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Simulating farming practices within a region using a stochastic bio-decisional model: Application to irrigated maize in south-western France

D. Leenhardt[a,*], L. Maton[a,b], J.-E. Bergez[a]

[a] INRA/INP-Toulouse, UMR 1248 AGIR, 24 Chemin de Borde Rouge, Auzeville, CS 52627, F 31326 Castanet Tolosan Cedex, France
[b] Syndicat Mixte du Bassin de Thau, 328 quai des moulins, F 34200 Sète, France

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ABSTRACT

Agricultural is a major contributor to environmental resource management problems. Modelling the distribution of agricultural land use to evaluate current situations or scenarios is an important issue for policy-makers and natural resource managers. A promising approach is the use of bio-decisional models based on decision rules. However, at the regional scale, the large number of farmers makes it difficult to identify decision rules, and the diversity of farmers' decisions is rarely considered. To this end, we developed SIMITKO, a spatialised and stochastic bio-decisional model, able to simulate the spatial and temporal variability in farming practices. We focused on the choice of varietal earliness and sowing practices of maize (*Zea mays* L.) in the Baïse sector (south-western France). Model development was based on statistical analyses of surveys of farmers' practices to identify their current strategies, the best variables to describe the practices and the probabilities associated with the values of the variables for each strategy. We tested SIMITKO by simulating the dynamics of areas sown with maize. Comparing model predictions of practices to observed data showed generally good predictions of sowing dynamics but less satisfactory predictions of varietal earliness choices. Possible improvements are suggested.

1. Introduction

Land use is responsible for many natural resource management problems (Lesslie et al., 2006). Agricultural land covers approximately half of the land area in many countries (e.g. Argentina, Australia, France, Italy, Mexico, Spain) and is a major contributor to these problems. Natural resource managers and policy-makers require tools to help better manage resources and evaluate scenarios of context changes or management options (e.g. Fulton et al., 2015; Steinfeld et al., 2015). To be effectively used by managers to solve complex management problems, these tools must represent correctly the resources and their environment (the landscape) and approximate well their behaviour in respect of the real thing (Parker et al., 2002).

The spatial and temporal configuration of agricultural land in a given region depends on the cropping systems used by farmers (Barson and Lesslie, 2004). It may be feasible to use experimental monitoring to estimate impacts of current cropping systems on the environment or on the evolution of natural resources. However, the use of modelling and simulation is a better approach to isolate interacting factors (e.g. climate) or to study impacts of alternative cropping systems at a regional scale and for a variety of weather conditions (Jakeman and Letcher, 2003). To develop such models, it is necessary to represent the decision-making processes of farmers across the region, which determines the succession of technical operations and their distribution across the area (Leenhardt et al., 2010).

Bio-decisional models have been developed to simulate farmers' technical decisions at the field scale. These models are based on decision rules, i.e. functions linking indicators of the system (e.g. weather; state of the plant, the soil, and resources), to actions (e.g. fertilisation, irrigation, harvest) (Bergez et al., 2010). A set of decision rules translates a farmer's strategy into an operational activity to reach a given objective to use resources according to constraints imposed on the farm. The model MODERATO (Bergez et al., 2001) simulates farmers' irrigation decisions to trigger or delay irrigation. The model DECIBLE (Chatelin et al., 2005) simulates fertilisation decisions for wheat. At the regional scale, i.e. on extents where the number of fields and farms is so great that it is impossible to enquire each farmer or go to each field, practices are likely to

* Corresponding author. Fax: +33 5 61 73 55 37.
E-mail address: Delphine.Burger-Leenhardt@toulouse.inra.fr (D. Leenhardt).

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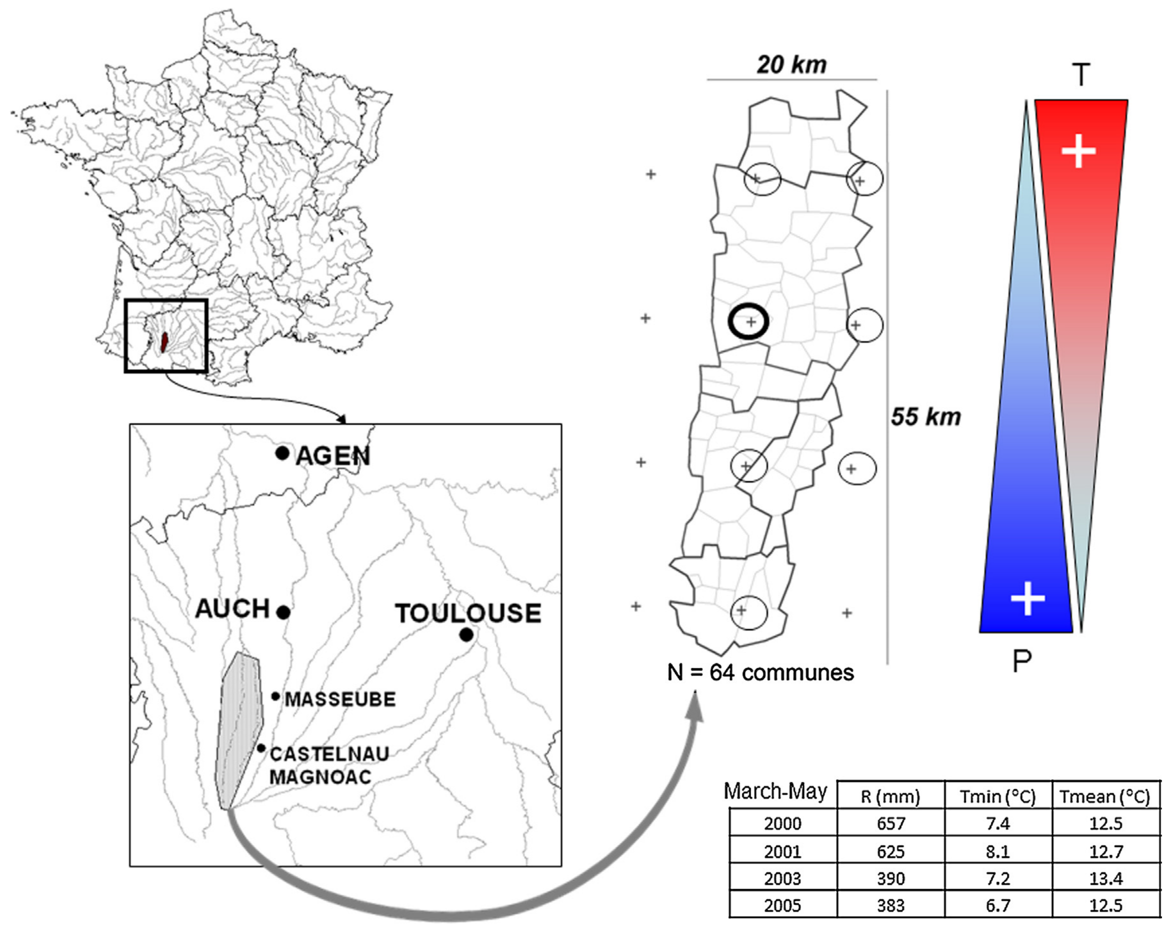

March-May	R (mm)	Tmin (°C)	Tmean (°C)
2000	657	7.4	12.5
2001	625	8.1	12.7
2003	390	7.2	13.4
2005	383	6.7	12.5

Fig. 1. The Baïse sector, approximately 55 km long (north–south) and 20 km wide (east–west), is located in south-western France. It includes 64 communes, corresponding to the LAU 2 level of the European Union nomenclature of territorial units [1] (light lines), and intersects 6 small agricultural regions (bold lines). Plus signs (+) represent the closest weather grid points (encircled signs were used in the simulations). The area has a north–south gradient for rainfall and temperature and interannual variability (bottom right table) in rainfall (R), minimum temperature (Tmin) and mean temperature (Tmean) from March to May at the most central grid point (bold circle). [1] http://ec.europa.eu/eurostat/documents/3859598/5916917/KS-RA-11-011-EN.PDF.

vary greatly. Accounting for this variability is important for natural resource managers because of its effects on studied impacts. For example, combination of particular practices under specific soil-weather conditions provokes water crises, but at the same time, variability in sowing or irrigation dates among farmers may reduce and spread peak water withdrawals (Murgue et al., 2015). At the regional scale, the large number of farmers makes it difficult to represent variability in practices, and specifically, decision rules. Leenhardt et al. (2004) overcame this difficulty by using a single set of decision rules for an entire region. Indicators and their threshold values did not vary, regardless of the location of the farm. The distribution of simulated actions (dates and quantities) at the regional scale was due to spatial variability in weather and soil and not to the diversity of farmers' strategies. However, as Dury et al. (2013) demonstrated for crop rotation, farmers' strategies vary greatly and depend on factors both outside and on the farm. Representing farmers' decisions via typologies linked to structural identifiers is a first step in considering the diversity of farmers' decisions at the regional level (Poussin et al., 2008). In our article we go further and present a spatialised and stochastic bio-decisional model which statistically represents a variety of behaviours.

In the agricultural domain, stochastic modelling is used to consider the uncertain character of natural processes (notably the weather), the production context (e.g. selling price of products, input costs), or the spatial variability in characteristic processes in the environment (e.g. weather, soil). These are usually deterministic simulation models which are run many times while varying the input data. Acutis et al. (2000) evaluated and compared water use and nitrate losses of cropping systems under variable weather conditions and different soil physical properties. Rosenzweig et al. (2013) used stochastic weather-pattern generators to provide varying weather inputs to crop models whose predictions were then compared. Clancy et al. (2012) used a budgeting model in a stochastic way by considering distributions of costs, yields and prices to estimate distributions of financial returns from willow and *Miscanthus*. The use of an intrinsically stochastic model, i.e. a model whose equation parameters vary from one simulation to another, is uncommon and is mainly done to model biophysical processes. For example, Iizumi et al. (2010) used Bayesian approaches to obtain the distribution of biophysical parameters of a simulation model and used this distribution to calculate agronomic and environmental variables. Another example is Graefe et al. (2010), who developed a process-oriented and stochastic simulation model for asparagus growth and yield. Stochastic modelling is rarely used to consider the variable character of farmers' decisions.

The Landsfacts model (Castellazzi et al., 2007) is a rare example; it allocates crops to fields in a region according to a stochastic and rule-based process which includes the rotational principles and agronomic constraints to which the farmers are subject. This example only applies to rotation decisions (i.e. choice of crop) and not to other technical decisions of cropping techniques, such as the choice of cultivar earliness, sowing date, irrigation, and