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ZonAgri: A modeling environment to explore agricultural activities and water demands on a regional scale

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ABSTRACT

To design integrated water management for a whole region, all agricultural activities need to be taken into account together with their irrigation water requirements and agricultural outputs. The aim of this paper is to present a modeling environment, called ZonAgri, that allows agricultural activities to be represented at regional scale and enables prospective scenarios concerning these activities to be tested. The modeling of agricultural activities is based on typologies of farms and production units (i.e. plant cropping systems) using a simple framework. A region is designated as a set of "sectors" that correspond to geographical spaces; each sector is designated as a weighted (by strength) sum of "farms". A "farm" is designated as a weighted (by size) sum of "production units" that can be linked with specific geographical "sites" in the region. Each "production unit" consumes inputs and produces outputs that can have prices. This framework allows the aggregated calculation of inputs and outputs, as well as of the incomes of farms, sites or sectors. Scenarios can be built to change the original values or to envisage changes that may occur over a period of several years. The results of multi-year simulations make up the database. The information contained in the database can be requested by area or by sector, and can be mapped and exported to be used in a GIS. Maps of agricultural activities or water demand can then be superimposed on maps of water resources and hydraulic facilities to check if they are consistent.

ZonAgri software was used to model agricultural activities in a plain in central Tunisia where irrigation depends on pumping from the water table. The resulting model enabled estimation of water demand for irrigation from public and private wells and the valorization of the water through agricultural outputs. In our case, the model was then used in collaboration with stakeholders to evaluate the effects of water tariffs or market prices on farm incomes. It could be also used to simulate farmers' reactions concerning their crop choices or irrigation practices.

Interactions between activities or between resources and uses cannot be modeled using the framework. However, representing these interactions would result in intricate models, and in addition, such interactions would change as a function of changes in production systems. It is thus more efficient to build simple models that enable stakeholders to understand the consequences of possible changes in their activities and the interactions between end uses of the water resource.

1. Introduction

For many years, water management was only based on supply, i.e. increasing water availability in terms of volume and of spatial and temporal distribution. Today however, it is increasingly necessary to manage the demand for water (Brooks, 2006) to prevent over-exploitation of free-access water resources, such as groundwater (Foster et al., 2000). How can water demand be managed? For the World Bank, management of water demand includes a set of different actions that can modify the parameters that affect water consumption (Berkoff, 1994). These parameters are linked with technological, institutional, economic and social mechanisms (Froukh, 2007). In the case of irrigation water, it is thus important to focus analysis on the farms where the choices of crops and techniques are made. These choices may change depending on changes in the technological and socio-economic context (Brush and Turner, 1987), especially crop choices that depend on incomes linked with the cost of inputs and the sales price of products. Thus, according to Lambin et al. (2000), the ability to represent farming systems and to test several changes is probably more important than the accurate estimation of crop water requirements through agronomic models.

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The balance between water demand and water offer has to be made at the level where the water resource can be managed or defined, i.e. an irrigation scheme, a water table or a watershed. To explore the demand for irrigation water at this "territorial" or "regional" scale, we therefore chose to focus on the farming systems. This can be done in two ways: by optimizing farming systems in response to policies and prices (Scheierling et al., 2006; Bartolini et al., 2007) or to environmental constraints (e.g. Sadeghi et al., 2009), or in collaboration with the stakeholders, by simulating changes in farming systems in response to such policies and prices. This second way is similar to the companion modeling approach suggested by Bousquet et al. (1999). Le Bars and Le Grusse (2008) chose this way at the scale of an irrigation scheme to facilitate the emergence of "compromise" solutions between farmers and dam managers. These authors built a farm typology and used a decision support system at farm level and a simulation game for collective decision-making. In this study, we chose to use the same approach by designing a conceptual framework to represent agricultural activities at regional scale. This framework suggests a nested representation of production activities from the regional to the plot scale, based on the typologies of farms and of plant and animal production units. Based on this conceptual framework, the modeling environment software, "ZonAgri", was developed to build computer-based simulation models of agricultural activities at regional scale. The regional simulation model can be used to estimate agricultural consumption (especially water for irrigation), outputs and income, and, in collaboration with the stakeholders, to explore possible changes in farming systems. As agricultural activities are generally associated with spatial location (Hessel et al., 2009), the results can be visualized on maps or used in a GIS.

The aim of this paper is to present our conceptual framework to represent agricultural activities at regional scale and the modelling environment ZonAgri that derives from it. To illustrate the features and use of ZonAgri, we then built a model of the Kairouan plain in central Tunisia, where the water table is overexploited for irrigated agriculture.

2. Conceptual framework

Thornton and Jones (1997, 1998) used optimization modeling to represent changes in agricultural land use. They proposed a framework to model agricultural land use: farmers own production activities implemented at specific sites that define production constraints and performances. The aim of their model was to maximize gross margins taking farmers' preferences into account. Matthews et al. (1999) used a similar methodology for rural land-use planning. In this study, we chose the simulation approach suggested by Le Bars and Le Grusse (2008), i.e. building the model with stakeholders, comparing regional water demand with water availability, calculating possible impacts of changes in water availability, prices or policies on farm incomes, and testing changes in production activity in response to these changes. This "participatory approach" in which stakeholders collaborate in modeling and in the development and testing of scenarios was also suggested by Walz et al. (2007) for integrated regional planning.

Trying to take into account the whole complexity of agricultural activities would result in a more realistic model but such a model would be difficult to use and to extend. So, following Thornton and Jones (1998), we chose a top-down approach that was kept as simple as possible: a region was designated as an aggregation of farms, and each farm was considered as an aggregation of agricultural activities distributed at several sites or sub-spaces of the region. This nested representation was based on a conceptual entity representing one production activity.

2.1. The "production activity" entity

The "production activity" (PA) entity designates a simple or composite activity that can be associated with a spatial location. A simple PA consumes inputs (e.g. m^3 of water, days of labor, tons of fertilizers) and produces outputs (e.g. tons of wheat, hectares of stubble for cattle, kg of nitrate in soil); the quantities of inputs and outputs are defined by a production function associated with the entity. A composite PA is an aggregation of PA entities; its production function defines how to aggregate the sub-activities. Following the principle of simplicity, this function is a weighted summation of sub-activities, each weight (w_i) representing the contribution of the sub-activity to the overall PA. Relationships between sub-activities can be represented for example using a given weight as a function of the other weights (i.e. $w_i = f(w_j)$). The PA entity is not specific to an agricultural sector. Inputs and outputs of PA can be different (e.g. employment, calories, mouths to feed).

This conceptual entity thus does not enable representation of the multiple relationships between activities outside a given PA entity. Such relationships consequently have to be "managed" outside the model. But the simple model enables changes in such relationships to be taken into consideration in collaboration with the stakeholders through changes in the farming systems: relationships between farms within the region or between production units on a given farm.

2.2. Framework for agricultural activities at regional scale

A region is designated as a composite PA entity associated with a geographical area (Fig. 1). The region (a watershed, for example) can contain several districts. The PA "region" thus contains several sub-PA entities, called "sectors" that are associated with the first spatial subdivision of the whole area. All the weights associated with sectors are equal to 1.

Each sector is a composite PA entity that contains farms. The representation of the diversity of farms is based on a typology of farming systems (Dobremez and Bousset, 1995; Landais, 1998). Each sector thus contains PA entities that correspond to farm types and weights that correspond to the strengths of the farms.

A given farm type contains several production units (a plant production unit corresponds to a cropping system, an animal production unit corresponds to a livestock system or to intensive indoor production) that can be associated with the sites at which they are implemented (association with a spatial area is optional). The sites correspond to the second spatial subdivision of the whole region. A farm type is thus an aggregation of production units weighted by their size.

Concerning farms, the diversity of production units in the region is represented using a typology. A production unit is a simple PA entity that consumes inputs to produce outputs. Their weighting corresponds to the unit quantities consumed and produced. Inputs and outputs can have prices, enabling the unit income of the activity to be calculated.

Inputs and outputs and income can be aggregated at several levels: sites, farm types, sectors or the whole region using the production functions of the PA entities.

3. The modeling environment "ZonAgri"

3.1. Design

Modeling agricultural activities at regional scale at a yearly time step corresponds to the definition of a database whose structure results from the different entities defined. The region is a set of