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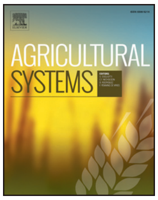

A framework for designing multi-functional agricultural landscapes: Application to Guadeloupe Island

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ABSTRACT

To improve agriculture faced with regional sustainability issues, agricultural landscapes providing a diversity and high level of ecosystem services are necessary. We have developed and tested the MOSAICA-f framework to build innovative multi-functional agricultural landscapes that can consider explicitly: 1) the performance of cropping systems at the field scale, 2) farmers' decision processes on the adoption of cropping systems, and 3) possible scenarios for innovations and policy changes at the regional scale. This framework is based on a scenario approach that encompasses normative, exploratory and optimized scenarios to assess the relevance of combinations of new agricultural policies, changes to the external context (market and regulations) and innovations in cropping systems. The impacts of these changes on sustainability issues are simulated using the regional bioeconomic model MOSAICA for farmers' decision processes regarding the adoption of cropping systems at the field scale throughout a region. Applied in Guadeloupe (French West Indies), the MOSAICA-f framework enabled the design of a scenario increasing agricultural added value, food and energy self-sufficiency, employment and the quality of water bodies and reducing greenhouse gas emissions. This sustainable scenario combines new cropping systems tuned to farm types with a reorientation of subsidies, an increased workforce and banning food crop production on polluted soils. It can be used to understand the potential contribution of agriculture to sustainability issues and to help local decision makers define policies that will account for the spatial diversities of farms and fields in a landscape. Beyond the design of such a win-win scenario, MOSAICA-f has revealed trade-offs in the provision of services by agriculture.

1. Introduction

Agricultural landscapes account for one third of the land used by humans worldwide (FAOSTAT, 2008). While agriculture has constantly increased food production, it is responsible for other positive and negative environmental, economic and social impacts at the global and local scales (Tilman et al., 2002). Although agriculture can ensure the production of food, energy, materials and services for society (including the alleviation of poverty), agriculture faces several sustainability problems, such as climate change and water and soil pollution. The ability of agriculture to provide multiple services in a sustainable manner is therefore being questioned (Klapwijk et al., 2014).

Agronomists have been designing new agricultural systems at the field and farm scales in order to improve sustainability. However, the design of innovative agricultural systems at these scales has certain limitations when addressing regional and global issues. For instance, at the field scale, some cropping systems may fail to respond to sustainability issues defined at the regional scale because of the low scaling integration and spatial heterogeneity at the regional scale (Dale et al., 2013). Agronomists must therefore integrate a landscape perspective when designing new agricultural systems adapted to local regions, and when addressing sustainability challenges at the regional scale (Dale et al., 2013, Benoît et al., 2012). The design of such systems at the regional scale will result in new crop compositions and organizations in landscapes that supply different ecosystem services (Castellazzi et al., 2010; Benoît et al., 2012; Schaller et al., 2012).

To determine whether a particular combination of factors such as agricultural policies (e.g. changes to subsidies, bans on certain inputs), the social context of agriculture (e.g. new markets) and the characteristics of cropping systems (e.g. new crops, new management) can drive agricultural change towards sustainability or have unexpected adverse outcomes, a scenario analysis using an integrated agricultural landscape model is required (Wei et al., 2009; Carmichael et al., 2004). In this case, an integrated model refers to one that includes different spatial scales in the decision-making processes of farmers and relative to different sustainability domains. The "drivers of change" represent potential

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causes of modifications to the characteristics of farming systems and their combinations at the landscape level, which will induce changes to the degree of sustainability that can be assessed using indicators (Florin et al., 2013).

Agricultural science has already used scenario analysis coupled with integrated models to analyse a wide range of sustainability issues relative to agricultural systems (Heckelei and Britz, 2001; Kropff et al., 2001; Van Ittersum and Donatelli, 2003; Arfini, 2005; Verburg et al., 2006; Bryan et al., 2011). However, the scenarios implemented in model-based landscape frameworks tend to focus on a given type of scenario, based either on exploratory "what-if scenarios" (Therond et al., 2009) or on the optimization of other indicators in the systems (Hengsdijk and van Ittersum, 2002; Groot et al., 2007) in order to determine targeted outputs for different objectives. These studies do not satisfactorily combine the different types of scenarios necessary to understand the functioning of agricultural systems and their impacts at a regional scale.

Moreover, some of these studies do no account for interactions between scales when trying to identify the factors driving spatial dynamics (Houet et al., 2014). Several modelling frameworks do not integrate the regional scale when assessing the services provided by farming systems (Janssen and van Ittersum, 2007; Riesgo and Gomez-Limon, 2006; Parra-Lopez et al., 2008) while others take no account of the field scale (Schönhart et al., 2011). Model-based frameworks based on bioeconomic models are seldom spatially explicit with regard to impact assessments of cropping systems due to a lack of information on field and farm locations (van Ittersum et al., 2008; Delmotte et al., 2013), and their impact assessments are not spatially located within an area of study (Meyer, 2007; Veysset et al., 2005; Gafsi et al., 2006; Van Ittersum et al., 2008; see the SEAMLESS project at http://www.seamless-ip.org/).

Chopin et al. (2015b) presented the MOSAICA regional bio-economic model and an example of its application for scenario design in Guadeloupe, based on a preliminary characterization of the diversity of farming systems (Chopin et al., 2015a). In the present paper, we propose a methodological framework for the design of scenarios for landscape evolution using this bio-economic model. This framework, called MOSAICA-f aims to build innovative multi-functional agricultural landscapes. This enables the representation of agricultural landscape changes under different drivers and assessment of their contributions to sustainable development at the regional level. The finality of the framework is to: i) gain step-by-step knowledge regarding the possible futures of agricultural landscape organization, and ii) identify the relevant changes to agricultural policies, the social context of agriculture and the characteristics of cropping systems needed to build multi-functional agricultural landscapes.

2. The MOSAICA-f framework

The framework presented in the paper aims to use the MOSAICA bioeconomic model in an iterative manner in order to aid the building of multi-functional agricultural landscapes. The model is applied in several steps involving different types of scenarios in order to understand the potential for improvements to the landscape in terms of their contribution to regional issues and to identify relevant drivers for change that will optimize their contribution.

2.1. The MOSAICA-f framework to define a multi-functional scenario

Our model-based framework consists of five steps (Fig. 1), each combining three framework components: scenario development, modelling and assessment. The loop between steps 2 and 4 is repeated for each sustainability indicator (Table 1).

- *The first step* is calculation of the reference contributions of agriculture to sustainable development using a reference mosaic of cropping systems. This mosaic is obtained from calibration of the model to the base year in our case study, which is explained in Chopin et al. (2015b). Several sustainability issues are selected. To assess the contribution of the reference mosaic to these issues, several indicators are used in the assessment (e.g. Y, W and V representing three given sustainability indicators). Cropping systems are located on each field of the region, and based on these locations, the assessment is performed by calculating the "reference" values for indicators of the contribution of agriculture to sustainable development (e.g. Y_{ref}, W_{ref}, V_{ref}). These references are then used to compare the contributions of mosaics from scenarios with the base year.
- *The second step* involves running optimized scenarios to reveal the potential to adapt cropping system mosaics in terms of their contribution to a set of sustainability issues. This potential represents the ability of the landscape to attain sustainability goals and is thereafter

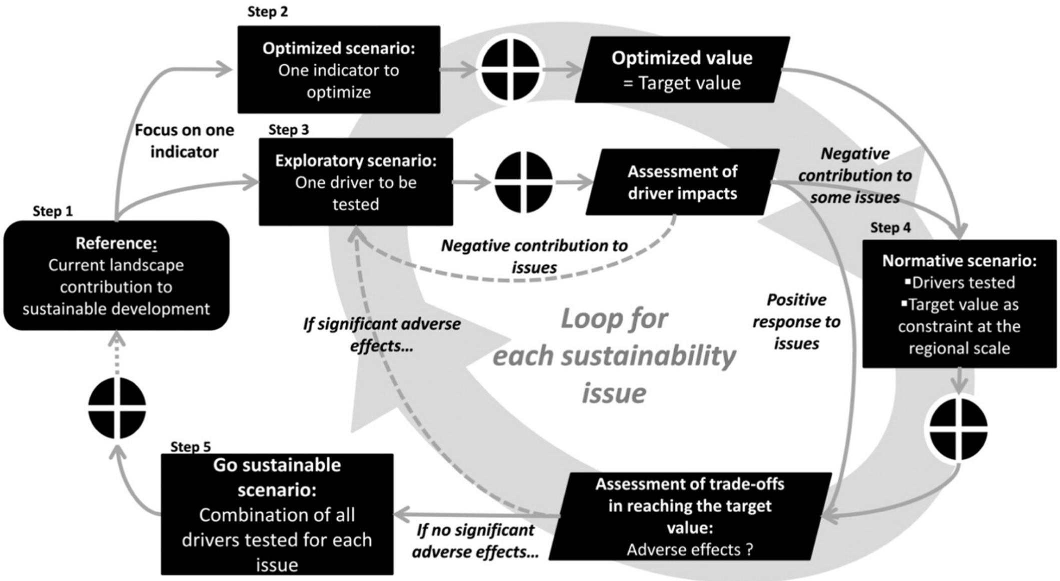

Fig. 1. The MOSAICA-f framework for designing multi-functional landscapes. Steps are represented by a pre-modelling (square), a modelling (circle) and a post-modelling phase (parallelogram).

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