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Observed and predicted changes in soil carbon stocks under export and diversified agriculture in the Caribbean. The case study of Guadeloupe

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ABSTRACT

Export agriculture in the Caribbean is often blamed for pollution of soils and water resources. At the same time, the reduction of preferences in the international markets for major agricultural exports from the Caribbean induced a partial reorientation of the agriculture towards the local markets, which included crop diversification. This study was carried out to assess the sustainability of that agricultural switch with respect to maintaining, increasing or decreasing soil organic carbon (SOC) stocks. We analysed the impact of export crops (sugarcane and banana monocultures) and diversified agriculture (as monoculture or in rotation with export crops) on SOC stocks using the case study of Guadeloupe (Lesser Antilles). Agriculture in Guadeloupe involves a mosaic of soils, climates, crops and farming practices, which well represent the tropical conditions of export and diversified agriculture in the region. The study was based on: (i) a soil database including information on the SOC stocks of numerous cropping system—agro-ecological region (AER) situations, (ii) a survey of farming practices performed on a network of 382 farmers (e.g. crop rotations and yields, management of residues and organic amendments), and (iii) the development of a simple model of annual C inputs and outputs to assess SOC dynamics at the AER scale. The model was calibrated and evaluated using 253 plots and included 827 SOC measurements selected from the soil database. The model produced satisfactory estimates of changes in SOC stocks and provided an explanation for differences between cropping systems and AERs in terms of the C inputs and outputs. While sugarcane and banana monocultures were able to preserve or increase SOC, diversification was likely to reduce it. These differences were due to higher C inputs from crop residues together with lower C outputs for export agriculture. Lower SOC outputs by mineralization were mainly associated with the longer cycle of these pluriannual crops (5 yr), which decreased the impact of soil tillage at planting. Banana monoculture in the most humid AERs was the only cropping system that displayed a clear pattern of C sequestration (+0.5 Mg C ha^{-1} yr^{-1}). The highest SOC losses were observed with vegetable crops in the same AERs (e.g. −2.0 Mg C ha^{-1} yr^{-1}). Calculations made using the model indicated that the sustainability of diversified agriculture in the Caribbean might be reinforced by adopting reduced soil tillage, organic amendments and the liming of the more acid soils to increase yields and crop residues. The results of this study suggest that the implementation of new agricultural policies to reduce the negative environmental impacts of export crops should involve measures to preserve their positive effect on SOC storage.

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1. Introduction

Agriculture in the island states of the Caribbean is currently facing crucial challenges because of the impact of trade liberalisation and the reduction or elimination of preferences for major agricultural exports in most international markets (United Nations, 2013). Moreover, because of the overuse of chemical fertilizers and pesticides, the sustainability of export agriculture is often questioned with respect to soil contamination and the pollution of coastal resources, such as fresh and sea water, flora and fauna (Castillo et al., 2006; Cabidoche et al., 2009). At the same time, the regional food import market is large and growing due to increases in population and tourism (FAO Subregional Office for the Caribbean, 2013). In this context, that FAO Office proposed that a significant proportion of Caribbean agriculture should be reoriented towards domestic markets in order to ensure a competitive replacement for imports as a means of enhancing food security in the region. To achieve this, it is necessary to use more sustainable cropping systems, as compared with monoculture production for export,

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including crop diversification and rotation, organic farming, the use of manure and composts and the application of land conservation practices (IFAD, 2014).

Although crop diversification and rotation in the Caribbean are increasingly being seen as credible alternatives to conventional agriculture based on monocultures of banana and sugarcane, a major agro-environmental concern regarding such a switch involves the impact of cropping systems on SOC stocks (IFAD, 2014). SOC stocks change in response to the balance between C inputs and outputs. For agricultural soils, inputs are driven primarily by the recycling of crop residues and external additions of C such as organic amendments, while outputs are largely driven by the rate of microbial decomposition of SOC, this being affected by climate, land use and soil tillage (Smith et al., 2012). In the Caribbean, diversification based on vegetable or tuber crops might affect SOC stocks because the mass of crop residue recycling in soil is smaller and soil tillage is more intensive than with export crops (Zinn et al., 2005; Lal, 2008). This picture may vary in soils under organic agriculture because using relatively high rates of organic amendments increases C inputs (Lal, 2004). As in other tropical regions (Milne et al., 2007), the paucity of data on changes in SOC stocks in the Caribbean is a significant limitation to a more comprehensive and quantitative assessment of the impact of crop diversification and rotation on the sustainability of these alternative cropping systems. There is therefore an urgent need to develop and implement models of SOC dynamics that can be applied at relatively small spatial scales (e.g. agro-ecological regions (AER) of 10^2–10^3 km^2 in the Caribbean) so as to facilitate decision making in the agricultural sector.

This paper presents an experimental and modelling approach designed to assess the impact of crop diversification and rotation on SOC stocks in the Caribbean, based on a case study in Guadeloupe. Guadeloupe is a French Overseas Department that has a long history of cultivation going back hundreds of years, while modern agriculture was introduced forty years ago following the green revolution. The main issue affecting this switch has been that of the intensification of agricultural land use and, more recently, changes in cropping patterns which involved the partial conversion of sugarcane and banana monocultures to rotations including crops for the domestic market (Agreste, 2011). Guadeloupe is unique in the Caribbean for three reasons: (i) in a relatively small territory of 1600 km^2 it presents a great diversity of soils and climates that are representative of most of the agro-ecological conditions encountered in the Caribbean region (Cabidoche et al., 2004), (ii) it also covers a large range of land uses from monocultures for export to more diversified systems including roots and tuber crops, orchards and vegetable crops (Clermont-Dauphin et al., 2004), and (iii) the SOC stocks of many soils in different AER and under different cropping systems have been analysed since 1998, and the georeferenced data has been structured in a software application that is simple to operate for modelling purposes. This database is also unique in that it brings together both farm and regional scale information on several variables that determine SOC stocks.

The objective of this study was therefore to assess the impact of crop diversification and rotation on SOC stocks in tropical soils of the Caribbean, based on the case study of Guadeloupe. For this we developed a simple model of C inputs and outputs which was calibrated and tested using experimental data obtained from plots included in the soil database. The data covered a broad range of soil types, climates and cropping systems. In contrast to complex models of SOC dynamics, a simple model requires minimal data inputs and few parameters and is therefore well suited to situations with scarce agricultural data, such as in the Caribbean. Data concerning crop yields and farming practices (rotation,

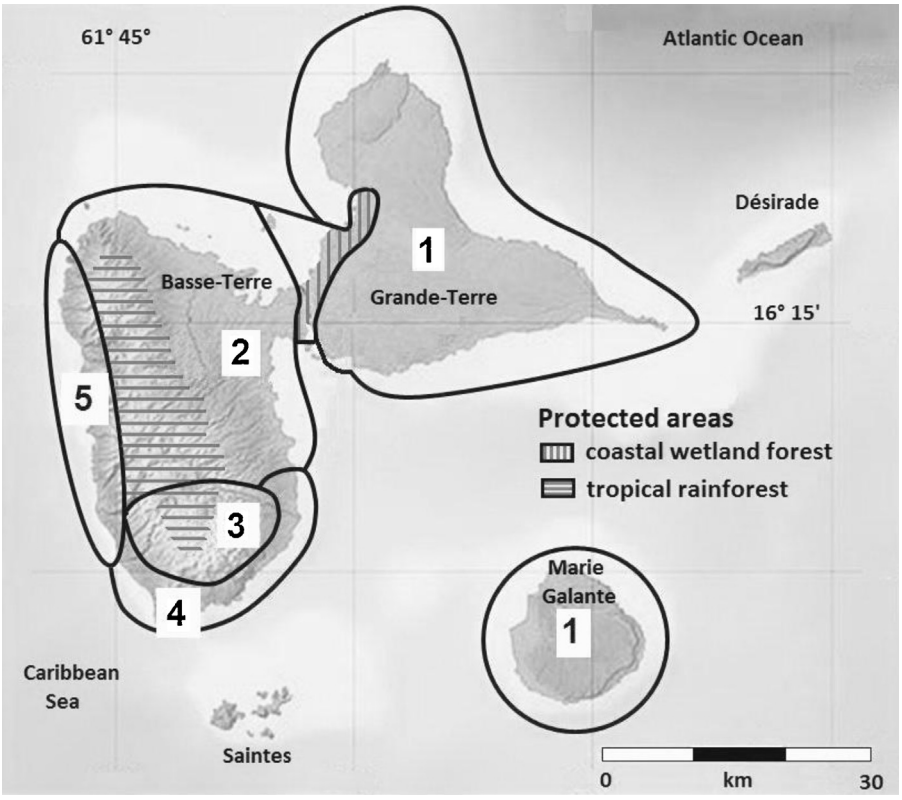

Fig. 1. The archipelago of Guadeloupe and its five agro-ecological regions (AER). Soils are vertisols in AERs 1 and 5, ferralsols in AER 2, andosols in AER 3 and nitisols in AER 4. Mean rainfall is 1100 mm yr^{-1} in AER 1, 2300 mm yr^{-1} in AER 2, 3800 mm yr^{-1} in AER 3, 2200 mm yr^{-1} in AER 4, and 900 mm yr^{-1} in AER 5. Mean air temperature varies from 23.9 °C in AER 3 to 26.6 °C in AER 5.

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