many studies suggest that the tools should be used with, rather than by, the learner (McCown et al. 2009). Actually most learners would not be able to use a cognitive tool without some form of guidance. The role of the coordinator is to help the learner to identify what might be important for him or her to learn, and create or maintain a fertile environment for inquiry. This person is a promoter rather than a teacher and may also be a learner to some extent. The actors may have different objectives and attitudes in the learning process. Researchers aim at disseminating scientific knowledge and developing appropriate means to do so. They look for pertinent research questions. Experts put research into practice and perform “informal” research. They draw on comparisons between farms, deliver general principles, taking into account constraints on the practicalities of farming and knowledge of the local context. Farm advisors work closely with farmers. They help in making diagnoses, articulating needs and ideas about possible solutions that are tailored to specific situations of soil, climate, farm resources and socio-economic environment.

The tool fosters interaction between participants. The learners concerned may have diverse dispositions and attitudes with respect to learning. For instance, they might be:

- conceptual, innovative, and interested in theories and deep understanding. These persons learn by thinking causally about the represented system. This is typically the attitude of experts in an exploratory approach;
- concrete, practical and concerned mainly with facts and procedures. These learners often prefer pictorial representation of phenomena and learn by trying things out. Farmers and advisors usually fall into this category.
Besides the knowledge contained in the tool, the use of the tool in a learning programme assumes that the participants in the programme (including the primary learners) share some common background knowledge about the target system and communicate using the same jargon. This background knowledge corresponds to the common level of understanding required in order for the participants to have a common, focused and well-defined problem space in which fruitful verbal exchanges can take place. The background knowledge associated with the cognitive tools considered in this paper is described in the next section.

In practice, the use of a cognitive tool enables one to generate situations (system states, figures etc.) that the learner can compare with his particular assessment based on his mental model. A mental model is a tacit representation (Norman 1983) that conveys action-orientated expertise, preferences, values and beliefs. Its content is personal (Eckert and Bell 2005), much more subjective and experiential than the background knowledge. Forming a mental model is a heuristic means to see the complex world in a concise way. Once available, a mental model governs how one thinks about the system and also how one takes action to influence the system in a desired way.

When there is close fit between the mental model and the background knowledge contained in or associated with the tool, the learning process might reinforce the learner’s beliefs. If not, it is likely to raise questions from the participants and lead to an inquiry into the cause of disagreement. This is where effective learning might take place, resulting potentially in a revision of the mental model of the user that might change something about his pre-existing aspirations and principles of management (Leeuwis 2004). In theory, the use of the tool may also question the background knowledge. From this information gained through exploratory interaction with the tool the learner can acquire a new understanding of the system behaviour, the component interactions and the performance drivers. Developing his discernment in this way is likely to enable him, as a consequence, to pinpoint and explain inconsistencies of the system configuration, and, above all, devise better ways of operating it.

Cognitive tools might support single or double loop learning (Argyris and Schön 1992). In single loop, a choice of management options is made, simulated, and the results are used to generate better options. Such iterative cycles of development, implementation, and analysis of results allow the designer to gather information about how well management behaviour is succeeding. This first loop feedback can also induce change in the values and assumptions that led to the management options in the first place. This constitutes the second loop learning. Helping learners to look at a management problem from different perspectives is, therefore, one of the most important features of double loop cognitive tool. Each participant in a group session might change his current understanding thanks to the feedback from the virtual experiments and also to the different perception the other participants have of the same experiments.

**Background knowledge in grazing systems**

**Background knowledge about management strategies in agricultural production systems**

The background knowledge assumed in the cognitive tools analysed in this paper concerns both the biophysical and decision systems involved in a production system. On the management side, the knowledge relates to the farmer’s role in operation management and to the notion of management strategy. Informally a management strategy is essentially a kind of flexible plan of activity, coming with its context-responsive adaptations. This “manually” elaborated construct includes also implementation details that constrain and tailor the stepwise
determination and execution of the activities as a function of the actual conditions (Martin-Clouaire and Rellier 2009). Due to evolving and unpredictable circumstances (weather, equipment breakdown, diseases but also unexpected social events etc.), the plans need to be flexible with respect to the timing of the activities concerned. The application of a management strategy combines planned and reactive behaviour in order to organize the work according to performance-orientated intentions, personal preferences, production system limitations and potentialities, and adjustment to anticipated contingencies as they occur. The tight coupling between sensing and decision-making in a timely manner is also of primary importance in production system performance and must therefore be part of the management strategy. The above general production management principles actually apply to any type of agricultural system. The next subsection addresses aspects specific to the management of pasture-based production systems.

**Background knowledge about grazing management**

Grazing management is the art of integrating animals and feed with land and other resources (Sheath and Clark 1996). Grazing management strategies are designed to ensure a year-round balance of forage supply and demand, almost always reducing the effect of seasonal and year-to-year weather variability. Basically the essence of grazing management and the long-term success or failure of any grazing management strategy hinges upon the farmer’s ability to control the frequency and severity of defoliation of plants over time and space in such a way as to meet desired goals under any weather conditions. The goals can vary greatly between farmers (Brodt et al. 2006). It is likely that they might want to produce a valuable product for profit and therefore ensure that the needs of the animals are met. This short-term goal often comes with the long-term goal of maintaining the productivity of grazing land for the years ahead. Other objectives might be to improve animal performance, reduce feed costs or labour or reduce environmental impacts. All impinge heavily on the design of an appropriate management strategy. The farm infrastructure is also a key constraint to be taken into account. It concerns, for instance, the geographical characteristics of the land available, the soil productivity, the types of vegetation and resources such as machinery and labour. The commonly shared background knowledge between practitioners and agronomists about grazing management is basically summarized in Fig. 1a. This knowledge only makes sense if it is accompanied with a good understanding of the biophysical processes at work in the production system (see the next subsection).

Managing grazing systems requires anticipation (i.e. planning) about the set of fields definitely allocated to grazing, the set of fields set aside to cope with weather fluctuations and grazed only if necessary, the supplementary feeding (harvested feed and concentrates) profile over time, the fertilisation, cutting and field rotation policies. These planning decisions underlie the day-to-day determination of the technical operations that should be done although these operations have to be compatible with and tailored to the actual situation. Based on the analysis on a large set of case studies relying on on-farm analysis relevant to the problem at hand (Coléno and Duru 2005), three main characteristics of the land use and feeding systems must be taken into account to design a cognitive tool for grazing management as well as for using it:

- the key variables of farm structure that determine feasible feeding systems. For example, the grazeable land area per cow and the yield of silage (or hay) dry matter per cow were recognized as the most important factors for determining periods in which silage is part of the diet;
• the management tasks whose timing is critical and specific to the system (turnout, day and night grazing, end of the first grazing cycle, closing of the silage silo, reopening of the silo in the summer etc.). Prioritization, timing and coordination of these tasks at farm scale must be specified in the farmer’s plan together with last-minute adjustments of this plan when required by the actual situation;
• the management rules for each task specifying what to do on a daily (or shorter) basis, as a function of the current state and available resources, in order to accomplish the planned trajectory. The different grazing tasks can be characterized by a profile of “grazing days in hand”, and a threshold of sward height before and after grazing.

**Background knowledge about key biophysical processes in grazing systems**

On the biophysical side, the background knowledge concerns mainly the behaviour of, and interactions between, the soil, plant and animal processes under given controlled (e.g. grazing intensity) and uncontrolled factors (e.g. weather) with their immediate and deferred effects. Of primary importance are the processes dealing with forage growth and yields, animal performance, environmental impacts of agricultural activities and external factors.

Having some knowledge about the biophysical processes is essential to grasp what is going on in a particular situation and be able to take proper action if necessary. The background biophysical knowledge is typically given in a descriptive or semi-quantitative way through a conceptual causal diagram that focuses essentially on the main variables involved and the positive or negative influences between them (Fig. 2).

Grazing system experiments, ecophysiological studies and on-farm observations show the importance of considering simultaneously two key sward attributes that can be driven by management practices. The first is the sward height, which is easy to measure and is strongly linked to the herbage growth, the senescence rates, the herbage digestibility (Parsons 1988; Duru and Ducrocq 2002) and the intake by grazing animals (Hodgson 1985). The second is the nitrogen fertilisation rate which largely determines the plant nitrogen status which in turn can be used periodically to estimate the fraction of the potential growth which is actually taking place. The main difficulty in the described management problem stems from the fact that the herbage production process interacts strongly with its concomitant use through grazing (Parsons 1988), as shown in Fig.2 by the signs + and - specifying the direction of influence of the relationship between variables, and by the numerous feedbacks. Therefore, to reach a given target in terms of herbage height before or after grazing, a wide range of grazing practices is possible. Thus, the acceptable practices vary throughout the season within a grazing system (high grazing intensity is preferable in spring, and a lower one is appropriate when herbage growth rate has decreased). They also depend on the expected farming system objectives (e.g. animal performance) or key farm constraints (e.g. available grazing area per cow). Thus the underlying control problem is a complex one because it involves a multivariable optimisation with both direct immediate effects (e.g. cow intake) and indirect delayed effects (availability and quality of the pasture for subsequent grazing episodes). An appropriate quantity/quality trade-off of the available herbage should be maintained throughout the period under consideration in keeping with the intended profile and constraints of the use of conserved feed and concentrate.

**Analysis of three cognitive tools for grazing systems**
Three grazing cognitive tools are analyzed (Table 1). The first and third were created several years ago whereas the second is just finished. For each of them we summarize the context and the purposes; then we describe their components and how they are or can be used for learning.

**AHV: a graphical visualisation of the Available Herbage Volume per cow**

**Rationale**

The usual recommendations for dairy cow grazing are based on residual sward height or herbage allowance per cow (Stakelum 1996; Peyraud and Delaby 2005) that are helpful for management at paddock level. The residual sward height is the pasture height at the end of a grazing episode on a field. Herbage allowance per cow is the mass of herbage per cow in a paddock at a point in time. These indicators are however inadequate for managing pastures over the entire grazing season because neither the sward height nor the herbage allowance at field level can indicate whether or not the size of the whole grazing area is appropriately set to achieve a high grazing efficiency. Indeed, sward height observed at a moment on the grazed fields does not provide enough information in advance about the total area to allocate subsequently to grazing and cannot support an anticipatory change in the grazing area to cope with an excess or shortage of grass. More generally, the residual height and herbage allowance assessed at paddock level do not indicate whether there is leeway for action through managing grazing intensity or nitrogen fertilization at the farm enterprise level. As pointed out by Peel et al. (1988) other criteria are required to meet a targeted sward height at field level through a close integration of grazing with cutting for conservation, which may vary widely from year to year. In this practical context, the available herbage volume per animal unit (AHV) on the whole grazing area of the farm provides a very useful indicator for grazing management (Duru et al. 2000). Indeed the AHV indicator divided by the average daily intake per animal defines the closely related indicator called “days of grazing in hand” that conveys integrated information about the rates of herbage growth and senescence on the fields, and intake rates of the animals.

**The tool**

The tool based on the AHV indicator was built through an iterative process involving agronomic researchers and advisors. It is based on on-farm analysis of management practices, which ensures conformity with the farmer’s mental model (Blanfort et al. 2009). This tool displays in an intelligible way the per-animal availability of grass over the season depending on the system configuration and management options (cf Fig. 1). It is essentially a visualisation tool based on a static paper-based representation (Duru et al. 2000) involving:

- a graph combining average stocking rate over the spring season and plant nitrogen index (the $y$ and $x$ coordinates respectively in the upper graph of Fig. 3a) in which curves connecting these two variables for different AHV reflect different grazing practices.

- a set of AHV profiles over the grazing season for typical grazing management strategies (e.g. from set stocking to deferred grazing), each of them being characterized by key dates at which changes in AHV target (e.g. 200 vs 400 m$^3$ per cow) values occur (lower part of Fig. 3a).

As already mentioned, the tool is assumed to be used in a setting where the background knowledge is shared by the partners. At the very beginning of an interaction session with this tool, the grazing management principles (Fig. 1) and the conceptual model of the key biophysical processes (Fig. 2) are presented. Particular cases of grazing systems can then be considered and characterized through properties such as their land use and
feeding schedules. For each case considered, the sum of the volume ingested on each field can be compared with the relevant AHV profile for the same grazing management strategy. When there is a discrepancy (under- or over-grazing: upper graph of Fig. 3a), the biophysical framework can be used by the advisor to discuss with the farmer to evaluate to what extent the residual sward height or the plant nitrogen status can be changed to fit better with the relevant AHV profile.

*Use of AHV by advisory services*

The tool was used in three regions of France (Aveyron, Burgundy and Brittany), leading to different forms of use. In Aveyron it proved to be effective to determine adjustments in short term grazing through stocking rate changes so as to make more profitable use of available herbage. The tested learning situations focussed (Duru et al. 2008) on: (i) a group of advisors, for building AHV profile reference templates through adaptation of existing AHV profiles to suit to the farm’s livestock (ewes or cows) and the location (soil and climate); (ii) farmers, to let them understand the importance of AHV amount with respect to technical performance and the timing of stocking rate changes at key moments. As analysed with some livestock advisors, this graph helps in figuring out management differences and in diagnosing abnormalities such as imbalances between the stocking rate and the fertilization policy (Blanfort 2009). In Brittany and Burgundy regions, the tool was used by advisors in several farm cases to improve the sharing of knowledge. In Brittany, on-farm observations for grazing schedules had allowed a set of system-specific grazing management strategies to be defined through threshold values of “days of grazing in hand”. It extended the body of guidance benchmarks that were previously solely based on stocking rate. In Burgundy, records of AHV measurements were collected during several years on suckler farms to extract correlations between farm features (target animal performances, land and labour availabilities) and AHV profiles (Kockman et al. 2009).

We draw two conclusions from analyses of the three case studies. First, the tool fits well with most farmers’ approach to the management of the whole grazing area. Second, advisors have produced unexpected applications of the tool. The initial intention was to use it as a support for monitoring a grazing strategy several times during the grazing season at farm level. Actually it was also used to categorize different grazing strategies, and to put together management advice produced by advisory organisations for different production systems (cows vs ewes; milk vs meat). There is evidence that the AHV tool has influenced the advisors practices in the three regions, but it is difficult to assess to what extent it has influenced or changed farmers’ practices (Blanfort et al. 2009).

*Herb’sim: a herbage growth simulator at field level*

*Rationale*

In order to assist dairy farmers in determining land allocation to grazing cows, regional experts provide local benchmarks that consist of either stocking rate patterns defined for a season and consistent with other management aspects (fertilisation level and defoliation regime) or weekly sward height measurements in a spatially distributed grassland network (Defrance et al. 2005). The first type of support relies on the comparative analysis of standing herbage mass profiles throughout a grazing season as a function of plant species and their management intensity. Since the data are not recorded together simultaneously with weather data they cannot be used to help work out dynamically how to take into account variation in growth rate or how to combine different
grassland types characterized by plant species composition. The second type of support aims at determining to what extent the farm grazing area should be changed to match the rapid evolution of herbage growth rate. For instance, in Brittany, regional grazing experts organize weekly recording of herbage height on a large sample of grasslands to estimate the net herbage growth. Local advisors use this type of information to deliver customized advice to the farmers, taking into account the type of grazing and feeding systems they have. It is very time-consuming, and does not easily allow year-to-year comparison of the herbage growth dynamics.

The tool

To overcome the limitations outlined above, we built Herb’sim, a spreadsheet-based grass growth model running at the field level (Fig. 3b) (Duru et al. 2010). It can be used alone for simulating the effect of plant nutrient status (which responds to fertilisation) and defoliation regime on net herbage accumulation for pure stand grass (Duru et al. 2009) or species-rich grasslands (Duru et al. 2008). One can compare standing herbage mass profiles over the grazing season for different management intensities and a wide range of grassland types to identify their complementary aspects over time. The tool can be coupled to a weather database to produce weekly maps of herbage growth for comparing sub-regions on the basis of measured (or interpolated) weather data and to compare them with respect to growth patterns of previous years.

Preliminary use

A beta version of Herb’sim was used by Normandy-region advisors and researchers for comparing growth patterns simulated on various fields under varying practices of residual sward height. It provided insight on the importance of this control factor: grazing at 5 or 7 cm above ground level induces a significant difference in the herbage use efficiency. In this sense, the tool helped to challenge their firmly held views and forced them to reflect on their grazing management practices.

The tool was also used by researchers in training sessions with advisors and teachers (agricultural education). It helped in spreading a more comprehensive understanding of the variability of herbage growth, enabling them to derive practical lessons adapted to the local climatic conditions. The tool was also used to quantify for a set of weather scenarios the freedom of management allowed by the species composition of the grasslands, the timing of defoliation and the fertilizer applied, or particular combinations of these management practices. Our experience showed the importance of the sharing of background knowledge. Exhibiting the schematic diagram of the management system (Fig. 1.) greatly facilitates the contextualization of the Herb’sim spreadsheet model and plays an essential role in making it a contextualized cognitive tool linking theory and practice.

SEPATOU: a farm level simulator of grazing management strategies

Rationale

Evaluating the pertinence and feasibility of some grazing management changes at farm level is much more complex than simply dealing with the effects of year-to-year weather variations on herbage growth. It requires making explicit the notion of management strategy that conveys how management activities have to be organized in time and space. It also necessitates a model of the decision-making process that scans the management strategy to produce the relevant decisions and actions as a function of the actual conditions on a
day-by-day basis. Such needs are clearly beyond the capabilities of tools such as AHV and Herb’sim. Furthermore, traditional extension approaches rely on farm comparisons that allow only a limited number of improvements to be considered, and system experiments that are expensive and time-consuming and are hardly reproducible due to uncontrollable factors such as the weather. In order to overcome these limitations and go one step further in dealing with management complexity, we built the SEPATOU simulator (Cros et al. 2003).

The tool

SEPATOU contains the background knowledge sketched out in Figs 1 and 2. In other words, besides the biophysical aspect SEPATOU includes a model of the farmer’s management behaviour that simulates the process of making and implementing decisions about timing, amounts and use of resources, especially grazing area and feedstuffs (maize silage) over the spring period on a dairy enterprise. The decision module makes it possible to specify in a uniform way the different management tasks and their organisation in a plan. The tasks and plan involve some decision variables whose values are determined by applying decision rules that ensure situation-dependent decisions. Altogether the tasks, the plan and the rules define a grazing (and feeding) strategy. The decision rules react to key events (e.g. turnout date, closing of the grass or maize silo) defined as functions of state variables (e.g. sward height on each field, set of fields allocated to grazing). As output, the simulator yields the feeding and grazing schedules, which are very similar to the paper documents used by advisers for preparing and evaluating a grazing season (Fig. 3c). SEPATOU also computes the dietary composition and dates when key events occur, depending on the weather variation from one year to another (Cros et al. 2001; Cros et al. 2003).

One of the roles of SEPATOU is to encourage and help the experts and advisers to clarify strategies that have to be made explicit before being submitted as an input to the simulator. This preliminary step encourages careful thought about the grazing management and results in a more precise and holistic consideration and formulation of the decision-making task. SEPATOU supports to some extent a trial-and-error training approach (Cros et al. 2004). The simulation results, compared with past experience, make it possible to evaluate the relevance of the decision rules, indicator threshold values and configuration parameters.

Examples of use

SEPATOU has been used as a virtual experimentation platform in several training sessions that succeeded in fostering a better understanding of the dynamic interactions between the biophysical and decision-making systems. Firstly, SEPATOU was tested in participatory research sessions with a group of dairy advisors in Brittany. Five management strategies designed and routinely used by a well-recognized extension service were considered. SEPATOU was used for assessing the robustness of grazing strategies across a range of environmental contexts (soil and weather). The interaction with the tool and discussions about simulation results raised stimulating questions that reinforced or enriched the advisors’ expertise. SEPATOU has been used once or twice per year over the last 6 years for training courses for advisors, each advising a set of dairy farms. The process has consolidated and extended the practical knowledge of the participants. Finally SEPATOU was appreciated as an effective interface and facilitator between researchers and advisors to share their grazing management knowledge and analyse case studies.
Using SEPATOU also made it possible to supplement the “paper document” created by grazing experts for dairy support services (Seuret et al., 2004). In addition, in the design phase of the tool, the representation framework for management strategies proved useful for eliciting knowledge, as noticed in other domains (Edwards et al. 2004). Trying to make explicit management strategies that were previously tacit and fairly vague induces a kind of critical and constructive thinking.

Discussion and lessons
The considered cognitive tools are used in collaborative learning sessions that involve small groups of people sharing knowledge and experience. The participants present, analyze and argue about views that the cognitive tools help generate, characterize and make intelligible. A group in a training session includes people with different skills, people who interact flexibly and informally on grazing management problems to which they are exposed in pursuit of a collective analysis or solution. Learning is enhanced when framed in a collaborative and social setting where the members of the group develop a shared repertory of stories, experiences, and ways of handling particular problems. Sharing one’s own ideas and views, and responding to others’ reactions increase involvement in learning, enriches thinking, promote a more balanced view of the issues involved, and deepens understanding. In practice, learning with cognitive tools requires that careful attention be paid to organising and leading the collective sessions (workshops, round-table meetings) so as to maintain a cooperative and fertile atmosphere within them. Useful insights on this methodological aspect have been brought forth by education research and need yet to be further exploited in participatory learning approaches that use cognitive tools.

On the basis of judgement made by the users, the three cognitive tools have consistently shown their effectiveness in helping (i) structure the views the session participants had of the problems, (ii) communicate about them, (iii) explore the solution space and generate improved practices, and (iv) stimulate exchange and integration of knowledge and ideas from various participants. The three tools considered have however big differences as revealed by their presentation in the preceding section (see Table 1). The rest of this section emphasizes some of them and points out other discriminating features. They are summarized in Table 2 that situates the three tools with respect to the following questions:

- who is involved in the use of the tool: farmers, advisors, researchers?
- is the tool intended to contribute to exploration of management options (design), or to improve exploitation of actual resources (control or short-term anticipation)?
- is there a relation between the problem to solve, the uses involved and the type of tool?

We deal with these questions in turn for the three types of tool structured according to the models that they involve. We draw some lessons from this point of view that strongly differentiates the cognitive tools with respect to the type of users, assets, scope and limitations.

**Tool involving no computer model**
This type of tool is usually designed for simple isolated operational issues within the farming system, mainly for assessing the rate at which pasture is produced and exploited. Usually based on an indicator of plant or soil state that is readily obtainable, it provides easily understandable graphic representations that fit well with real case studies. Their simplicity and limited scope make them attractive for farmers and advisors. For grazing management, tools similar to AHV, e.g. “farm grass cover” (O’Donovan and Dillon 1999), were developed but
usually were only described in grey literature. Such tools are often by-products of research projects that rather focus on the underlying biophysical processes.

Although very simple, such tools can help in making grazing decisions because they provide direct feedback by pinpointing mismatches between the current situation and recommended herbage profiles. In addition, they help managers to get a better understanding of their systems, allowing them to determine which management practices work best under a range of conditions. They allow incremental innovation through single loop learning. The effectiveness of the tool depends on the learners’ knowledge about the relationship between intensity of management and performance (e.g. Fig. 2), and on their ability to make grazing decisions at the farm scale, considering the whole forage system.

**Tool involving only a biophysical computer model**

Biophysical simulation tools concern fairly specialised management problems on a limited time scale (usually a single season) and of moderate complexity, as underlined by March (2006). They are appropriate for (McCown et al. 2009): (i) learning to reduce uncertainty, i.e. establish a bridge between an outsider’s and an insider’s views of a farm’s management, rather than for decision-making; (ii) providing information that users can integrate in their usual decision-making processes. However, few models performed well for learning with stakeholders (see some examples for grazing and feeding systems in Table 2), because they are usually research models that are not really appropriate for learning support.

Being more difficult to handle than the previous ones, this type of tool can be used by experts for leading working sessions with advisors or farmers. Their use allows comparing herbage yield for different environments (soil, weather) and management practices (fertilization, defoliation regimes, species composing the sward) on a single field. Learning comes from the comparative critical analysis of the simulation results and the argumentation developed around them. Simulating real cases is useful to validate the model and to give confidence to the participants in a learning session. Although the construction of the scenarios to be simulated is a group activity, the session leader (intermediate partner) must provide the necessary data (e.g. weather in particular) and has to guide their construction toward the goal of achieving clear explanatory insight about the system behaviour. This remark applies equally well to the next type of tool discussed.

As mentioned above, a major limitation is that this type of tool can do little to resolve problems caused by shortage of grazing resources at the farm level. Furthermore, if the model is used in training sessions based on prototype case studies, some model parameters (e.g. plant nutrient status) have to be guessed. Defining them by expertise would be sufficient for initiating a single learning loop. However, for simulating real cases of grazed fields, the model parameters have to be estimated with greater accuracy, either from expertise or from calibrated field measurements (Romera et al. 2010).

**Tool involving both decision and biophysical computer models**

A cognitive tool incorporating both decision and biophysical models is appropriate for exploration of management options. Using this type of tool requires describing and incorporating site-specific and attitude-specific management rules that reflect individual constraints and goals for a prototypical class of farm rather than a particular farm. These features make this type of tool more suitable for experts rather than for advisors or farmers. The complexity of the tool requires the involvement of a modelling specialist.
In a learning perspective, such simulation tools are used in a trial-and-error process in which the performance and properties of various alternative management strategies are explored. They provide basic figures about the behaviour of the biophysical system which makes it possible for the user to assess the merits and shortcomings of the strategy considered. An important asset of this tool is that it enables the participants to explore the behaviour of the whole-farm grazing system and the difficult issue of coordinating the production and exploitation of grazing resources on the different fields. By letting the participants evaluate outputs with respect to their own values and preferences such a simulation tool avoids the difficulty of optimisation approaches that require numerical data which may be difficult to obtain and capture in aggregating formula.

Such simulation-based cognitive tools are intended to support the development of new viewpoints for structuring and managing a production system rather than to provide actual recommendations (Hayman 2004). Such new viewpoints sometimes cast doubt on the current understanding of the learners and leads them to reconsider and alter their mental models as their understanding of the system develops. In this way, the cognitive tool contributes to a double-loop learning because its use may reshape the studied system (van Mierlo et al. 2010).

With tools of this type, the lessons learned from the cases explored can go beyond the particular situations and narrow practical questions, thanks to the explicit representation of processes and the ability to inspect the simulation output. Indeed these tools support the design of innovative management practices and can contribute to their adoption. For instance, Martin et al. (2011) have extended the SEPATOU approach to take into account the diversity of plants, animals, grassland and farmland, and to design more elaborate management strategies that exploit this diversity as a source of flexibility and that can cope with the complexity that this might induce.

Concluding remarks

This paper has presented three contrasting and complementary cognitive tools that help to provide a better understanding of grazing system’s behaviour and to develop diagnosis, anticipation and management capabilities in such systems. These tools (called boundary objects in Jakku and Thorburn 2010) are not intended to be used only or directly by any particular actor but serve as a mediator between people usually from different groups, e.g. researchers and experts, experts and farmers’ advisors, or farmers’ advisors and farmers. The three examples visited in this paper clearly show that the sophistication of the computer models included in a tool increases with the complexity of the question to be addressed and affects consequently the types of participants involved actively in the corresponding learning sessions.

With these tools learning is an active, contextualized process of constructing knowledge rather than acquiring it from a teacher or knowledgeable person. These tools, together with the background knowledge that must accompany them, rigorously support the process of reflective inquiry. They belong to a constructivist view of learning (Jonassen 2000) in which individuals create meaning and knowledge by experimenting, extending or modifying their current personal knowledge and skills. Knowledge is acquired through the transformation of personal experience (Kolb 1984) forming the mental model of each participant. In order to play their intended role efficiently the cognitive tools need to be used within a well-defined and focused problem space. Therefore it is essential to characterize and make explicit the background knowledge that ensures a basic common understanding of the domain and sets up the conditions for situated learning. Learners continuously test
hypotheses through social interaction that yields a cross-fertilisation of the different beliefs, values and interpretations. The social dimension of the learning process facilitates the establishment of a bridge between scientific knowledge (the model included in or accompanying the tools) and practical knowledge brought by the participants. The tools constitute intermediate objects (Vinck 1999) that can tie up relations and convey messages between the different participants in a learning session (researcher-expert; expert-advisers; advisor-farmer or consultant-farmer); the type of tool needed being dependent on the partners. Of course what has been observed with grazing systems is transposable to other types of farming systems that involve big interactions between physical, biological and human decision-making processes.

In the near future the rapid pace of change in the environmental and economic context of agriculture will increase the demand for cognitive tools to develop the ability of professionals to maintain the production system functions in face of new situations and to guide long-term changes. In the tools presented, the past experience of learners and short-term process knowledge provided the basis on which learning could take place. A new generation of cognitive tools is currently being developed. They give more emphasis to both short- and long-term processes, wider scales (beyond the farm scale and over a horizon of several decades), consideration of risk, and practical issues concerning work organization and resource management. These tools take into account the evolutionary nature of change, and hence that the future dynamics of such systems are subject to risk and uncertainty. Although it may be possible to identify tendencies for system change, they remain highly unpredictable in practice. This implies that detailed control and management of these systems is impossible and so more flexible and responsive approaches are needed. This is in contrast to more reductionist approaches which seek to assess the optimal course of action based on an assessment of the estimated costs and benefits of future options, assuming quantifiable assessments of uncertainties. The next generation of cognitive tools will continue to emphasize the role of virtual experiments to provide a setting for learning to take place, often at very different scales. Although models can only approximate real-world system dynamics, they enable adaptive strategies to be tested quantitatively, identifying potential feedbacks and unintended consequences. Actually the cognitive tools required will probably need to provide more sophisticated ways of exploration, mixing simulation with optimisation. For instance one may need to address the issue of allocation of resources (labour, machinery, fuel, water) in short supply to the different technical activities in a production system, which is likely to gain importance. Scenario development and simulation will increasingly be used to help decision-makers better understand, anticipate and respond to the sorts of dynamic and uncertain change that are likely to happen in future. No doubt the cognitive tools will aim at fostering innovation towards more robust and resilient production systems, keeping the focus on learning by virtual experimentation, participation and interaction between actors involved in group learning sessions.

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References


Stone P, Hochman Z (2004) If iterative decision support systems are the answer, have we been asking the right questions? New directions for a diverse planet, Proc. of the 4th International Crop Science Congress, Brisbane, Australia (Eds T. Fischer et. al.)


Caption of figures

Fig. 1. Background knowledge about grazing management: key components for characterizing management strategies (1a); schematic diagrams of decision models (1b)

Fig. 2. A causal diagram showing the effect of key processes in grazing systems on standing herbage mass (a) and herbage nutritive value (b); dotted lines indicate feedbacks; +/- means that the sign of effect depends on the length of the regrowth

Fig. 3. Examples of artefact outputs and learning contributions for the three tools
Fig. 1.

1a

Decision variables:
- reproduction calendar
- animal performance target
- fertility of fields
- stocking rate
- feeding complementation
- severity of defoliation by grazing and harvesting
- partition of fields according to intended use

Grazing management strategy:
- turnout determination relying on number of days of grazing currently available for a specific herd
- moving herd out on a field when forage height has reached a certain threshold
- moving herd in a field that is ready (has enough forage and rest since last grazing, soil in acceptable conditions)
- assessing every day the current situation on fields and, in particular, the standing forage
- adaptation if necessary of the number of grazing fields, severity of grazing and complementation feeding throughout the rest of the grazing seasons on the basis of forage resource availability (observed or anticipated) or animal performance

1b

Key events and associated rules

Turn out...

Kg DM per cow and day

Grazed feeding

Indoors feeding

Available grazing
Area per cow (ha)

Available silage
and hay per cow

Variables of structure

Management units

Grazing rules

Spring grazing

Summer grazing

Silage yield

Spring

Summer

Autumn

Fig. 1.
Fig. 2.
Average critical curves of available herbage volume per cow (m³) determining different management types in a "stocking rate - plant growth" framework during the "full" spring period (adapted from Duru et al. 2000).

Learning is based on the comparison of field measurements to critical or typical curves of AHV.

Typical curves of available herbage volume per cow (m³) over the growing season given more or less room to cope with short term variation in plant growth, and determining the grazing season length (higher AHV allows deferred grazing), (adapted from Duru et al. 2000).

Examples of simulated curves of herbage accumulation over a growing period for two defoliation regimes (full and dashed curves).

Learning is based on the comparison of simulated scenarios: 2 or more growing seasons, 2 or more defoliation regimes, 2 or more plant vegetation types (Duru et al. 2019).

Example of simulated feeding calendar for a given strategy (specific planning and acting rules), (adapted from Cros et al. 2004).

Learning is based on the comparison of outputs of simulated grazing and feeding strategies (planning and acting rules): grazing and feeding calendars, dates at which key events occurred (e.g. turn out) and milk production.

Fig. 3.
Table 1
Comparison of components of the three tools

<table>
<thead>
<tr>
<th>Name</th>
<th>Management system</th>
<th>Biophysical system</th>
<th>Artefact (material support)</th>
<th>Data requested to use the tool</th>
<th>Questions addressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHV (Duru et al., 2000)</td>
<td>Schematic representation of the management system (Fig. 1). No computer model in the tool</td>
<td>Conceptual model (Fig. 2)</td>
<td>Paper-based graph showing the available herbage per cow</td>
<td>Sward height measurements and stocking rate for the whole grazing area †‡</td>
<td>Are sward heights and defoliation intervals well suited to the objectives and constraints of the farm?</td>
</tr>
<tr>
<td>Herb’sim (Duru et al., 2010)</td>
<td>Schematic representation of the management system (Fig. 1). No computer model in the tool</td>
<td>Pasture plot model</td>
<td>Spreadsheet model and companion tools allowing graphical display</td>
<td>Soil and weather database †</td>
<td>How to build contextualized advice for operational grazing management at seasonal scale?</td>
</tr>
<tr>
<td>SEPATOU (Cros et al., 2003)</td>
<td>Computer model (rules can be changed in the software)</td>
<td>Computer model of farm pastures and cows</td>
<td>Dedicated representation language, discrete event engine and graphical display</td>
<td>Databases: set of decision rules for each forage system; weather database</td>
<td>How robust are grazing and feeding management strategies over a range of weather and soil conditions?</td>
</tr>
</tbody>
</table>

Additional material needed: shared representation of the management system † (e.g. Fig. 1) and a conceptual model of the biophysical system‡ (e.g. Fig. 2)
**Table 2**  
Features of cognitive tools depending on the computer models involved

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Computer models involved</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>no computer model</td>
</tr>
<tr>
<td></td>
<td>only biophysical model</td>
</tr>
<tr>
<td></td>
<td>biophysical and decision models</td>
</tr>
<tr>
<td>Purpose and scale</td>
<td>comparison of actual available herbage mass w.r.t target values at farm scale</td>
</tr>
<tr>
<td></td>
<td>field-scale exploration of standing herbage mass dynamics depending on management options</td>
</tr>
<tr>
<td></td>
<td>empirical design of farm scale management strategies combining the various feeding resources</td>
</tr>
<tr>
<td>Technical support</td>
<td>paper-based graphs</td>
</tr>
<tr>
<td></td>
<td>spreadsheet model coupled with databases (e.g. weather, soil)</td>
</tr>
<tr>
<td></td>
<td>discrete event simulation, representation formalisms for decision and biophysical models</td>
</tr>
<tr>
<td>Users involved</td>
<td>advisor/ farmer</td>
</tr>
<tr>
<td></td>
<td>expert/advisor</td>
</tr>
<tr>
<td></td>
<td>researcher/experts</td>
</tr>
<tr>
<td>Assets</td>
<td>- easily understandable graphic representations and interpretations; higher intelligibility and transparency</td>
</tr>
<tr>
<td></td>
<td>- users can create their own interpretation grid</td>
</tr>
<tr>
<td></td>
<td>- dynamic model easier to handle than a whole farm model</td>
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<tr>
<td></td>
<td>- provides a focus view of the growth process in response to management</td>
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<tr>
<td></td>
<td>- dynamic model allowing to get a comprehensive view of herbage production and use at farm level</td>
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<tr>
<td></td>
<td>- can reveal potential bottlenecks on feeding resources</td>
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<tr>
<td>Limitations</td>
<td>- static picture</td>
</tr>
<tr>
<td></td>
<td>- cannot take into account weather variability and resource bottleneck</td>
</tr>
<tr>
<td></td>
<td>cannot take into account resource bottleneck</td>
</tr>
<tr>
<td></td>
<td>model difficult to handle, even for experts</td>
</tr>
<tr>
<td>Case study</td>
<td>real farm</td>
</tr>
<tr>
<td></td>
<td>real or virtual farm</td>
</tr>
<tr>
<td></td>
<td>virtual farm (chosen from a set of farm types)</td>
</tr>
<tr>
<td>Examples described in the paper</td>
<td>AHV</td>
</tr>
<tr>
<td></td>
<td>Herb’sim</td>
</tr>
<tr>
<td></td>
<td>SEPATOU</td>
</tr>
</tbody>
</table>