Modelling regional land use: articulating the farm and the regional levels by combining farmers' decision rules and regional stochastic regularities

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The spatial organization of agricultural landscapes impacts many major ecological processes such as biodiversity, soil erosion or water pollution. In order to favourably orientate these processes, it is necessary to understand how landscapes are spatially organized and to identify the driving forces sparking off this organization. The spatial organization mostly results from individual farmer decisions made in different farming territories and dealing with annual crop choices and allocation to land. Even if individual, some of these decisions can be generic and result in spatiotemporal regularities that can be identified at the landscape level. Identifying the determinants of individual decisions impacting the spatiotemporal landscape regularities and organization is a key step for helping in designing environmental policies.

This paper proposes a coupled analysis of (1) farmers' decisions driving the spatio-temporal organization of their farming territory and (2) stochastic spatiotemporal regularities at the landscape level. These two approaches have been commonly used by agronomists, but so far in separate ways. This paper aims at combining them for modelling regional land-uses.

Methodology

On the basis of the Niort plain region (France) example, we propose to identify the main characteristics of the two approaches and to build links between them.

(1) The identification of farmers' decision logics requires specific on-farm surveys and a representation of decisions through a generic framework including decisional variables, rules and their internal or external determinants. For allocating crops to land at farm level, such descriptive variables have been identified as: suitable cultivation area (SCA) for each crop (all suitable plots for the considered species), crop return time (acceptable time to replant the same crop on the same plot) or preceding-following crop pairs (acceptable temporal crop sequences) (Navarrette and le Bail, 2007). Rotational principles may then be expressed for each farm and tested with the farmer. These on-farm understandings of land allocation and rotational principles are now considered as the determinants of regional patterns detectable by statistic methods (Castellazzi et al, 2007; Mignolet et al, 2007). We applied this method to describe farmers' decisional variables and their determinants dealing with the management strategies of alfalfa production and irrigated corn in the Niort plain.

(2) Stochastic modelling for data mining is a convenient way of building statistical and probabilistic models capturing spatiotemporal data variability. These models try to fit the observations – land use (LU) or temporal LU successions – made at the regional scale according to some streamlined assumptions. The Markov chain assumption assumes that the distribution of LU at time *t* – the blocking plan – depends on the previous observed blocking plans. The Markov random field assumption assumes that the probability of observing a particular LU at a given place depends only on the neighbouring LU. We used this modelling framework to cluster the landscape of the Niort plain into patches with well-characterized distributions of LU or LU successions (Lazrak et al., 2010) and to mine their time-spatial relationships. Once we had identified landscape spatiotemporal regularities in the Niort plain, we compared them with farmers' decisions identified with on-farm surveys and assessed the coherence of the combined results.

Results and discussions

Results of farmers' surveys showed two management strategies for alfalfa. On arable farms, alfalfa when cultivated only represents a diversification crop. Its SCA is thus restricted to a few plots stable over time and with alfalfa of the same age. On the contrary, on dairy farms, alfalfa is cultivated for auto-consumed fodder production. Considering that alfalfa yield depends on its age, breeders want to have alfalfa plots of each age to stabilize the annual fodder production. The SCA is thus larger: alfalfa of different ages is included in commercial crop sequences either on several plots in a scattered farm territory, or in a patch made of contiguous plots in a compact farm territory.

The stochastic clustering of the Niort Plain landscape exhibits a class of patches characterized by frequent items where alfalfa of different ages appears in the spatial and temporal vicinity of alfalfa and other arable crops (e.g. wheat, corn, barley). This preliminary result suggests that the above described breeders' decision rule is likely to prevail over this class. Further data mining and/or GIS investigations on this specific class would be required to more precisely characterize the regional extent of this rule.

The second example illustrates how a regional statistical regularity can make sense when combined with on-farm survey results. The data mining of LU evolution in neighbouring locations over the 1996-2007 period shows that corn became less frequently close to sunflower, rapeseed and forests while it became frequently closer to grasslands. In parallel, the total corn area decreased while the grasslands area slightly rose over this period.

These regional regularities are consistent with the results of farmers' decisions dealing with corn management in a local context of increasing irrigation bans (Martin et al., 2009). Farmers' adaptation strategies to this changing context partly depend on their farming system and access to deep soils. When they have access to deep soils on their farm territory, the SCA for corn consists of these soils: corn is grown as a monoculture and in the vicinity of grasslands traditionally located in deep and humid soils. When farmers have no access to deep soils, their crop choices mostly depend on the farming system, the annual fodder needs and the irrigation capacity (modulated by a risk of restriction). Thus, corn tends to decrease on arable farms where it is not a priority crop, while it is mainly maintained on breeding farms with access to irrigation. In parallel, since irrigated corn production is increasingly risky, breeders tend to extend grasslands to complement fodder production. This decision is consistent with the fact that corn is statistically becoming closer to grasslands: it is mostly maintained on breeding farms with significant grassland areas on their farm territory.

As a conclusion, this methodological work shows that these two approaches aid one another: stochastic regularity modelling in the appropriate areas at the regional scale reveals and validates some generic farmers' decisions identified first by on-farm surveys. Conversely, a diversity of farmers' decisions can explain *a posteriori* some regular landscape patterns and/or its evolution over time. Linking the two methods gives thus the possibility to assess the coherence of the combined results, to decrease time spent for collecting data about regional LU drivers and to bring a more valuable meaning to the regional regularities by introducing elements of causality.

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