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Model-based assessment of technological innovation in banana cropping systems contextualized by farm types in Guadeloupe

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ABSTRACT

Farmers are inundated with advertisements about many innovations that are supposed to increase their yields or reduce environmental impact. However, the benefit of these innovations depends on the farming context. Here we present the *ad hoc* adaptation of the crop model SIMBA and a method to evaluate 16 innovations in six types of farms previously selected through a typology of the banana farming systems in Guadeloupe. The innovations include regulation of pesticide use, rotations and fallows, intercropping, conditional application of pesticides, resistant cultivars, and integrated systems. Our results show that, for a given innovation, the yield and pesticide reduction vary widely with different farm types. We show that environmentally friendly innovations often cause a greater decrease in yield in more productive farm types. Nevertheless, despite an apparent trade-off between yield and pesticide use, some innovations address both production and environmental issues, e.g., rotation with fallows improved with cover crops, regular fallows, and rotations with pineapples for the most intensive farm types. Our modelling study confirms the importance of innovation-farm type interactions and the usefulness of models for assessing large numbers of technological innovations among a wide range of biophysical and technical contexts.

1. Introduction

Given the increasing societal demand for more eco-aware farming practices, farmers are faced with choosing among a plethora of innovations, from new cultural practices or cultivars to new pest management planning. In addition to these complex choices, they have to make trade-offs between production, labour, subsidies, and environmental risks (Waller et al., 1998). There is growing interest in methodologies for designing more sustainable cropping systems. Many authors have now demonstrated that crop models are useful tools for designing innovative systems (Dogliotti et al., 2003, 2004; Keating et al., 2003; Loyce et al., 2002a,b; Sterk et al., 2006; Stöckle et al., 2003; Tixier et al., 2008a). Nevertheless, published approaches often deal with new combinations of current cultural practices and rarely with radical new technical innovations. Furthermore, these approaches do not pay attention to the diversity of farming situations to which the innovations are applied (Sterk et al., 2007).

Some innovations might be very efficient in some farming contexts and completely inadequate in others (Orr and Ritchie, 2004), mostly because of environmental conditions, economic endowments and current farming systems, which vary widely among farmers (Bernet et al., 2001). This context is not taken into account to an appropriate extent and most agronomists tackle only one or a few theoretical situations that can be unrealistic and often not well described (Sterk et al., 2007). Hence, the assessment of innovative cropping systems may be biased. Thus, evaluating *ex ante* the production and the environmental performances of innovations in the specific context of each farm type becomes an important part of prototyping new cropping systems that target high productivity and are more environmentally friendly. This evaluation is the key point that helps researchers and stakeholders promote innovations for farms where they are most suitable and to guide the dissemination and the adoption of innovations (Diederen et al., 2003).

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However, adopting an innovation also depends on many factors, e.g., social, economic, or personal (Edwards-Jones, 2006). In this study, we focus on production and environmental performances of innovative cropping systems.

When a farmer integrates an innovation into their current cropping system, this integration usually requires some adaptation resulting in an innovative cropping system specific to the farm type. The conditions of a farm include a biophysical context, i.e., climate, soil type, plant-parasitic pressure, and a technical context, i.e., level of inputs, labour, and technical knowledge. In a given production area, there is often a wide range of farm types. This diversity in farm types is generally even greater in tropical conditions. Technical innovations are the basis of progress in cropping systems; they include genetic innovations such as pest resistant varieties, intercropping, integrated pest management, new type of fertilization, or new crop rotations. Innovations provide different economic and ecological services, e.g., increased yield, reduced pesticide uses, and protection against erosion and runoff.

Throughout the world, banana production (*Musa* spp., AAA, Cavendish sub-group cv. Grande Naine) for export is mainly based on intensive monocropping systems. There is a wide range of production types, from organic to high input systems. However, most intensive systems are not environmentally friendly. The agronomic and ecological sustainability of these systems is often hampered by a high level of root parasitism, including nematodes (Tixier et al., 2007b). Air, soil, and water quality may be adversely affected by the frequent applications of chemical pesticides that are required to control parasitism and by soil and plant management practices that may lead to severe erosion. These risks are magnified in fragile, tropical, insular conditions such as those found in Guadeloupe, in the French West Indies (F.W.I., 16°15′N, 61°32′W), where inhabited areas, coral reefs, and rainforests are located close to agro-systems (Bocquene and Franco, 2005; Bonan and Prime, 2001). This issue also concerns all areas of intensive production of banana (Castillo et al., 2006; Chaves et al., 2007; Matthews et al., 2003). At the same time, managing the labour, adapting to a fluctuating and highly competitive market, and limiting pesticide use are major economic problems that threaten the entire banana production sector in F.W.I. (Bonin et al., 2004). In the specific case of Guadeloupe, there is a wide range of farm types, from the intensive systems similar to the ones in intensive production areas of Latin America to very extensive systems with very low input, similar to the ones found in a small rural farm context.

In this paper, we present the *ad hoc* adaptation of the crop model SIMBA (Tixier et al., 2008a) and a method to evaluate several innovations in six types of farms in Guadeloupe that have been previously identified through a typology of banana farming systems. The SIMBA model was chosen for this study as it allows us to account for a wide range of technical operations. We then present a detailed evaluation of 16 innovations with regard to yield and pesticide use for six farm types. We analyze the performances of these innovations relative to current cropping systems. In the perspectives, we highlight how model-based evaluation of innovation can interact with farm- and landscape-scale prototyping methods. To our knowledge, this is the first time that a biophysical model-based approach has been used to assess innovations in the context of different farm circumstances.

2. Materials and methods

2.1. Current cropping systems and farm context

In Guadeloupe, banana-based cropping systems range from very intensive to very extensive. A typology of these cropping systems has been published previously (Blazy et al., 2008).

This typology was derived from a cluster analysis based on data collected from a sample of 67 banana growers in the territory, which represents a sampling rate of 25%. The variables used in the statistical analysis for the grouping of farms into few farm types were selected to describe the technical management of banana and the environmental and socio-economic conditions of the farm. This has led to the definition of six farm types (Table 1). The most intensive farm types (1–4) use a high amount of fertilizer, pesticides, labour, and frequent replanting with ploughing, and are characterized by a wide range of agronomical performances (from 21 to 46 tons ha^{-1} $year^{-1}$). On the other hand, the less intensive farm types (5 and 6) are low-input perennial systems that are less harmful to the environment but have a very low level of production (15.8 and 18.5 tons ha^{-1} $year^{-1}$). All these farm types also have different flexibility for innovation as they differ in production factors like labour, land, access to information, and financial resources. For this reason, a high number of modalities of innovation have been tested in this study. For this modelling study, we defined one theoretical farm for each farm type. For every technical decision rule and soil and climate condition, we selected the mean or the modal value of each farm type. These mean values were extracted from the 67-farm database used to build the typology (Blazy et al., 2008), in which each farm type has very low intraclass variability.

2.2. Soil and climate conditions of banana cropping systems in Guadeloupe

Table 2 presents the climate, soil, and topographic characteristics of each farm type. There is a correlation between the farm types we defined and the altitude. For example, the most productive types are at low altitude (below 300 m for types 1–4), while the less productive types are at higher altitudes (above 300 m for types 5 and 6). All the farms are based on volcanic ash soils. Type 2 is mainly found on ferralitic soils that are old and compacted, with 2795 mm of rain annually, which makes it susceptible to drought. Types 4–6 are at higher altitude on andisols that are less evolved and characterized by fast drainage in areas that receive 3500 mm of rain annually, ensuring no risk of drought in this area. Types 1 and 3 are on nitisols, which are mid-evolved soils in areas that receive 2700 mm of rain or less annually. In these areas, there is a risk of drought, which is minimized by irrigation for type 3. Temperature and sunlight vary little across farm types. Variations of environmental conditions can be explained by spatial heterogeneity of farms location, mainly in terms of altitude and exposure to sun and wind. For all these systems, root nematode pressures differ considerably (Clermont-Dauphin et al., 2004). This distribution emphasizes the fact that the more competitive innovations cannot be the same for all farm types.

2.3. Innovative cropping systems

We assessed 16 innovations: 13 single innovations (innovations that only concern one component of the cropping system) and three integrated innovations that combine single innovations. Table 3 presents the characteristics of the 16 innovations and their agro-ecological services. Innovations A1, A2, and A3 consist of stopping the use of pesticides (nematicides and herbicides); they can be considered innovations based on extreme societal regulation in comparison with the current practices. Innovations, B1, B2, and B3 consist of rotations with fallows improved by cover crop (*Crotalaria juncea*), regular fallows that use herbicides, and an 18-month rotation with pineapple. These cover crops help reduce the plant-parasitic nematode population during fallows, thus shortening fallows before banana plants are planted. Innovations C1, C2, and C3 are based on intercropping with *Canavalia ensiformis*, *Brachiaria decumbens*, and *Impatiens* sp.; they are currently under