Use of crop sequences for data-mining of remotely sensed time series across multiplescales: opportunities for scaling up research on agricultural dynamics

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1 Introduction

Farming activities are rapidly evolving thanks to technological improvements, even though global statistics indicate a stagnation or a collapse in total yields for major crops. Further improvements require therefore agronomists to enhance the ways they address the farming use of land and water(Acevedo 2011). Considering the limitedness of these two resources farming would definitely benefit from smarter spatial design of cropping and mixed crop-livestock systems(Dury *et al*. 2013; Moraine *et al*. 2014; Murgue *et al*. 2015). Moreover, researchers both from agronomy (e.g., Boiffin *et al*. 2014; Leenhardt *et al*. 2010) and from interdisciplinary approaches, such as the land change science (Rounsevell *et al*. 2012) and the ecoagriculture(Scherr & McNeely 2008), call for stronger integration of farming features in the research on land management systems. Accordingly, it is crucial to scale up the research on farming systems from plot/farm level to landscape level (Rizzo *et al*. 2013; Thenail *et al*. 2009) so as to build farming system design upon an improved understanding of the land patterns determined by the interactions between farming practices and natural resources (Benoît, Rizzo*et al*. 2012). This impliesto addressin a spatially explicit way how farmers are choosing what to cultivate and the way to manage it, hence dealing with farming systems from a landscape agronomy perspective. Such an approach, however,largely depends from the availability of data over large areas and for long periods and on the methods to tackle them.Our aim hereby is to present a data-mining method to handle land cover sequences. In particular, we will discuss how segmenting a landscape by using the observed land cover sequences can help identifying flexible land units and their potential for cross-scale farming system studies.

2 Materials and Methods

The methodwe present provides a spatial wise synthesis of land cover sequences to get the most out of available datasets in terms of farming features. In this regard, we make the hypothesis that the observation and modelling of land cover sequences, with a focus on crops and pastures, can incorporate a relevant part of the farmers' medium-term decision-making processes(Schaller *et al*. 2012). The method isbased on stochastic segmentation with *hierarchical*Hidden Markov Models(HMM) whose spatial states are temporal HMM capable of assigning a probability to a time sequence. It was originally developed to handle large and labor-demanding survey datasets like TerUti(Mari & Le Ber 2006).

The method firstly identifies temporal regularities of the crop/grassland sequences, then use them to segment into homogeneous patches the study area (potentially ranging from farmland to region). In summary, the method includes three steps (Fig. 1a): data preparation, model topology choice and parameterization, model training on data and time-space segmentation(Mari *et al*. 2013). The method builds upon aMarkov field hypothesis that considers theland coverof a given locationas depending onlyon the land covers of the neighboring locations. Accordingly, the input data – sampled on a regularly spaced point grid – are scanned with a fractal curve where each point holds a time sequence of land covers. The key features of this approach and its potential for a landscape agronomy perspective on farming systemsare illustrated referring tothe Yar case study, a watershed of 61.5 km² (Brittany, France) where the main crops – maize, wheat and grasslands – are relatedto industrial breeding. A 12-year time series (1997-2008)of satellite images was classified into 6 land cover classes for individual field polygons, then sampled with a 20m regular point grid.

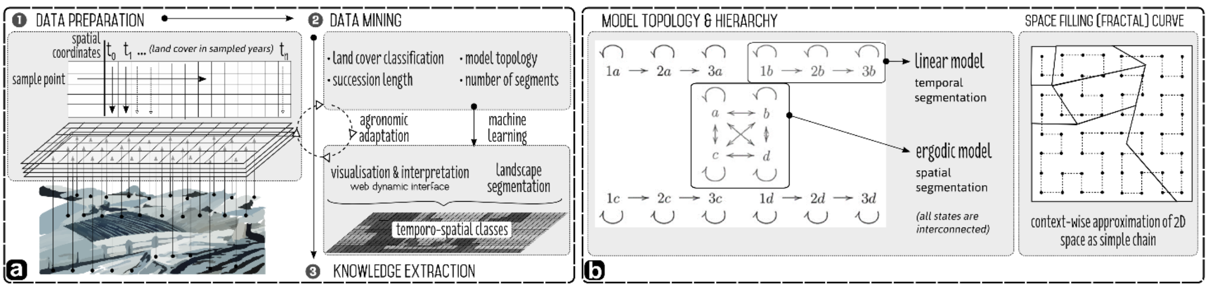

Fig. 1. Schematic diagrams of the method: (**a**) steps and parameters, (**b**) model topology and hierarchy.

3 Results - Discussion

The interpretation of results lead to revise the model parameters in an iterative and interactive process with domain specialists; for instance different sequence lengths and numbers of landscape segmentations were tested and compared. Althoughinput maps derived from remote sensing were thematically less diverse than those derived from field surveys, time-space segmentation revealed some interesting spatial dynamics of land cover sequences. Finally, we distinguished permanent from temporary grassland and identified and localized the type of rotations in which temporary grasslands were involved. Of interest, these crop sequences faced major changes after 2003, identifyingpossible hotspot zones at the origin of the high nitrogen rates observed forseveral years in the local rivers. Hence, our approach provided relevant insights to better understand the agronomic relations between landscape patterns and natural resources that can be highlighted at the watershed level(cf. Dusseux *et al*. 2011).Generally speaking, farming system study requires the use of different data sources for being studied in a landscape perspective. Yet, available land cover maps rarely ensure continuity in time, seamless covering of large areas and detailed crop classification. Data about farming management are even more difficult to retrieve, also because of the continuous adaptations of agricultural techniques implemented by farmers in response to complex driving factors (Landais & Deffontaines 1988). Altogether, in-farm surveys still appear the best way to achieve an adequate description of local cropping systems, even though it is a highly time-demanding activity, thus generally limited to small areas or for short periods. However, some land cover dataset like the French TerUti(cf. Xiao *et al*. 2014) or the European Land Parcel Identification System (cf. Murgue*et al*., 2015) appear to provide promising bases to reconstruct agricultural land cover sequences. Advances in remote sensing can further help facing the lack of data, at least about agricultural land cover maps, although improvements are still needed to increase thematic detail (i.e., improving the list of identified crop types). In this perspective, the major novelty of ourapproach is to processes time-space data in a time-dominant modeling framework, so as to propose an effective approach to visualize specific patterns that occur repeatedlyor in sequence and constitute units that are geographicallylocated.It already proved its applicability at different scales (cf. Mignolet *et al*. 2007; Xiao *et al*. 2014). Indeed, fostering patches of similar land cover sequences supports a multi-scale approach ranging from farmland to regional areas including multiple farmlands(Schaller *et al*. 2012)thus allowingto go beyond the inter-annual local variability of patterns and expected rotations.

4 Conclusions

The watershed segmentation into patches of land cover sequences is an innovative approach to identify land management units relating farmers' choices and natural resource management. Accordingly, it could inform local planners'decision-making by providing spatially explicit insights about farming system dynamics. In perspective, this can ultimately facilitatea shared landscape design allowing account to be taken of the diversity in farming systems.

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