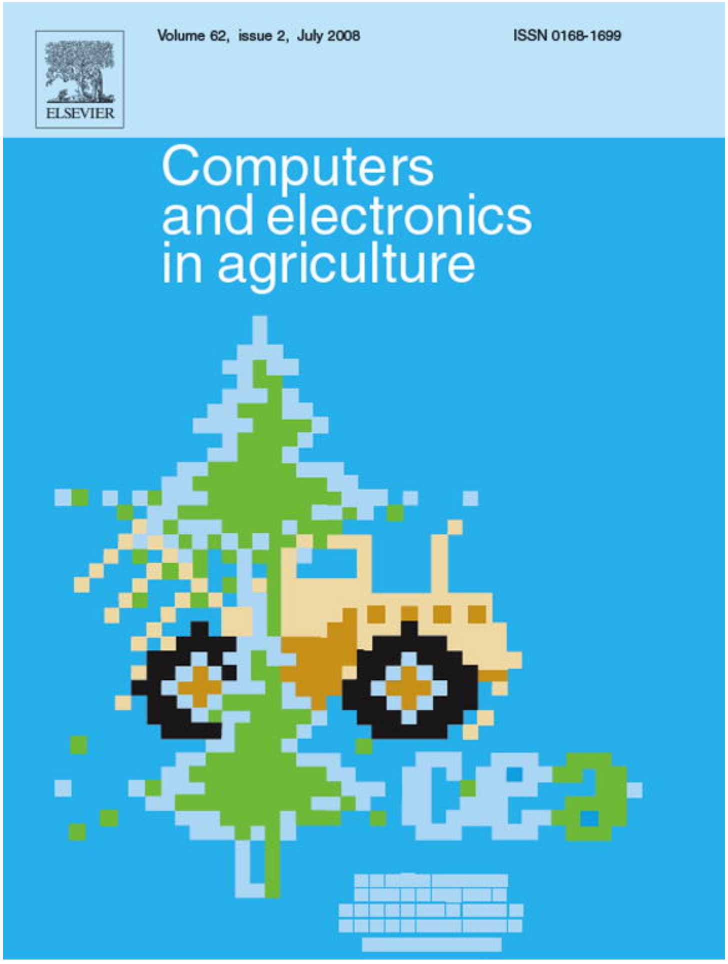
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Use of a decision support system and a simulation game to help collective decision-making in water management

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ABSTRACT

This paper presents a method based on a participatory approach involving a decision support system and a simulation game to improve discussion between actors and to facilitate the emergence of acceptable compromise solutions in water management. An example is provided of how the method can be applied using data from an irrigated perimeter in Tunisia. This is a good example of a conflict between dam managers, farmers and administration concerning water allocation. First, we present the global model with results from a number of scenarios. Then we present a simulation gaming developed to rapidly construct scenarios in collaboration with decision-makers.

1. Introduction

At the territorial scale, appropriate methods and tools are needed to facilitate decision-making processes in water management as well as to provide support in negotiations with water users (Barreteau, 2003; Etienne, 2003).

Our knowledge of different approaches to territorial modelling led us (i) to formulate a first level of methodological analysis, and (ii) to define tools for the implementation of joint actions between players in order to create value (Le Grusse, 2001). Several studies have described and analysed participatory methods (Mendoza and Prabhu, 2005; Rauschmayer and Risse, 2005), which have been considered to be the most appropriate and effective way to assess agricultural sustainability (Mickwitz et al., 2006; Siebenhüner and Volker, 2005). These methods allow stakeholders to play a more active role in the management planning process, and in making decisions about management strategies and their implementation (Haggar et al., 2001; Kuntashula and Mafongoya, 2005).

Our approach is based on a decision support system (DSS). The concept of *decision support system* is very broad. The term has been used in different ways (Alter, 1980; Power, 2002), and even defined in different ways depending on the author's point of view (Druzdzel and Flynn, 1999). Here, we use the Sprague and Carlson (1982) definition of DDS: "*interactive computer-based systems that help decision makers utilize data and models to solve unstructured problems.*" Later, Turban (1995) defined DSS more specifically as "*an interactive, flexible, and adaptable computer-based information system, especially developed for supporting the solution of a non-structured management problem for improved decision making. It utilizes data, provides an easy-to-use interface, and allows for the decision maker's own insights.*" Different applications have been developed to support irrigation (Thysen and Detlefsena, 2006). DSS for irrigation is extensively cited in the literature, but only a few operational decision support systems have been reported (Mateos et al., 2002). Of these, only a limited number is web-based. Most irrigation systems are expert systems (Mohan and Arumugamand, 1997) (for a review see Thysen and Detlefsena (2006)).

In the past, such methods and instruments were used to help individual farmer's decision-making (Attonaty et al., 1991, 1999). Today, we are increasingly faced with problems in

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which several actors with different interests are involved. In this case, the aim is not to find an optimal solution as do models based on linear programming or game theory (Thoyer et al., 2001), but to create models to reach compromise solutions that are acceptable to the different actors.

The main objective of this paper is to present a method based on a participatory approach involving a decision support system and a simulation game to improve discussions between stakeholders and to facilitate the emergence of acceptable compromise solutions. We describe its application in an irrigated perimeter in Tunisia, which is a good example of a conflict in water resource management. We first present the global model and some scenario results. We then present a simulation gaming developed to rapidly construct scenarios in collaboration with decision-makers.

2. Olympe: a decision support system to improve collective decision

Olympe software (Attonaty et al., 2005) can integrate both economic and technical aspects (e.g. crop management) of farm operations and externalities (e.g. nitrate leaching). Modelling with Olympe (Le Bars and Snoeck, 2007) enables the consequences of different scenarios envisaged by the farmer or by the authorities to be forecast (Fig. 1). Using a model that simulates the consequences of certain aspects of its management enables the model to learn and modify or confirm its decision parameters. Consequently, it can evaluate the relevance of its parameters with regard to its projects and to the future development of the farm concerned. This tool allows us:

- to obtain a database on operating systems;
- to evaluate the consequences of investing in, getting rid of, or adding an input/output per crop, a change in a crop schedule, a change in crop management, etc;
- to enter unknown factors in the simulation and to assess the consequences of unforeseen events for the results of the project (price fluctuations, climatic factors, changing market trends).

The Olympe software allows groups of farms to be constructed by a matrix made of the number of farmers classified as one type. The simulator acts by highlighting the impact of changes on the crops or management methods but does not allow the strategies and courses of action of the various stakeholders to be represented. In order to model the complete operation of the system, it is important to understand and formalize the stakeholders' rules for decision-making as well as the laws that govern these rules. Olympe was designed to work interactively with farmers, either individually or as a group (Le Grusse et al., 2006).

3. Application in an irrigated perimeter in Tunisia

3.1. *The context*

Tunisia is located on the southern shore of the Mediterranean Sea and the Tunisia government is especially concerned about water management because it is reaching the limits of its resources. In the past, the Tunisian government invested heavily in irrigation and today its main efforts are focussed on improving management of its irrigated area. It should be noted that, in an irrigated area, with the disappearance of subsidies and a slight increase in the price of water, farmers' incomes decrease. In our study area, the cultivation of sugar beet was formerly encouraged. This crop is a big water consumer with no competitive production costs. The total area under sugar beet was 4900 ha and comprised 1500 farmers. In such a system, the interests of the different actors (administration, sugar factory, dam manager and farmers) diverge over time. Administration wants to increase sugar production and improve water availability. Dam administrators must manage the water resources and restrict use to avoid shortages and to obtain satisfactory revenues. The sugar factory must ensure its supply of sugar beet. Farmers want a better income. The Tunisian government prefers to valorise water resources in a more general way. To build a negotiation framework for production choices in accordance with water availability, different potential solutions have to be evaluated before searching for negotiable solutions. To facilitate the dialogue between the different stakeholders, we used Olympe to design an area model to simulate different scenarios.

The work (Ali, 1996) was carried out in three phases:

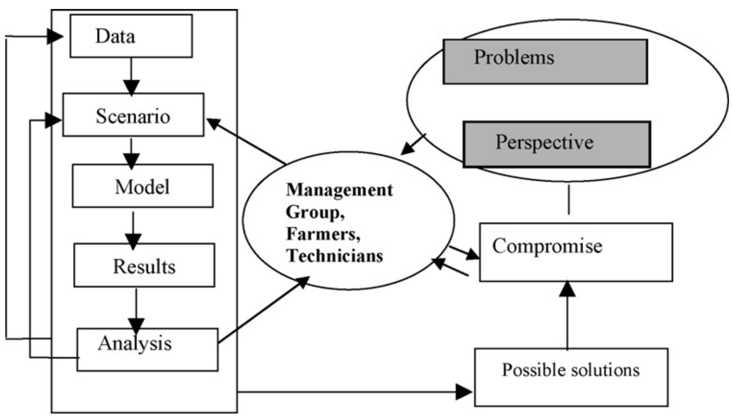

Fig. 1 – Modelling under Olympe and co-construction of the model.

- collection of technical data on farms together with data concerning their socio-economic environment;
- design of a model of the irrigated zone; and
- simulation of scenarios to improve the dialogue between the different actors and to facilitate emergence of new solutions.

3.2. *Typology and production systems*

A typology was formulated based on data analysis techniques and on the classification of the 1500 farms (Le Grusse et al., 2006; Poussin et al., 2008). We identified one or more farmers of each type and, in collaboration with the farmers, created different scenarios for future changes on their farms. We used an Olympe model that runs over 9 years: 6 years of forecasting and 3 earlier years to validate the model. The 9-year phase allowed us to collect basic information on the different crops and to validate the data by comparing past results given by the model with real results collected in the field. This phase enabled us to establish a typology of years and to define inputs and outputs for every crop for every type of year. The investigation was carried out on a total area of 662.7 ha and 25 farms.

We determined three types of year as a function of annual rainfall and water reserves in the dam during the agricultural year:

- type A: sufficient reserves in the reservoir and light rainfall;
- type B: limited reserves and average rainfall;
- type C: sufficient reserves and heavy rainfall.

3.3. *Global model*

Using a set of data on crop production and the historical record of three agricultural years of the 25 farms investigated, we regrouped all elementary data treated before adjusting the activity to the sector scale. Olympe software comprises three parts:

- a technical part to define inputs and outputs for different levels of production (crops, animals, orchard) for farms in each zone;
- a part concerning the types of farms. Every type of farm has a name, is in a given zone and has a weight. For each farm type, we introduced a cropping plan using data concerning past crop rotations, orchards, livestock, and fixed costs;
- a part of hazard definition. This results from the definition of several types of year (year of type A, B or C) that entails variations in inputs and outputs (income, water consumption, etc.).

Olympe provides, by choice, for a farm or for farms in a given zone, or of a given type, or for the set of farms of the whole sector, results in quantity and in value for the last 3 years and forecasting for 6 years depending on the climatic scenarios under consideration (Tables 1 and 2).

Table 1 – Comparison of cropping area with the model and observed data before and after validation (in ha.)

Crops	Statistical data	Before validation	%	After validation	%
Wheat	2050	1890	92	2004	98
Sugar beet	984	1162	118	1063	108
Early potatoes	207	133	64	159	77
Late potatoes	214	128	60	128	60
Total area	4695	4609	98	4608	98

3.4. *Model validation*

To validate the model, we compared the results of the model to observed data, from statistics concerning cropping area, production figures from the sugar beet factory, and water consumption from the dam administrator. Concerning total surface area, the model results reached an average of 98% of the observed values with an inter-yearly variability not exceeding 6%. But there were big differences for certain crops and in particular for two crops. The shift was accentuated for late potatoes, which is explained by the nature of the crop which is a catch crop and was consequently often forgotten by the farmer during the interview. Observations of the area under sugar beet for three agricultural years resulted in overestimations and led us to formulate the hypothesis that farmers overestimated the area they had under sugar beet by distrust and to show that they respect the regulations; indeed the price of water is based on the area under sugar beet. We checked this hypothesis in a further set of interviews and modified certain variables in the model. Tables 1 and 2 show real and estimated area and production, both before and after validation. For water consumption, the model initially provided somewhat lower consumption than reality. A detailed analysis completed by interviews showed that in years with high rainfall when the level of the water in the dam was high, the farmers irrigated less than the crops needed. In dry years with sufficient reserves in the dam, there was very heavy use of water. The model results coincided with normal rainfall and limited reserves. In this case, the irrigation rules were respected by restriction measures imposed by the administration. We noted a general tendency to waste water when there was no shortage of resources. This was explained by farmers' practices, use of water by non-farmers, and losses in the irrigation network. The losses were restored in the model as shown in Table 3.

Table 2 – Comparison of production figures with the model and observed data before and after validation (in ha)

Crops	Statistical data	Before validation	%	After validation	%
Wheat	8,477	6,567	77	7,067	83
Sugar beet	48,204	58,200	121	54,220	112
Early potato	3,122	2,183	70	2,581	77
Late potato	2,635	1,350	51	1,350	51

Table 3 – Comparison between the model predicted and real annual water consumption in the study area (in Mm^3)

	Year A	Year B	Year C	Average
Water consumption	10.5	7.8	5.1	7.8
Other water uses	0.5	0.5	0.5	0.5
Water losses (15%)	1.65	1.25	0.84	1.25
Total water consumption in Olympe	12.65	9.55	6.44	9.55
Invoiced real consumption	14.02	9.71	5.83	9.85
%	90	98	110	97

3.5. *Results*

We qualified the different types of years, not only by rainfall amount but also by the water resources available in the dam. In order to allocate frequencies to these years, we analysed rainfall records for 33 years. This analysis gave the following results: year – type A (25%), year – type B (50%) and year – type C (25%). We identified three main actors in the study zone who had different interests: the dam administrator, who had to balance his accounts and is interested in water consumption and water pricing; the manager of the sugar factory, who was interested in the quantity of sugar beet produced; and finally, the farmers, who were interested in improving their income. In addition, extension services provided data collected at the farm level that corresponded to more intensive production. To facilitate negotiation between the three actors, we established different scenarios with different cropping plans and different levels of intensification.

3.5.1. *Scenario 1: intensification in sugar beet cultivation*

The sugar factory plays an important role in this region and is trying to increase sugar beet yield. Different more intensive techniques are known but require more water, and this presents problems.

We simulated different scenarios with increasing levels of intensification. The summary results presented in Table 4 reveal the advantage of intensification for the sugar factory and for the water supplier, who both increase their revenues. However, the water supplier faces the risk of not being able to provide the amount of water needed every year. In contrast, farmers who are obliged to intensify their crops do not benefit from their efforts as their income increases very little.

Table 4 – Averaged results of the consequences of intensification of sugar beet production (in %) [a]

Scenario	Water needs	Water fees	Sugar beet	Farm income
Initial situation	100	100	100	100
Intensification II	115	115	114	102.5
Intensification III	128	128	125	104

[a] The units are in percent. In initial situation all results are 100%. For different levels of intensification, we compare with the initial situation, the increase (or decrease) of results for: water needs and fees (water supplier), sugar beet (sugar factory) and farm income (farm point of view). For example, for the first level of intensification, sugar factory and water supplier have both increase their income (15% for the first one and 14% for the second one).

Table 5 – Consequences of no longer growing sugar beet (%) [a]

Scenario incomes	Water needs	Water fees	Sugar beet	Farm income
Initial situation	100	100	100	100
Variant 1	64	83	0	98.6
Variant 2	64	83	0	97.4
Variant 3	64	83	0	96

[a] Following the first simulations (Table 4), the farmers and the dam administrator questioned the interest of continuing to grow sugar beet. The results, shown in Table 5, result in a considerable decrease in water consumption (36%). Dam revenues decrease slightly (17%) because the price of water is higher as it does not benefit from the reduced price for the cultivation of sugar beet. The dam administrator is interested in this solution because his income is slightly lower and he can consider selling water to other irrigated zones. Farmers are also interested as they discover that not growing sugar beet does not decrease their income very much (3–4%). The results of these simulations demonstrated the interest of intensification.

Table 6 – Consequences of intensification without sugar beet (in %) [a]

Scenario incomes	Water need	Service charge	Sugar beet	Farm income
Initial situation	100	100	100	100
Level 1	64	83	0	98.6
Level 2	84	108	0	109.3
Level 3	104	133	0	116

[a] This table shows results with general crop intensification without sugar beet. The results show the interest of intensifying or no longer growing sugar beet for the dam manager (8–33% service charge increase) and for farmers (9–16% farm income increase).

3.5.2. *Scenario 2: sugar beet is no longer grown*

Following the first simulations, the farmers and the dam administrator questioned the interest of continuing to grow sugar beet. To this end, with local agronomists we drew up lists of different crop rotations including pulses and field vegetables. The results, shown in Table 5, result in a considerable decrease in water consumption. Dam revenues decrease slightly because the price of water is higher as it does not benefit from the reduced price for the cultivation of sugar beet. The dam administrator is interested in this solution because his income is slightly lower and he can consider selling water to other irrigated zones. Farmers are also interested as they discover that not growing sugar beet does not decrease their income very much. The results of these simulations demonstrated the interest of intensification.

3.5.3. *Scenario 3: consequences of different levels of intensification*

We simulated two levels of intensification with different cropping plans. The results (Table 6) show the interest of intensifying or no longer growing sugar beet for the dam manager

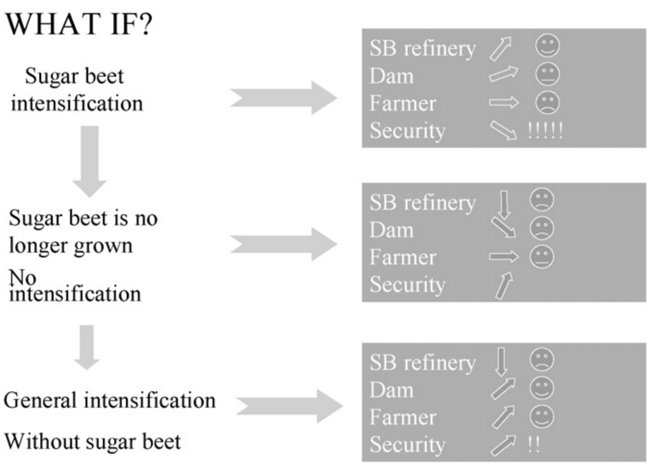

Fig. 2 – Consequences of scenario tested.

and for farmers. To survive, the sugar factory has to increase sugar beet prices, but cannot do so without increasing its production costs or receiving a big grant-in-aid. The increase in sugar cost would entail a loss of its outlets.

The results of the three scenarios are summarised in Fig. 2.

3.5.4. *Scenario 4: sensitivity of price variations*

The above-mentioned results were directly produced by the model. But they were based on price hypotheses and are therefore questionable. We consequently used another simulator function to perform a sensitivity analysis: we progressively decreased the gross product from other crops until the results achieved with sugar beet were reached.

This analysis showed that for the different intensive variants the sensitivity is weak: the gross product has to be reduced by 31–45% with intensification to obtain the same income as with sugar beet.

For an outside observer, the results seem clear; sugar beet should no longer be grown. In practise, the decision is incumbent upon the local actors: the model only offers elements for negotiation. It is based on a farm typology and a detailed analysis. The design of a global model of the zone and its validation by comparison to existing global data showed the limits of individual interviews and complementary interviews concerning the actual cropping areas and irrigation practices were in fact required. Once this model was satisfactorily validated, it was interrogated, and informed the different actors of the progressive consequences of changes in crop rotation and in levels of intensification.

The presentation of this model to the actors revealed the need for an initial detailed presentation of the data used in the model. The global result can only be presented and discussed after the inputs and outputs of the main crops and the typology used in the model have been presented and discussed. The conclusion concerning the low profitability of sugar beet was shared by participants who now, some years after this study, no longer have a sugar factory. The working group created on this occasion still exists and has requested a new simulation to improve other decisions. Other irrigated zones need similar studies and we tried to respond by training local students to understand local problems and local agricultural practices. In fact, this paper is the result of an experiment carried out by the authors and a Tunisian student and required 6 months of work. It appears to be easily repeatable and several comparable studies are currently in progress.

4. From a global model to a simulation game

Our previous experience confirmed the need to develop methods and instruments to rapidly construct scenarios with the decision-makers so that their questions can be answered and the scenarios modified in accordance with the decision-makers' ideas. This stage also brought to light the opposing interests of the different actors and existence of different coalitions.

In recent years, in water management, we can observe the use of simulation gaming to put decision-makers into a virtual situation of making strategic choices. The method of simulation and gaming is well suited for dealing with complex interrelated problems. The method has a significant potential in connection with environmental problems and sustainable development. Ulrich (1997) reviewed simulation games on environmental issues and analysed their objectives, their underlying models and other characteristics. A game enables (i) group dynamics that are always justified, and (ii) exploration, testing, and development of new issues. Furthermore, the player receives rapid feedback on the consequences of his actions. He also becomes aware of causal relations. The analysis of solutions is more important than the solutions themselves (Barreteau et al., 2001; Mathevet et al., 2006).

Following similar studies, using the same approach and the same tool (as described in Section 3), we used the collected data and Olympe software to create a simulation game.

This approach puts players in a situation where they are obliged to make decisions, forcing them to negotiate in order to establish a cropping plan that takes both global constraints and the other players' decisions into account. The objective of the game is that in a "virtual" situation, the actors can learn to act better in a "real" situation. We developed a simulation game (Allaya et al., 2004) with students and the following case study is a simplified case inspired by a Mediterranean zone.

4.1. *The context of the game: different production systems in an agricultural region*

The virtual region includes four main cropping systems with different potentialities, technical levels and numbers of farms.

- system A has field vegetable crops with 500 farms of 10 ha each;
- system B has field vegetable crops and cereals with 100 farms of 50 ha each;
- system C has field vegetable crops and orchards with 100 farms of 30 ha each;
- system D has cereals and orchards with 50 farms of 200 ha each (orchards: 5 ha peach trees and 25 ha apple trees).

Each production system comprises production factors, crop potentialities and production techniques as a function of three levels of intensification. The main inputs are land, workforce, and water quotas with different prices. The agricultural region is also determined by its production history, by changes in the consumption and the availability of production factors, as well as changes in markets and prices. In the game, water availability is uncertain and is randomly fixed every year. The different products have a function that combines price and the total quantity produced with different elasticity depending on the product. All these elements are initially unknown to the players who discover them progressively.

4.2. *Progress of the game*

Each type of farm is "managed" by a group of students. The group knows all the technical potentialities of its production system and those of other farms as well as the historical record on a regional level.

Each group has to decide on its production plan without knowing what the other groups decided in the past or what they will decide for the coming year. No group knows either the precise evolution of availability of the production factors outside the farm, production quantities and the market prices.

4.2.1. *The game takes place step-by-step*

Each group decides on a cropping plan based on its technical and financial capacities, and on the availability of water and of a workforce. All decisions are aggregated in the regional simulator and the total production is calculated in accordance with climatic conditions, which are randomly selected. Market models defined by product calculate quantities sold and sale prices on different markets. In return, these elements enable total income to be calculated for each farm. The results are then given to each group, which must then take a decision for the coming year. These results comprise the results of groups of farm as well as regional results. The game is structured in two stages:

- the first stage during which there is no communication between players;
- the second phase during which all the players can discuss and negotiate.

During the first game period characterised by no communication between players, there is overproduction of certain products and underproduction of others. Water capacity and manpower availability are immediately reached, and deficits appear; generally due to intensive production levels which theoretically bring in more cash. Individual optimisation models based on linear programming used by groups reinforce the search for the best results and therefore increase the intensification process. Prices of some products fall due to overproduction and those of other products not produced in sufficient quantities increase considerably. In the following periods, we observe the emergence of production diversification to minimise risk. Water consumption decreases and more or less agrees with availability. Farms and regional results are improved, but surpluses and important deficits persist.

In the second stage, the players are allowed to meet to discuss and negotiate. In our case, this stage began with the exchange of information about the different production systems. A joint analysis was made of the region and of changes in markets and resources. This first exchange resulted in a decrease in information asymmetry between actors, but failed on two points: determination of the items to be discussed and how to discuss. In the following periods, we noted the progressive emergence of agreements between players: the definition of quotas for some products, and the negotiated creation of a monopoly for a few products. Lastly, a water market appeared. These negotiations resulted in a marked reduction in surpluses and an increase in farm revenues.

4.3. *Learning from the results of the simulation game*

The experimental game taught us several lessons:

Without negotiation, individuals improved their overall performance, but a maximum threshold was quickly reached in a system where resources and markets are limited and uncertain.

In parallel, an optimisation model of the region was used that provided the optimum that the region could reach with knowledge of available resources and markets.

The comparison between the optimal solution (regional linear programming model) and the results of the simulations show there is still a considerable progress margin after the second phase. We believe that continuation of the game would have enabled further improvement; but we were unable to verify this hypothesis due to lack of time. Additionally, we think that basic training in game theory would have allowed the players to progress more quickly; but this hypothesis will have also to be tested.

In a context where markets and prices change rapidly and production techniques are also changing, farmers are obliged to react quickly. Many methods and instruments of varying degrees of sophistication are now at the disposal of extension services and are used to varying extents. But help with individual decision-making is limited because many of the problems that occur are a level other than at an individual one. Markets, environmental conservation, or natural resources management must thus be considered at a more global level and must lead to a dialogue between different groups of actors with conflicting interests. From this point of view, simple techniques like simulations used in an interactive and progressive way with decision-makers can produce interesting results at a low cost.

One of the advantages of Olympe is that it is easy to understand: Olympe software shows results on the computer without delay and the data used are easy to see. The different experiments that we conducted showed that, after a short training period, farm advisers or students could use it (BellaubiFava, 2004; Penot et al., 2004; Le Grusse et al., 2006). In our case using it for a review of the concrete problems faced by decision-makers proved to be an excellent preparation for a global approach (Carmona et al., 2007).

The simulation game is based on the same type of data and on the use of Olympe software. It is a natural extension of the previous approach to show the need for co-ordination between different decision-makers and the value of negotiating to establish a set of applicable rules. It is very educational though rather time consuming. Its use by students is certainly possible, but its use by real decision-makers remains to be demonstrated.

In fact, these different approaches are very complementary and can be used successively. The initial data collection phase and their validation are a fundamental step. Once such data are available, a decision-makers' working group can be created by asking questions and analysing answers. In this way, a true dialogue can start about real problems that will avoid solving "false" problems in a merely academic way.

5. Discussion and conclusions

Over the past few years, many instruments have been developed for individual decision-making. Optimisation and simulation models have frequently been used. The choice between these approaches depends on the one hand on the user-friendliness of the tools, and on the other hand on basic assumptions about the ability of decision makes to make rational decisions.

In this paper, we have shown that global models and simulation games are not in opposition but can be used sequentially and can be adapted to a specific problem. The "real" problem may not be clear at the beginning but will emerge progressively with the use of such tools.

Different tools are now available: some are already operational and are in use; others are still in the research stage and require improvement and/or validation (Le Bars et al., 2005).

But whatever the quality of the tools used to solve problems, their use is meaningless if we do not benefit from the support of a group of stakeholders concerned by the problem at different levels and by the changes in the way the problem is formulated.

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