



Assessment of regional variability in crop yields with spatial autocorrelation: Banana farms and policy implications in Martinique

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ABSTRACT

Agricultural research can support farmers and policy makers' decisions by identifying the causes of spatial variability in crop yield at a regional level. In this paper, we propose a method that combines spatial autocorrelation measures and a farm network survey. This method is intended to describe the causes of spatial variability in crop yields, along with key crop management practices for reaching the best yields and the physical and socio-economic constraints of adopting these practices. This causal and hierarchical analysis of cropping system performance has the advantage of (1) preventing bias in the correlation between variables from the yield gap analysis and (2) formulating spatially targeted policies that are aimed at relaxing adoption constraints at the territorial level. After introducing the method and its different steps, we present the results of the assessment of the spatial variability in banana yields in Martinique (Caribbean). Our study has clearly shown that the planting stage is one of the most important aspects of banana production: allowing a long fallow period, plowing for soil preparation and using seedlings that are produced by tissue culture were associated with the best yields. However, several constraints limit their adoption by farmers at the regional level. The limiting factors were steep slopes, small farm size and low cash flow. We observed no relationship between pesticide use and yields. These study results finally permit the elaboration of spatially targeted policy recommendations to improve crop yields in a sustainable manner. It mainly consists in promoting and facilitating the adoption of good plantation practices for smallholders.

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1. Introduction

The agriculture sector must increase global crop production to feed a growing population that is expected to reach 9 billion people by 2050 (United Nations, 2002). The amount of available land for agriculture is decreasing and competition for arable land is increasing in many parts of the world, which makes the cultivation of new croplands difficult (Spiertz, 2012; Ramankutty et al., 2002). This is particularly true in small tropical islands where the populations are developing and land availability is limited because of insularity. In many areas around the world, yield potentials are far from being reached by current cropping systems (Neumann et al., 2010; Foley et al., 2011). Chemical intensification of crop management can be a way to increase yields, but the negative impacts of short- and long-term intensive agriculture have been clearly stated (MEA, 2005; Tscharntke et al., 2012).

Agricultural research can provide solutions to farmers by developing methods that identify the drivers of spatial variability in crop output at the regional level, ultimately leading to a sustainable increase in farm productivity. This diagnosis is a preliminary step

in the design of innovative cropping systems in which the practices are modified and then tested by farmers.

Depending on the scale, availability of data and project scope, the factors chosen for yield gap analysis can either be biophysical parameters or crop management practices. Licker et al. (2010) worked on the gap in grain production at the Earth scale on the basis of datasets that only included physical parameters, growing degree days, soil moisture availability and the type of climate. However, agronomists are principally interested in yield gap analyses at the regional scale and in farmers' practices.

There are three main types of approaches for yield gap analysis at the regional level. First, there are field trial-based approaches that are made up of a network, station or on-farm experiments with balanced statistical treatments (Boling et al., 2010; Kalra et al., 2007). However, these methods are costly and a limited number of factors can be tested. Second, Doré et al. (1997, 2007) conceptualized an approach called on-farm regional agronomic diagnosis in which field experiments are combined with the on-farm monitoring of current practices. To understand the relationships between crop management system performance and farmer practices or physical conditions, a functional analysis is performed on crop and environment status data that are collected from a network of farms. Doré et al. (2007) underlined the importance and difficulty of estimating the potential yield from an area, with emphasis on

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choosing good indicators and establishing relations between yields and limiting factors. This methodology has been used in different situations (Clermont-Dauphin et al., 2004, 2005; David et al., 2005; Le Bail and Meynard, 2003). The third method consists of establishing statistical correlations between yield and crop management. Data are collected from interviews with a sample of farmers that are representative of the diversity of the region. As mentioned by Doré et al. (2007), this method is not time or money-consuming, but its main drawback is that significant correlations between two or more variables do not always reflect causal relationships and bias can be observed in parameter estimation (Prost et al., 2008). The risk of biases is particularly high when farms are very heterogeneous from a physical and socio-economic point of view. This is particularly true for mountainous tropical areas, such as volcanic islands, where the spatial heterogeneity of physical and socio-economic conditions of farms is high (Blazy et al., 2010). Farmers who do not have sufficient economic endowments or poor soil suitability can therefore have constraints to adopt the most efficient crop management system. This strengthens the need for identifying these structural constraints of adoption and to propose targeted policy adaptations.

Since few approaches consider the biotechnical understanding of the yield gap and the analysis of its socio-economic drivers at the same time, we propose an improvement of current yield gap analysis methods by (1) following a step-by-step procedure to identify causal relationships between farm performance, crop management and farm socio-economic and physical characteristics and (2) integrating spatial autocorrelation measures to avoid bias in the selection of model variables. Spatial autocorrelation has been widely used in epidemiology (da Rocha Junior et al., 2010), but to our knowledge, no studies have used this method for regional yield gap analyses. Ping et al. (2004) have studied the parameters that are responsible for yield gaps in cotton by using observed yields from sensors that are employed for precision agriculture at the field scale.

The method we propose has been applied to banana farms in Martinique. In this tropical island, the banana plays a key role in the economy of the island, but productivity is low on average, at approximately 30 tons per hectare per year, while the potential is close to 70 tons (Lassoudière, 2007). The banana is one of the most produced fruit in the world (Food and Agriculture Organization, 2011) which underlines the importance of determining the yield variability of this crop. Few studies have been conducted on banana performance variability. Okumu et al. (2011) studied the production gradients in smallholder banana farms in Kenya and highlighted the importance of soil organic matter content in enhancing the rooting system (cv. Giant Cavendish). Clermont-Dauphin et al. (2004) showed that the biological activity of banana soils is highly affected by intensive practices in Guadeloupe (Caribbean). Bathan and Lantican (2010) used a Cobb–Douglas function of banana yields to study the effects of seedling quality, higher input utilization (fertilizer and labor) and the dissemination of information about good pest and disease control.

The structure of this paper is as follows: first, we present the method and its different steps. Then, we introduce the study area and methodology for data collection and analysis in Martinique. We then present the results and finally formulate recommendations for banana yield improvement in Martinique. We discuss the contribution of this study to yield gap analysis research.

2. Method

2.1. Overview

The method is aimed at explaining causes of spatial variability in crop yield at the regional level and is made of two main steps (Fig. 1). The first step is to identify the practices of the crop management

that have significant influence on yield variability, while taking into account spatial autocorrelation of farms. The second step consists in highlighting farm socio-economic and biophysical factors affecting the adoption of these key practices. Although farm socio-economic condition is also partially determined by the environment and biophysical conditions can directly affect the performance of the crop, we consider in the method a simplified framework of causality. Since the nature of the cropping system is also driven by the biophysical context of farm, we considered that studying at the same time the influence of both factors on yield can introduce bias in the understanding of cropping system influences on yield. Our framework requires therefore controlling for the spatial heterogeneity of farms in the yield model, which is done by capturing spatial autocorrelation across the territory. The advantage of this framework of analysis is that it leads to strong and unbiased causal relationships that are helpful to define simple spatially targeted policy aimed at promoting the adoption of best practices.

Fig. 2 presents the different steps and treatments that were used by our method. The first step consisted of defining a set of variables and a network of farms on which a dataset was built to describe the causal links between the physical and economic situation of the farm, the crop management system and its performance. Then, a principal component analysis provided correlations between types of performance and made it possible to highlight key factors, which were considered to be those performances that had an important influence over the others. The analysis of performance variability over the territory made it possible to quantify performance gaps at the regional scale. The links between the crop management system and its performance were analyzed by spatial autocorrelation measures. These treatments display clusters of farms with opposite trends in performance, which were further characterized by descriptive statistics. The comparison of these areas is helpful in highlighting the practices responsible for yield variability at the regional scale and the socio-economic drivers of these practices at the farm scale. The technical operations of the crop management system that were responsible for performance gaps were then identified through statistical tests, either by Student's *t* or Chi² tests after checking the normality of the distribution of variables. Finally, the causal links between performance, crop management system and the physical and economic situation of the farm were tested and quantified by regression models. This procedure led to a causal diagram to link performance, crop management and the physical and economic situation of the farm. This diagram provided a clear and systemic explanation of the origin of performance variability at the regional scale.

2.2. Method steps

2.2.1. Choice of variables and farm network

For the purpose of studying crop performance gaps at the regional scale, three types of information were recorded at the farm level: (i) the performance of the cropping system, (ii) crop management practices and (iii) the physical and economic situation of the farm. For this step, it is highly recommended to involve local experts. Technical management details are exhaustively described with respect to the modalities and frequencies of each technical operation of crop management. The physical and economic situation of the farm consists of the economic, physical and social factors that might influence the technical nature of the cropping system (Blazy et al., 2009a,b). Many socio-economic variables have been highlighted in the literature for influencing farmer decision-making processes. These include the farm size, labor availability, socio-economic status and access to institutional services such as extension and input supplies (Edwards-Jones, 2006). Variables that are related to physical conditions can include the soil type, slope and altitude. Performance could describe the agronomic productivity,

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