Land Use Policy 62 (2017) 132–142

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

A novel approach for assessing the contribution of agricultural systems to the sustainable development of regions with multi-scale indicators: Application to Guadeloupe

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ARTICLE INFO

Article history:
Received 1 February 2016
Received in revised form
14 December 2016
Accepted 18 December 2016
Available online 4 January 2017

Keywords:
Agricultural landscapes
Indicators
Cropping systems
Integrated assessment
Ecosystem services
Multicriteria assessment
Farming systems

ABSTRACT

The assessment of agriculture at a regional scale is necessary to better guide regional agricultural planning. To improve the contribution of agriculture to sustainable regional development, assessments must take account of the locations and diversity of cropping systems. We have therefore developed a method based on a set of multi-scale indicators to assess the contribution of agriculture to the sustainable development of regions, and its evolution over time. This method can identify: i) sustainability issues, ii) relevant indicators that will provide information on impacts at the field scale, iii) a method to aggregate indicators, iv) data on cropping systems, and v) a database containing spatial units to analyse the whole region. Application of this method to Guadeloupe (2004–2010) enabled the definition of ten issues and 16 indicators, with three procedures to aggregate information from 36 cropping systems allocated to 11,908 fields between 2004 and 2010. Economic, social and environmental sustainability was poor in 2004, with high dependency on subsidies (47.3 M€ yr^{-1}), low agricultural added value (48.5 M€ yr^{-1}), low employment (only 1799 workers), significant risks of crop contamination and pressure on water quality. The total value of subsidies and the risks of river pollution tended to decrease between 2004 and 2010 because of a reduction in intensive banana cropping systems. In parallel, we were able to see that sugar cane, the most widespread crop in Guadeloupe, made only a small contribution to employment and food self-sufficiency during the studied period. The spatial representation revealed that improvements have been seen in southern Guadeloupe due to reductions in banana cultivation. This method was therefore helpful in identifying the most critical agricultural development issues and helping to highlight areas where relevant agricultural land use policies could be formulated.

1. Introduction

Agriculture has strongly affected ecosystems worldwide and been the cause of a broad range of environmental, economic and social issues at the local and global scales (MEA, 2005). Agriculture needs to face these new sustainability issues by increasing its services to society while reducing its negative externalities on the environment. The successful implementation of agricultural policies is often hampered by a lack of knowledge of the impacts of agricultural systems, such as farming systems and cropping systems, on the sustainable development of regions (Reidsma et al., 2012). A farming system refers to a resource management strategy designed to achieve economic and sustained production that will meet the diverse requirements of the farm household while maintaining a high level of environmental quality (Cochet, 2012; Lal and Millar 1990). A cropping system refers to a set of management procedures applied to a given, uniformly treated agricultural area, which in this case is a field or group of fields (Sebillotte, 1990).

Study of the sustainability of cropping systems has produced a large body of scientific literature, together with several sets of economic, social and environmental indicators (Schindler et al., 2015; Carof et al., 2013; Sadok et al., 2009). However, most of these integrated assessments are performed at the scale of the cropping system (Carof et al., 2013) or farm (Rosnoblet et al., 2006) while policies which target sustainability issues (e.g. river pollution) go far beyond field or farm boundaries. Methods for the integrated

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http://dx.doi.org/10.1016/j.landusepol.2016.12.021
0264-8377/

Table 1
Comparison of some examples of methods to address spatially explicit multi-issues assessments of agricultural landscapes.

Category	Method or model	Regional level included (yes/no)	Cropping system diversity (yes/no)	Multi-issues (yes/no)	Spatial explicitness (yes/no)	References
Cropping system assessment methods	MASC	No	Yes	Yes	No	Sadok et al. (2009)
	ROTOR	No	Yes	Yes	No	Bachinger and Zander (2007)
	MODAM	No	Yes	Yes	No	Meyer-Aurich, 2005
Agricultural landscape assessment	SIPPOM-WOSR	Yes	Yes	disease dispersal	Yes	Lô-Pelzer et al. (2010)
	Landsfacts	Yes	Yes	GM pollen dispersal	Yes	Castellazzi et al. (2010)
	I-Pest	Yes	Yes	Water pollution	Yes	Houdart et al. (2009)
Land use studies	ASSESS	Yes	No	Yes	Yes	Hill et al. (2005)
	CLUE-S model	Yes	No	Yes	Yes	Verburg et al. (2002)

assessment of agriculture at a regional scale are therefore urgently required.

At the regional scale, agriculture comprises several fields to which a farmer attributes and manages a cropping system or livestock production system. Regional agriculture is thus the result of farmers' cropping plans managed at the farm scale. Crop composition and crop arrangements play an important role in the environmental processes that take place within a region, such as the spread of pollution (Houdart et al., 2009), erosion (Joannon et al., 2006) or the conservation of biodiversity (Castellazzi et al., 2010), and they exceed the boundaries of fields and farms. In the present case, these large areas of environmental interest are called sub-regional areas and may be rivers, watersheds, or environmentally protected areas, for example. There is therefore a need to be able to assess the contribution of agriculture to the sustainable development of regions that will: i) link the field scale at which cropping systems are operated by farmers, and the regional scale at which regional externalities are generated, ii) be spatially explicit, meaning that they account for the spatial location of cropping systems, and iii) account for the diversity of cropping and livestock systems (Benoît et al., 2012; Sattler et al., 2009; Dizdaroglu and Yigitcanlar, 2014; Tirczka and Ferencsik, 1998).

Indeed, most methods or models used to assess cropping systems focus on the field scale and have produce multi-criteria decision support tools (see Table 1 for some examples of the methods used for the integrated assessment of agricultural systems), but they did not incorporate the spatial location of the cropping system concerned (Carof et al., 2013; Sadok et al., 2008). Furthermore, most agricultural landscape assessments are designed to determine the contribution of agriculture to sustainability issues at a broader level than farms, but focus on a particular issue such as disease spread (Lô-Pelzer et al., 2010) or water pollution by pesticides (Houdart et al., 2009) and no multi-criteria analyses of landscape sustainability have been performed to date. As for land-use studies, the contribution of urban, forest or agricultural land use to regional sustainability is mostly approached in terms of the provision of ecosystem services (Wolff et al., 2015; Lee et al., 2015) but the data on agriculture are too aggregated to account for the diversity of cropping systems (Dossa et al., 2011). This is a drawback because each cropping system has different externalities. For this reason, diversity should be included in a multi-scale assessment (Deffontaines et al., 1995). In France for example, regional planning, development schemes and other regional plans encompassing agriculture land use still adopt a simple view of agriculture. This could be modified by including an agricultural system approach so as to better inform the reorganization of activities and sectors within a region, and to identify both appropriate innovations that will improve the contribution of agriculture to sustainable development of regions and relevant incentives to foster the emergence of such innovations (Boiffin et al., 2014).

Here, we present a method to assess the contribution of agriculture to the sustainable development of regions using a set of multi-scale indicators that account for the location and type of farmers' cropping and livestock systems. This method includes several indicators that enable i) an overall assessment of the contribution of agriculture to sustainable regional development, and ii) a spatial view of the heterogeneity of this contribution within the region under study.

2. Methods

2.1. Overview of the integrated assessment of sustainability at a regional scale

The method we propose comprises five steps: i) the definition of several sustainability goals, ii) the selection of indicators, iii) a description of scale changes, iv) the collection of data describing the cropping and livestock systems, and (v) the creation of a geodatabase of fields which includes the spatial units to which they belong (Fig. 1). The spatial explicitness of this method to assess farming systems is ensured by integrating spatial components from the geodatabase in the scale change procedure, in step 3.

2.2. Description of the five steps

2.2.1. Sustainability issues

Most methods designed for the integrated assessment of agriculture are based on the three pillars of sustainability, which are then sub-divided into different categories. This categorization of sustainability issues matches the objective of assessing the multifunctionality of agriculture in an integrated manner (Bezlepkina et al., 2014). Following the recommendations of Bezlepkina et al. (2014) and Alkan Olsson et al. (2009), the issues are transformed into a goal oriented framework to enable an assessment of the impact of changes to local agriculture on sustainability goals (Alkan Olsson et al., 2009). All issues are either economic, social or environmental, linked to the changes in cropping systems. Hence, issues linked, for instance, to the disappearance of agricultural land are not included since this problem is not directly correlated to the change in the characteristics of cropping systems. The issues include one or more indicators which provide information on the contribution to issues (Bockstaller et al., 2015). Some are local issues that are specific to the study area, while others are global in the sense that they are faced by policy-makers everywhere, such as climate change. The goals include both impacts on agriculture sustainability itself and the impact on a contribution to the sustainable development of society (Alkan Olsson et al., 2009). The list of issues is first established from data in the literature contextualized to the studied area, based on agriculture orientation and planning documents and on local scientific knowledge (Marraccini et al., 2013; Gomez-Sal et al., 2003). A more refined list based on policy-makers' perceptions of