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Ex-ante sustainability assessment of cleaner banana production systems

Pierre Chopin*, Jérôme Tirolien, Jean-Marc Blazy

ASTRO Agrosystèmes Tropicaux, INRA, 97170, Petit-Bourg (Guadeloupe), France

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As one of the largest users of pesticides in the world, banana production is responsible for numerous types of pollution affecting water, soil and air and causing a variety of health issues. Agroecological innovations can help to reduce pesticide use and achieve cleaner and more sustainable banana production systems. Innovations must be well suited to the diversity of banana farms and acceptable to the stakeholders involved in production. We tested the impact of 18 agroecological innovations in Guadeloupe on the sustainability of three contrasted production systems, using the multi-criteria assessment model MASC. These innovations included different types of fallow (A), bans on pesticides (B), conditional applications of pesticides (C), intercropping (D), resistant cultivars (E), and integrated systems (F). In the assessment, we introduced the views of 29 stakeholders involved in sustainability issues relative to banana grouped through three sets of weightings, obtained by direct weighting of the indicators used in a multi-criteria assessment tool. We analysed the effects of each set of weightings on the sustainability level for these different banana production systems. Our results showed that the adoption of innovations can have negative, positive or no effects on the overall sustainability of banana production systems. Although none of the innovations had a positive effect on all cropping systems, some innovations were relevant to several farm types. However, this depended on the sets of weightings considered, because we found several types of stakeholder with opposing views on the importance of sustainability components. Integrated and organic systems produced the best results in terms of increasing sustainability and were relevant to current farming systems. However, in order to obtain cleaner banana production at the landscape scale, a combination of these innovations, tailored to the diversity of farmers' situations and stakeholder preferences, still needs to be proposed.

1. Introduction

Banana is one of the most widely consumed fruits in the world, at 107 million tons per year (FAO STAT, 2013). In most countries in Latin America, the Caribbean, Asia and Africa, farming systems are pesticide-intensive because bananas are produced as monocultures. This has generated numerous social issues, which included health problems experienced by farmers in different parts of the world (Brisbois, 2016), and also other people living near banana plantations (Potera, 2014) and banana consumers (Landau-Ossondo et al., 2009), because of pesticide residues in the fruits or water (Tixier et al., 2007). Intensive pesticide use has also contaminated aquatic (Diepens et al., 2014) and terrestrial ecosystems (Cabidoche et al., 2009) and their associated biodiversity (Grant et al., 2013). Despite these environmental and social issues, banana production represents a very important economic sector in these regions of the world. These issues are at the origin of a call for cleaner and more sustainable banana production throughout the world (Barraza et al., 2011).

The concept of sustainable agriculture, that is capable of maintaining its productivity while preserving ecosystems and non-renewable resources (Ikerd, 1993), is now fully integrated in agricultural research on banana production (Bonicelli et al., 2015). Agronomists seek to design agricultural systems that are environmentally sound, resource-conserving, economically viable, socially supportive and adapted to a changing context (Martin et al., 2013; Christen, 1998). These banana systems need to be designed at the smallest scale, the cropping system, and a set of management procedures applied to a given, uniformly treated area, which may be a field, a part of a field or a group of fields, in order to target

* Corresponding author.
E-mail address: pierre.chopin@antilles.inra.fr (P. Chopin).

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specific sustainability issues related to the local and global context (Sadok et al., 2008). Sustainability represents global stakes to be achieved by the society, but it remains a subjective concept (Wilkins, 2003). To turn this concept into an operational goal, we hypothesize that it needs to be defined locally considering i) the diversity of stakeholders' perceptions of local issues of importance (Yegbemey et al., 2014; Reed et al., 2009), and ii) the diversity of farming contexts (Craheix et al., 2016; Sutter, 2003).

In agronomy, the diversity of stakeholders involved in farming system design introduces a broad range of perceptions and views regarding the expected contribution of agricultural systems to the sustainability of territories and social communities (Mascarenhas et al., 2015). This diversity of perceptions should be taken into account when trying to find the most interesting combinations of innovations that should be encouraged to obtain cleaner and more sustainable production (Craheix et al., 2015). Stakeholder preferences are often translated through weighted social preferences that reveal differences with respect to local sustainable development (Reed et al., 2009; Garmendia and Gamboa, 2012). Therefore, when assessing agricultural systems, these social preferences should be integrated in order to determine whether they give rise to differences in the innovations that need to be implemented by farmers to improve the sustainability of their banana cropping systems. To fulfil the objective of identifying those combinations of practices that will improve the sustainability of banana-based cropping systems, methods have been designed to support the integration of these preferences (Schindler et al., 2015; Carof et al., 2013; Sadok et al., 2008).

In parallel, current farm-scale assessments of the impact of innovation on the sustainability of agricultural systems are made *ex-ante* by means of modelling approaches (Janssen and van Ittersum, 2007; Dury et al., 2012; Acosta-Alba et al., 2012). However, these approaches do not involve multi-criteria assessments that result from aggregating sustainability indicators and permitting a comparison of the impact of innovations with different social weightings on the overall sustainability of farming systems. Some other approaches are only focused on specific areas regarding the sustainability of agricultural production systems, such as the carbon footprint (Roibás et al., 2016) of agricultural products, the energy (Kamp and Østergård, 2016; Ingwersen, 2012) or the water consumed by agricultural activities (Munro et al., 2016). These multi-criteria methods are used *ex-ante* to explore the optimum pathways towards achieving successful innovation processes in agricultural systems.

Likewise, cropping system assessments are often made without considering the diversity of farms that might adopt innovations; this tends to promote the dissemination of uniform crop management systems that are not tailored to the tropical farming contexts in which farmers are managing their banana fields. This lack of farm-scale information limits the systemic approach currently adopted to fit solutions to local conditions (Ikerd, 1993). The characteristics and performance of banana cropping systems are closely linked to the socio-economic and biophysical context of the farm, as well as farmer's personal characteristics and objectives (Chopin and Blazy, 2013; Aouadi et al., 2015; Edwards-Jones, 2006). Integration of the farm context is therefore mandatory if innovations are to fit well into the diversity of banana farms when proposing the best set of innovations that will achieve cleaner banana production and more sustainable cropping systems.

During this study, we performed an ex ante assessment of how agro-ecological innovations could be integrated in banana cropping systems to improve their sustainability. This assessment was carried out in Guadeloupe using the MASC sustainability model (Sadok et al., 2009). The model had been adapted to the local tropical context and integrated stakeholder preferences regarding the banana sector before it was applied to several farm types. After presenting the method that was implemented and the systems studied, we present the results of the assessment and highlight the influence of the farming context and stakeholder preferences on the sustainability levels that can be attained. Finally, we discuss the implications of our study for the ex ante sustainability assessment of innovations in agriculture, and notably with respect to banana production.

2. Materials and methods

A five-step method was developed to test the impacts of innovations on the sustainability of banana farming systems contextualized by farm types with different stakeholder preferences: i) the characterization of cropping systems and farm types, ii) establishment of a list of innovations that would improve the sustainability of cropping systems, iii) adaptation of the MASC model (Sadok et al., 2009) to the type of cropping system targeted and the local context, iv) an assessment of stakeholder perceptions of the importance of various sustainability issues, and v) a sustainability assessment of the initial systems and the impact of innovation per farm type according to the different sets of stakeholder preferences. After introducing the context of banana production in the French West Indies, we present details on the five steps of the method.

2.1. Sustainability issues and banana production in the French West Indies

In the French West Indies, the production of bananas for export plays a key role in the economy of these small tropical island territories. Despite a significant reduction in the banana production area and the number of banana farms since the early 1980s, this structured sector sustains 700 farms occupying an area of 10,500 ha which achieves a final production of 260,000 tons of banana, earning income of €160 million. In a context of high unemployment, the banana sector provides constant work for 6000 people. In order to maintain its sustainability, this sector needs to address numerous economic and environmental challenges. First, economic liberalization has resulted in lower selling prices on the world market; this has undermined the competitiveness of Caribbean production in the face of producers in Latin America and Africa, where labour costs are lower and the operating structures are much larger. This has led to an intensification of production based on banana monoculture, increased ploughing and the use of biocides to control the development of pests. Intensive monoculture practices have resulted in a reduction in soil fertility and in pesticide contamination of both surface water and terrestrial and marine ecosystems (Cabidoche et al., 2009).

To improve sustainability in the sector, plant health and fertility restoration techniques have been developed since the early 1990s. Various studies have reported the usefulness of introducing fallow or service crops in rotation, in particular to control parasitism and thus reduce pesticide use (Chabrier and Queneherve, 2003). Despite the establishment of institutional arrangements to support the introduction of fallow, current adoption levels appear to be low and differ among farm types (Blazy et al., 2009a). Therefore, a new innovation approach that takes account of both stakeholder perceptions and farm diversity is needed to improve the sustainability of banana production.

2.2. Characterization of cropping systems and farm diversity

The population of farmers often covers a variety of characteristics, and hence cropping systems, for production of the same crop.