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RESEARCH ARTICLE

# Co-designing innovative plantain cropping systems to support the diversity of agroecological pathways in Guadeloupe

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**Abstract**

In the French West Indies, and particularly in Guadeloupe, agricultural policies mainly support the banana and sugarcane export sectors. However, driven by consumer demand, policy-makers are increasingly interested in developing local and agroecological food systems. Plantain (*Musa* spp., AAB), cultivated by a wide range of farmers, plays a key role in the diversification of local production and food systems, contributing to food security. However, important gaps in knowledge about plantain cropping systems are hindering the understanding of their contribution to the agroecological transition of farms. Farmers are also requesting more guidance from technical advisers and research. The aim of the work, presented in this article, was to co-design agroecological plantain cropping systems with farmers in order to fill this knowledge gap and to support local food systems. The co-design process was based on the characterization of the diversity of plantain farming systems, the evaluation of changes in practices implemented between 2017 and 2019, and the co-design of a system experiment. We identified six types of plantain farming systems defined by the role of plantain in the production strategy of the farm and a gradient of agroecology in plantain management practices. Our results also show progress toward agroecology between 2017 and 2019. Four innovative plantain cropping systems were designed based on a combination of existing knowledge held by farmers from the six types of farming systems. These results confirm that plantain cropping systems are contributing to the agroecological transition of farms in Guadeloupe and highlight that there are multiple possible agroecological transition pathways for plantain farmers. These results also provide a concrete example of integration of academic and non-academic knowledge for the co-design of agroecological systems.

**Keywords** Agroecology · *Musa* spp. · AAB · Participatory approaches · Guadeloupe · Solutions · Barriers · Trajectories Co-design

## 1 Introduction

Agricultural systems worldwide are facing an increased demand for food under an accelerated degradation of ecosystems and exposition to climate risks. Agroecology is increasingly presented as a credible practice, science, and movement to cope with these challenges (Wezel et al. 2020). Agroecology is defined by a set of biophysical principles such as enhancement of biodiversity, recycling of biomass and nutrients, and efficient use of natural resources as well as governance principles such as sustainable governance of natural resources and co-creation of knowledge. These principles can be applied from crop level to the entire food system (Gliessman 2016; Wezel et al. 2020).

There are two main pathways for agroecological transitions. The first is a weak agroecological transition based on

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a search for higher efficiency or the substitution of mineral fertilizers by organic ones yet does not break with dependence on purchased fertilizers and pesticides. The second is a strong agroecological transition based on the enhancement of biodiversity and ecological processes in agricultural systems (Duru et al. 2015a, b; Horlings and Marsden 2011). This second pathway calls for the exploration of radical innovations (Martin et al. 2013).

Co-design approaches in agronomy aim to support farmers in the design of innovative practices, with a combination of practices at crop, farm, or territory scales, including the design of innovative decision support systems. They may be led by the farmers themselves or by researchers engaged in a participatory process. They are based on a diagnosis of the objectives of the farmers and the problems they face (Le Gal et al. 2011; Meynard et al. 2012; Duru et al. 2015b). From a researcher's perspective, co-design approaches help to identify the diversity and performance of farmers and techniques being implemented, based on the farmers' own creativity. From a farmer's perspective, such co-design approaches support network building and technique/technology co-development. It also makes it possible to design systems in synchrony with the environment and knowledge of farmers (Geilfus 2008).

There are diverse design theories, but they share similar concepts, namely the designation of the object of transformation, the choice of specific goals, and the identification of intended users of possible solutions resulting from the design process (Martin et al. 2013). Meynard et al. (2012) described two ways of designing agricultural systems: the improvement of existing systems (rule-based design) and innovation (innovative design). Rule-based design mobilizes existing knowledge for problem solving (Le Masson et al. 2006), while innovative design opens up the field of possibilities by using stakeholders' creativity.

The co-design of innovative farming systems is generally based on a description of existing farming systems and the exploration of new systems using prototyping, modelling, focus group discussions, and/or experimental stages, such as system experimentation, to assess the achievement of assigned objectives (Giller et al. 2008; Meynard et al. 2012). Design workshops are key elements in the co-design of agricultural systems with actors. Jeuffroy et al. (2022) identified four main axes to be considered: (i) the design target, (ii) the choice of participating actors, (iii) the knowledge sharing, and (iv) the sequencing of the workshop meetings.

Various authors have described the main characteristics of co-design processes used to support agroecological transitions (Duru et al. 2014, 2015b, a; Berthet et al. 2016). Given the transdisciplinary nature of agroecology that integrates academic and non-academic knowledge to understand and build complex agricultural systems (Montenegro de Wit and Iles 2016; Wezel et al. 2020), one of the main challenges in these approaches lies in the consideration of scientific and endogenous knowledge to design innovative systems (Berthet et al. 2016). This integration of knowledge is crucial for under-researched crops that are not supported by public policies although they play a key role in local food systems.

In the French West Indies, there is growing interest on the part of both policy-makers and consumers to develop local and agroecological food systems in regions dominated by export-oriented agricultural systems (mainly banana and sugarcane). This interest follows a major scandal linked specifically to the use of a remnant pesticide, chlordecone, an obsolete organochlorine insecticide and colorless solid, now banned worldwide, in export banana cropping systems that contaminated, in part, the food system (Cabidoche and Lesueur-Jannoyer 2011) of Guadeloupe. Recently, the Regional Council launched an agroecological plan (Regional Council 2020) aiming to support innovative projects favoring local food sovereignty based on the agroecological principles of recycling, farm and food diversification, valorization of local knowledge, cultures, and circular economies to meet the interests of civil society (Barlagne et al. 2015). In Guadeloupe, plantain (*Musa* spp., AAB) is a food crop used for cropping system diversification, which plays a key role in the local food system, as it is strongly anchored in the traditional diet (Fréguin-Gresh et al. 2020). However, despite the importance of plantain for the Guadeloupean diet and agriculture and important research and development programs on plantain in other tropical areas (Côte et al. 2010; Dépigny et al. 2018, 2019), in Guadeloupe, the crop has been under-researched and poorly supported by agricultural policies compared to export (Ozier Lafontaine et al. 2018). The studies that have been carried out have been exploratory and have highlighted the great diversity of farming systems growing plantain with practical and experiential knowledge on plantain cropping practices (Forite 2011; Ogisma 2011; Delone 2014; Bezard 2017; Morin 2019) (Fig. 1). Farmers are now asking for more support from research and development actors, to develop their plantain cropping systems to meet local demand.

Given the scant scientific research on plantain cropping systems and the increasing demand from policy-makers and civil society to develop under-researched crops dedicated to the local diet following agroecological principles, this work aimed to co-design innovative agroecological plantain farming systems that integrate knowledge held by farmers on plantain cropping systems.

To achieve this objective, we characterized the diversity of existing plantain farming systems in Guadeloupe (in the two main islands, Basse-Terre and Grande-Terre), we analyzed the evolution of plantain cultivation practices between 2017 and 2019, and we co-designed alternative systems with farmers through a series of structured interviews and focus

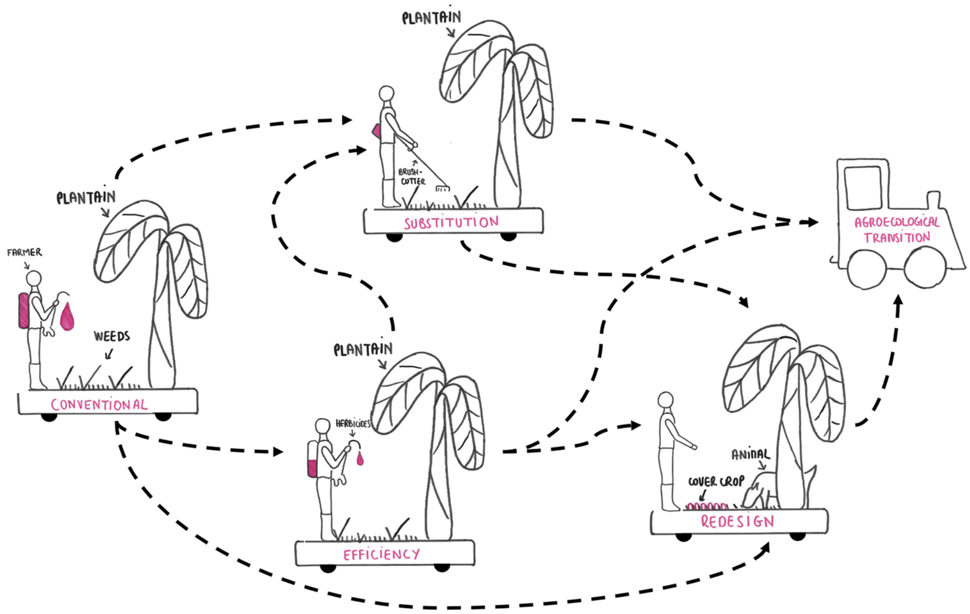


**Fig. 1** Plantain farmers in Guadeloupe are engaged in a diversity of pathways along an agroecological gradient compared to conventional practices used in export farming systems with subsidized purchased inputs. In this figure focusing on the farm scale, weed management illustrates the transition from conventional management using herbicides toward more agroecological practices. The arrows illustrate the diversity of transition paths. It is not always a gradual pathway; it is possible to move directly from conventional to redesign or to substitution or from efficiency to redesign. At the efficiency level, herbicides continue to be used, but in reduced amounts and more effectively (optimal doses). At the substitution level, the farmer replaces herbicides with a brushcutter. The redesign level involves an animal and the implementation of a cover crop for weed control. Other sociotechnical changes are involved at food system and global scales (authors' elaboration)

groups. We discuss the contribution of this work to the literature on the integration of farmers' and scientists' knowledge for the co-design of agroecological systems.

## 2 Materials and methods

### 2.1 Case study

Guadeloupe is a French overseas region in the Caribbean (16° 15′ N, 61° 35′ W) (Fig. 2A), composed of two major islands, Basse-Terre and Grande-Terre, the study areas, and several smaller islands (Marie Galante, Saintes, Désirade, and Petite Terre) (IEDOM 2021).

Agriculture in Guadeloupe is still widely dominated by two export monocrops (sugarcane and Cavendish banana) (Agreste 2020). The historical area of export banana production known as the banana belt (in French the "croissant bananier") is in the southeast of Basse-Terre on fertile nitisols (Lucien Brun 2014; Sierra and Desfontaines 2018). Sugarcane is grown in two different areas: North Basse-Terre on ferralsols and Grande-Terre on vertisols, the latter characterized by a limited availability of water for crops (Lucien Brun 2014). Diversified agriculture (livestock farming, food crops such as plantain, etc.) is present throughout the territory and is intended for the local market (Agreste 2020) (Fig. 2B).

According to the Ministry of Agriculture, plantain is among the crops intended for local markets and is grown on 120 hectares, with a total production of 1116 tons of green bananas (Agreste 2020). In Guadeloupe, many farmers, and particularly those growing crops for the local market, are not officially registered as farmers (Andrieu et al. 2022). Since these crops are poorly supported by public services, and because most farmers engage in multiple economic activities, the farmers tend not to declare themselves as farmers and fail to be registered in national statistics. Consequently, 120 hectares is probably an underestimate of the actual plantain production. Plantain is produced on vertisols, nitisols, ferralsols, and andosols. The latter are particularly fertile (Sierra and Desfontaines 2018).

### 2.2 A three-step methodological approach

The methodological approach used to co-design plantain cropping systems was based on three steps (Table 1): (i) analyzing the diversity of plantain farming systems, (ii) analyzing changes in plantain production practices between 2017 and 2019 (years when the surveys were conducted), and (iii) co-designing workshops to define alternative systems

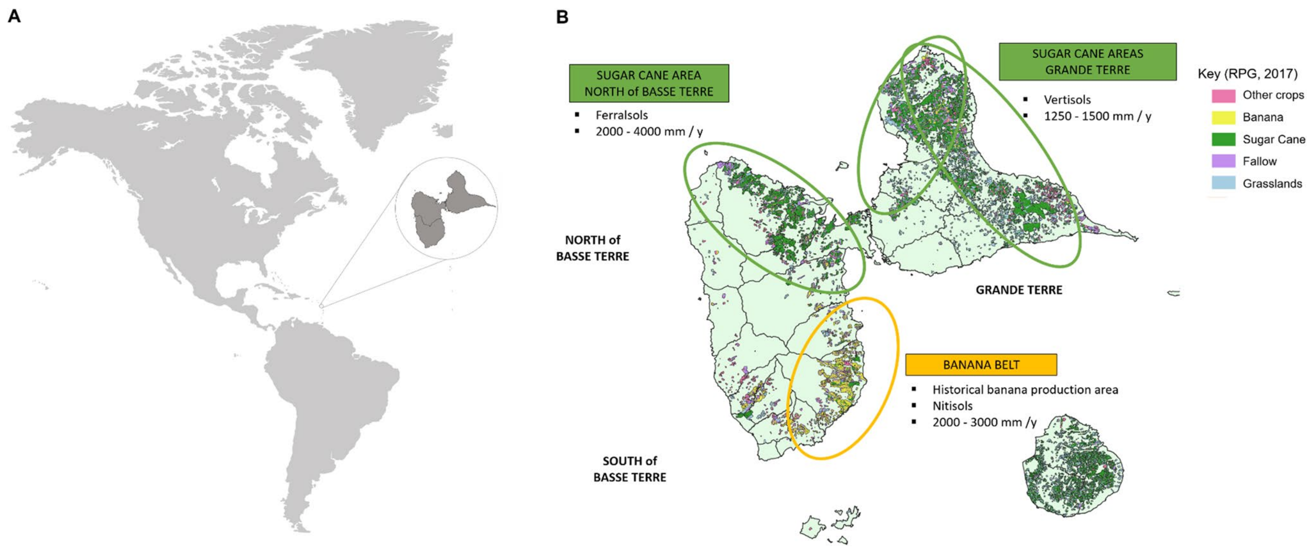


**Fig. 2** **A** Guadeloupe location. **B** Export crop areas in Guadeloupe are in South Basse-Terre for export banana and in North Basse-Terre and Grande-Terre for sugarcane with various agropedoclimatic contexts. Diversified agriculture is not linked to a specific area. On this map, only export crops (banana and sugarcane) have been represented since they are the best described in official statistics. The latter do not offer information on the location and surface area of plantain, which is included in a "Creole banana" category (which does not allow to discriminate the plantain). There is no agricultural production in central Basse-Terre as it is occupied by a National Park (authors' elaboration based on data from the "*Relevé Parcellaire Graphique 2017*", Direction de l'Alimentation, and de l'Agriculture et de la Forêt, Guadeloupe)

**Table 1** Mixed research methods were used to understand the diversity of agroecological pathways in plantain farming systems in Guadeloupe in a three-step approach

| Steps | 1. Analyzing the diversity of plantain farming systems | 2. Analyzing the evolution of plantain production practices between 2017 and 2019 | 3.1. Co-designing alternative plantain cropping systems | 3.2. Co-designing alternative plantain cropping systems |
|---|---|---|---|---|
| Years | 2017 | 2019 | 2019 | 2021 |
| Methods | Semi-structured interviews<br>Snowball sampling | Semi-structured interviews | 2 rounds of focus groups (in 3 different locations to favor farmers' participation) to co-design cropping systems<br>Qualitative discourse analysis | 1 focus group to discuss the barriers to the implementation of the new cropping systems proposed |
| Sample | 41 farmers (initial sample) | 29 farmers (18 from the initial sample) | 15 farmers for each round (30 in total) | 9 farmers |
| Stakeholder group in charge of the step | Research team | Research team | Farmers and the research team (facilitators) | Farmers and the research team (facilitators) |
| Variables | Role of plantain in the production strategy<br>Commercialization strategies | Plantain production practices | Plantain plot plans<br>Plantain production practices<br>Barriers and solutions to plantain production | Types of plantain farmers<br>Types of barriers<br>Types of solutions |
| Outputs | Typology of plantain farming systems<br>Statistical analysis | Typology update<br>Graphic and statistical analysis | Alternative cropping systems<br>Categorization of barriers and solutions to plantain production | Analysis of the barriers and solutions to plantain production<br>A system experiment tested on-station |

(Deytieux et al. 2012; Harvard et al. 2017) and to analyze with farmers the associated barriers and solutions. In this work, the first two steps aimed at establishing a diagnosis of existing agroecological transitions or barriers faced by individual farmers to transition toward more agroecological systems based on a description of current plantain farming systems and practices along an agroecological gradient, and the third step aimed to collectively co-design innovative agroecological plantain cropping systems (Jeuffroy et al. 2022). Such sequential steps based on the characterization of current practices, the understanding of the performances of cropping systems, the exploration, and implementation of new cropping systems are similar to the ones proposed in the DEED (describe, explain, explore, (re)design) methodology (Giller et al. 2008).

### 2.2.1 Analyzing the diversity of plantain farming systems

The objective of this first step was to analyze the diversity of plantain farming systems. Semi-structured interviews were conducted in 2017. Farmers previously surveyed and willing to be re-surveyed were engaged in the sampling (Forite 2011; Ogisma 2011). Since many farmers are not registered on public administration lists because they are not formally considered to be farmers, we used a snowball sampling approach (meaning that a first survey was used to identify more farmers to be surveyed, (Reed et al. 2009)) to identify at least one farmer per agroecological zone of Guadeloupe (Mantran et al. 2017). In 2017, 41 semi-structured interviews were conducted, followed in 2019 by 29 interviews (including 18 from the 2017 sample), for a total of 52 farmers interviewed. We only surveyed plantain farmers who were the owners. We did not include export banana workers, who also produce plantain in remote areas of Cavendish export farms, because they did not want to be surveyed.

A typology of plantain farming systems was constructed in two stages considering different time and space scales: (i) the description of the role of plantain in the production strategy and (ii) the evaluation of the agroecological gradient of plantain cropping systems based on the production practices in 2017 for the different production strategies. The description of the role of plantain in the production strategy of the farm was based on the description of the dominant crop and the year that plantain had been introduced. The efficiency-substitution-redesign (ESR) framework defined by Hill and MacRae (1996) is often used to describe a gradient of agroecological practices at field and farm scales. Gliessman (2016) proposed adding the food systems scale to the latter two scales. The ESR grid highlights gradual steps of transition corresponding to the following: (i) increasing the efficiency of conventional or industrial practices to reduce the use of expensive and environmentally harmful inputs, (ii) replacing industrial or conventional practices with alternative practices in substitution to expensive and environmentally harmful inputs, and (iii) redesigning the agroecosystem based on ecological processes to promote internal synergies and recycling of biomass and nutrients. We used the ESR framework to assess the gradient of agroecology of plantain production practices described by farmers. For this, we evaluated five plantain production practices: (i) fertilizer application, (ii) weed management, (iii) pest and disease management, (iv) crop diversity (including crop rotation and crop combinations), and (v) irrigation. For each production practice, the minimum score (0) corresponded to conventional practices characterizing export banana systems in 2017, while the maximum score (4) corresponded to the most agroecological practices found during the interviews (Table 2). The maximum score for irrigation was 2 since only three practices were observed during the surveys. The total score was obtained by summing all five practice scores. The highest possible score was 18 while the lowest was 0. The median was 9. We then categorized the practices of the farmers into "high agroecological level" or "low agroecological level" according to the total score obtained. High agroecological level corresponded to a total score higher than 9 (equivalent to the substitution and redesign levels in the ESR framework), and low agroecological level corresponded to a total score between 0 and 9 (equivalent to the efficiency level or lower).

Each interviewee was asked about their commercialization strategies. Two possible strategies were identified, namely pricing strategies and non-price competition strategies. We defined pricing strategies as strategies to maximize plantain yield, minimize production costs, and sell large volumes through cooperatives, whereas non-price competition strategies distinguish the product by its quality, integrate the mode of production, sell small volumes of higher quality products.

To compare the significance of differences of practices between farmers' strategies, we used a Kruskal-Wallis test. This nonparametric test renders it possible to compare means between groups when there are over two categories, the data does not follow a normal distribution, and the variances are unequal. We then performed a nonparametric post hoc test (Munzel and Hothorn 2001) to make a pairwise comparison of significant differences. Statistical analyses were performed with R software (R Core Team 2022).

### 2.2.2 Analyzing the evolution of plantain production practices between 2017 and 2019 (29 farmers)

A second series of field surveys was conducted in 2019 to characterize changes in plantain production practices since 2019 and their drivers (*i.e.*, conjunctural drivers linked to

**Table 2** The calculation of the gradient of agroecology for plantain practices was based on the efficiency-substitution-redesign ESR framework for five production practices. For fertilizer applications, recommendations for conventional practices were to apply 100 g (of mineral fertilizers) per plant and per month (which corresponds to the 0 score)

| ESR framework | Conventional | Efficiency | | | Redesign |
|---|---|---|---|---|---|
| Agroecological score | 0 | 1 | 2 | 3 | 4 |
| Fertilizer application | 1.2 kg mineral fertilizer/plant/year | 0.6 kg mineral fertilizer/plant/year | 0.3 kg mineral fertilizer/plant/year | 0.1 kg mineral fertilizer/plant/year | Organic fertilizer (no mineral fertilizer) |
| Weed management | Herbicides only | Herbicides + mechanical control (brushcutter and/or tractor) | Herbicides + manual control | Mechanical control (brushcutter and/or tractor) + manual | Manual control only (machete, mulching, etc.) |
| Pest and disease management (out of crop rotation) | Fungicides only | Fungicides and leaf removal | Fungicides occasionally + alternative controls (pheromone traps, cinder, neem decoction, and leaf removal) | Alternative controls only (pheromone traps, ashes, neem decoction, and leaf removal) | Leaf removal only (no input) |
| Crop diversity (including crop rotation and intercropping) | Number of crops = 1 or fallow < 6 months | Number of crops = 2–3 or fallow from 6 to 12 months | Number of crops = 4–6 | Number of crops = 7–9 | Number of crops = 10 or more or fallow of more than 12 months |
| Irrigation | Irrigation (in response to a water deficit) | Irrigation (in response to the observation of water stress on the plant) | Rainfed | | |

climatic conditions or more strategic drivers). In total, 29 farmers were interviewed, including 18 from the initial sample. Their production practices were assessed based on the evaluation framework used in 2017 (Table 2). For the new interviewees (11 farmers, identified by snowball sampling), their practices both in 2017 and 2019 were surveyed and assessed.

We compared the agroecological score for the five practices between 2017 and 2019 using the Wilcoxon signed rank test to compare the significance of differences. We chose this nonparametric test as we compared 2 years ($n$ = 2), and the data are not independent (the same farmers were surveyed in 2017 and 2019.

### 2.2.3 Co-design of agroecological plantain cropping systems

Three rounds of focus groups were conducted (two in 2019 and one in 2021) in three locations to facilitate the participation of farmers from the different production areas of Guadeloupe (South Basse-Terre, North Basse-Terre, and Grande-Terre).

The first round of focus groups aimed at co-designing various plantain cropping systems. It involved 13 farmers from the initial sample and four new farmers who had heard about the exercise from the farmers who had been surveyed.

Two engineers, one technician, and one trainee facilitated the focus group. They first presented the results of the surveys from steps 1 and 2 to (i) collectively validate them and (ii) ensure knowledge sharing with farmers (Jeuffroy et al. 2022). They also shared information on the experimental station (soil type, surface, wind direction) where the most promising cropping systems would be tested.

In North Basse-Terre, farmers were split into two groups of four participants, and in Grande-Terre and in South Basse-Terre, four and five farmers participated, respectively.

The second round focused on co-designing the management practices associated with the cropping systems defined in the previous round and involved the 15 farmers who attended the first focus group. The focus group was facilitated by the same four facilitators. A qualitative discourse analysis was conducted based on the focus groups to identify and categorize the biotechnical and economic barriers to implementing innovative production practices in plantain production and the technical and organizational solutions that could potentially address them. An analytical framework was built as follows: the barriers were classified into four categories (technical, economical, sanitary, and other), and the solutions were classified according to the ESR framework (Hill and MacRae 1996). A solution was categorized in the efficiency or the substitution level if it involved a single change of practice and in the redesign level if it involved a change in the entire cropping or production system.

The third focus group (in 2021) aimed at the following: (i) prioritizing the barriers and the solutions identified in 2019 and (ii) linking barriers, solutions, types of plantain farms, and context. The participants were identified by a specific color related to the type of plantain system they belonged to. After participants were given the opportunity to complement the list of barriers and solutions identified in 2019, they were asked to prioritize the barriers according to four modalities: (i) non-existent, (ii) minor (*i.e.*, a barrier that exists but that is not an obstacle to plantain production), (iii) medium (*i.e.*, a barrier that exists but is manageable), and (iv) major (*i.e.*, a barrier that is an obstacle to plantain production). Farmers then identified which solutions could address which barrier. To assess the importance of the solutions, their nature and frequency (how often they were chosen) were recorded.

During all of the focus group discussions, individual times of reflection preceded collective times to limit fixation effects (the exploration of a limited number of unvaried solutions) (Jeuffroy et al. 2022) and to allow farmers exploring a broad diversity of practices. Paperboards were used to allow farmers to draw the cropping system they wanted to explore using their own representations.

# 3 Results and discussion

## 3.1 Characterization of plantain farming systems: production strategy, degree of agroecological transition, and marketing strategies

### 3.1.1 Three production strategies of plantain farms

Based on the dominant crop in the farm and the year of introduction of plantain, three main production strategies of plantain farming systems were defined as being derived from the following: (i) export banana farms (EB-strategy), (ii) sugarcane farms (SC-strategy), and (iii) diversified systems (D-strategy) (Fig. 3A).

Sixty percent of the EB-strategy farmers (13 farmers) stopped exporting Cavendish bananas and replaced this crop with plantain. None of the interviewees had grown plantain at the beginning of their careers. They explained that they chose plantain to replace Cavendish because the production practices were very similar to those applied to Cavendish (*e.g.*, fertilizer applications or weed management) but were less constraining because they did not need to meet export standards.

For the SC-strategy farms (22 farmers), sugarcane remained the most important crop (in terms of area), and plantain was introduced to diversify crops and incomes. For

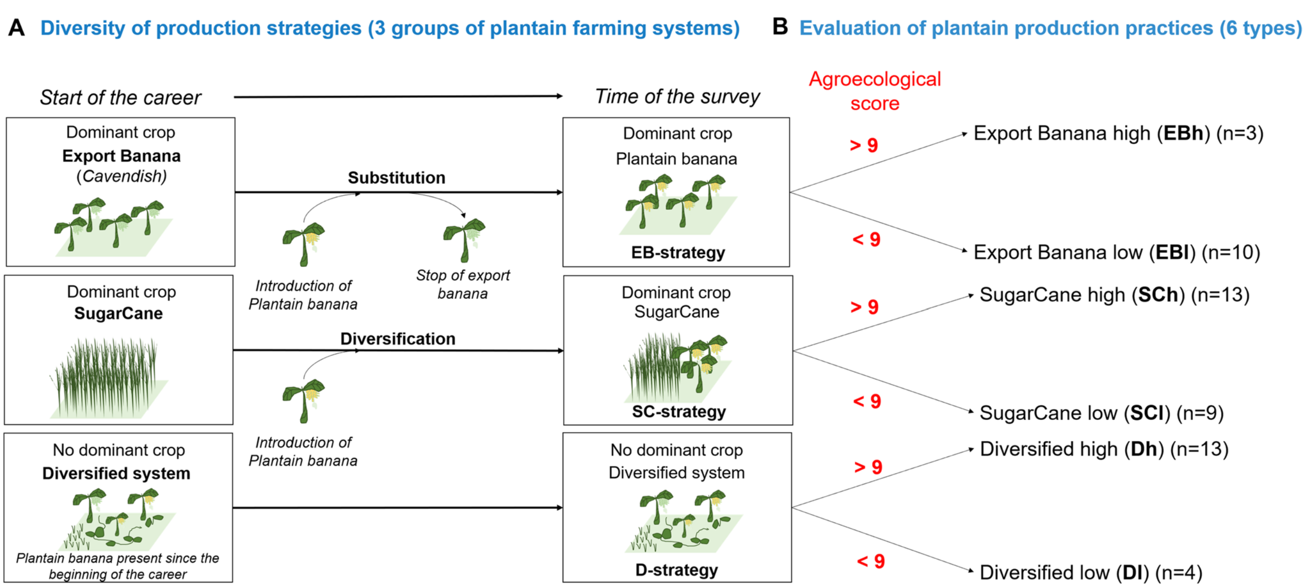


**Fig. 3** Construction of the typology in two steps. **A** Three production strategies for plantain farming systems were defined according to the dominant crop and introduction year of plantain: systems that were (i) specialized in export banana (EB-strategy), (ii) specialized in sugarcane (SC-strategy), and (iii) diversified (D-strategy). **B** Six types of plantain farming systems were defined by intersecting the production strategies and the agroecological scores: farms having an export banana strategy with a high score (EBh) (three farmers), farms having an export banana strategy with a low score (EBl) (ten farmers), farms with a sugarcane strategy with a high score (SCh) (thirteen farmers), farms with a sugarcane strategy with a low score (SCl) (nine farmers), farms with a diversified strategy with a high score (Dh) (thirteen farmers), and farms with a diversified strategy with a low score (Dl) (four farmers)

two thirds of the SC-strategy farmers, introducing plantain was a way to respond to incentives related to land reforms (Zébus 1999) or to respond to demands from local markets and/or cooperatives. The plantain farmers using this strategy were the only ones who did not grow plantain continuously, doing so only when the crop was deemed interesting due to high prices and good marketing opportunities. They tended to abandon plantain cultivation as soon as they estimated that it was no longer profitable. For example, 2021 was characterized by a surplus of plantain on the market and a subsequent drop in plantain prices. As a result, at least eight farmers in the sample (out of a total of 52 farmers from the 2017 and 2019) abandoned plantain production in 2021.

The last group of plantain farms (D-strategy) corresponded to diversified systems (17 farmers) in which plantain has been present since the beginning of the farm's history for the majority of the interviewees.

Banana and sugarcane export systems structure agricultural strategies in the French West Indies (Della Rossa et al. 2020; Fanchone et al. 2020). Here, we see that the role of plantain in cropping systems differs according to the level of the preponderance of these export crops in farming systems. This has also been observed in neighboring islands such as Dominica (Barclay et al. 2019).

### 3.1.2 Weak and strong level of agroecological practices associated with a specific marketing strategy

The characterization of the five plantain production practices highlighted a wide diversity and showed a varied commitment to agroecological transition depending on the type of farmer.

We found six plantain agroecological scores of plantain cropping systems: export banana high (EBh), export banana low (EBl), sugarcane high (SCh), sugarcane low (SCl), diversified high (Dh), and diversified low (Dl) (Fig. 3B).

The characteristics of each type are presented in the Table 3.

The differences between the farmers' groups in 2017 were related to four practices: fertilizer application, weed management, pest and disease management, and crop diversity. Significant differences between groups are marked by an asterisk (*) in (Table 4, part A.) Posthoc tests provide a better understanding of where the significant differences lie. They have shown that for fertilizer applications, the differences were significant between Dh and Dl, between Dh and EBl, between Dh and SCl, between Dl and SCh, between EBl and SCh, and between SCh and SCl. For weed management, differences were significant between Dh and SCl, between Dl and SCh, and between SCh and SCl. For pest and disease management, there were significant differences between EBh and EBl. For crop diversity, differences were significant between Dl and EBh and between Dl and SCh (Table 4, part B).

There was a link between the farming system types and the marketing strategies. The types with a low agroecological score (EBl, SCl, Dl) mostly had pricing strategies as defined in section 2.2.1 and chose cooperatives as their preferred marketing channel. This strategy implied the use of conventional production practices such as the use of pesticides and mineral fertilizers. On the other hand, the types with a high agroecological score preferred non-price competition strategies. Farmers with a high agroecological score sold their plantain via various short marketing channels (on the farm, basket delivery to consumers, on local markets, or specialized shops), which are less demanding in terms of volumes. Therefore, they did not aim at achieving high yields. On the contrary, the lower use of mineral fertilizers and pesticides was used as a marketing argument.

This diversity of marketing strategies can be linked to the absence of a structured market and probably to the large share of informal production. The diversity of marketing strategies highlights the adaptation of farmers to changing circumstances and to manage risk as highlighted in the analysis of Hansson et al., (2013). This adaptability is one pillar of agroecological systems that aim to diversify their livelihoods and strengthen links between producers and consumers (Wezel et al. 2016).

## 3.2 A shift toward more agroecoecological practices between 2017 and 2019

The agroecological score was compared in 29 plantain farming systems between 2017 and 2019. The score increased for the majority of the systems (16), remained the same for four systems, and decreased for nine (Fig. 4). The differences between 2017 and 2019 for each practice, regardless of the strategy, are not significantly different as shown by the Wilcoxon signed rank test (Table 5, part A). Looking at the practices separately, the differences are not statistically significant for five types: farms having an export banana strategy with a high agroecological score (EBh), farms having an export banana strategy with a low agroecological score (EBl), farms with a sugarcane strategy with a high agroecological score (SCh), farms with a diversified strategy with a high agroecological score (Dh), and farms with a diversified strategy with a low agroecological score (Dl). The differences are statistically significant for the weed management for farms with a sugarcane strategy with a low agroecological score (SCl) (Table 5, part B).

Thus, the use of mineral fertilizers and pesticides decreased between 2017 and 2019 for each plantain farming system (Fig. 5). The farmers belonging to the types having a high agroecological score (EBh, SCh, Dh) explained this decrease by their increased awareness of the negative

**Table 3** Characteristics of the six types of plantain farming systems: farms having an export banana strategy with a high agroecological score (EBh), farms having an export banana strategy with a low agroecological score (EBl), farms with a sugarcane strategy with a high agroecological score (SCh), farms with a sugarcane strategy with a low agroecological score (SCl), farms with a diversified strategy with a high agroecological score (Dh), and farms with a diversified strategy with a low agroecological score (Dl).*Creole gardens are modelled after the former home gardens that enslaved persons, who worked on large export farms, once cultivated to meet their food needs. They are characterized by complex crop associations and high biodiversity and are now studied as models for agroecological practices (Chevalier 2017)

| Type (agro-ecological score) | Fertilizer application | Weed management | Pest and disease managements | Crop diversity | Irrigation |
|---|---|---|---|---|---|
| EBh (12) | Organic fertilizers preferentially or combination of organic and mineral fertilizers (especially at the end of the cycle) | Mostly mechanical or manual weeding | Alternative methods (pheromones to trap weevils) | The majority of the farmers associated other crops with plantain | Mostly without irrigation (rainfed) |
| EBl (6) | Only mineral fertilizers | Herbicides | Fungicides to cope with cercosporiosis | Sole crop | Systematically for the majority |
| SCh (13) | Mineral fertilizers but in smaller quantities (between 100 and 300 g per plant and per year) and combined with organic fertilizers such as manure | Combination of herbicides (in and between the rows) and mechanical (brushcutter) or manual method | Most use leaf removal to control cercosporiosis, and only one used fungicide | The majority of the farmers associated other crops with plantain | Mostly without irrigation (rainfed) |
| SCl (6) | Mineral fertilizers (between 600 and 1200 g per plant and per year) | Herbicides (in and between the rows) | Fungicide only or combined with pheromones traps | Rotation with sugarcane | Systematic irrigation in the driest areas |
| Dh (14) | Very little use of mineral fertilizers (around 100 g per year and per plant) and always combined with organic fertilizers such as manure or vermicompost | Brushcutter mostly and manual management | Leaf removal and for some alternative methods such as decoction of plants (*e.g.*, *Azadirachta indica*) and ashes | Various associated crops as in the traditional creole garden (jardin créole in French)* | Mostly without irrigation (rainfed); none use systematic irrigation |
| Dl (6) | Mineral fertilizers | Herbicides | Leaf removal | No associated crops but rotations with other diversification crops such as pineapple and vegetable (tomatoes, pumpkins, etc.) | The majority irrigates (systematically or according to the observation) |

**Table 4** (A) Kruskal-Wallis rank test of the differences between farmers' practices for each production strategy in 2017 and (B) post hoc test to identify where the significant differences lie. The farmers' strategies are farms having an export banana strategy with a high score (EBh), farms having an export banana strategy with a low score (EBl), farms with a sugarcane strategy with a high score (SCh), farms with a sugarcane strategy with a low score (SCl), farms with a diversified strategy with a high score (Dh), and farms with a diversified strategy with a low score (Dl). Significant differences are marked by an asterisk (*)

| A. Interaction practice strategy (practice: strategy) | *P*-value | | | |
|---|---|---|---|---|
| Fertilizer: strategy | < 0.01* | | | |
| Weed management: strategy | < 0.01* | | | |
| Pest and disease management: strategy | 0.01* | | | |
| Crop diversity: strategy | < 0.01* | | | |
| Irrigation: strategy | 0.22 | | | |
| B. Post hoc test | *P*-value fertilizer | *P*-value weed management | *P*-value pest and disease management | *P*-value crop diversity |
| Interaction | | | | |
| Dh and Dl | 0.00* | 0.06 | 1.00 | 0.51 |
| Dh and EBh | 0.35 | 0.19 | 0.21 | 0.70 |
| Dh and EBl | 0.01* | 0.08 | 0.20 | 0.89 |
| Dh and SCh | 1.00 | 0.53 | 1.00 | 0.94 |
| Dh and SCl | < 0.01* | 0.04* | 0.31 | 1.00 |
| Dl and EBh | 1.00 | 0.28 | 0.92 | 0.00* |
| Dl and EBl | 1.00 | 0.99 | 0.87 | 0.99 |
| Dl and SCh | 0.01* | 0.02* | 1.00 | 0.01* |
| Dl and SCl | 0.95 | 1.00 | 0.92 | 0.09 |
| EBh and EBl | 0.99 | 0.44 | 0.03* | 0.17 |
| EBh and SCh | 0.45 | 0.96 | 0.21 | 0.99 |
| EBh and SCl | 1.00 | 0.06 | 0.06 | 0.55 |
| EBl and SCh | < 0.01* | 0.14 | 0.20 | 0.16 |
| EBl and SCl | 0.87 | 0.71 | 1.00 | 0.75 |
| SCh and SCl | 0.03* | <0.01* | 0.31 | 0.26 |

impacts of the use of mineral fertilizers and pesticides, whereas the others, belonging to the types having a low agroecological score, explained this decrease as a response to newly imposed regulatory constraints (for example a herbicide ban in October 2018). This is coherent with earlier work by Barlagne et al. (2016), who found that internal (*e.g.*, education, performance of the advisory services) and contextual (*e.g.*, evolution of the agricultural regulatory framework) drivers either enabled a smooth transition or coerced farmers into adopting agroecological practices.

The change in the agroecological score was high for the types with the lowest scores in 2017 (Fig. 4). The decrease between 2017 and 2019 of the average score for the SCh type, the only one for which the score decreased, was explained by farmers as a result of weather conditions. The year 2019 was drier than 2017, so farmers used more water, resulting in a negative impact on the agroecological score.

For Nicholls et al. (2016), the agroecological transition is the application of agroecological principles in a comprehensive manner rather than just the implementation of a set of agroecological practices. Implementing agroecological practices alone would not allow the necessary systemic change. In this study, the farming system types with high agroecological scores were in an explicit transition toward agroecology with the associated systemic transformations of the farms, whereas the types with lower scores were only reacting to regulatory bans and substituting their conventional practices with alternative ones.

Events like regulatory changes can be related to "drivers of change" (Barlagne et al. 2016) and "triggering events" (Sutherland et al. 2012). As in this study, Sutherland et al. (2012) show that a major change occurs in response to a "triggering event." If such events are absent, practices tend to be maintained or follow a similar trajectory over time. In the case of Guadeloupe, Barlagne et al. (2016) anticipated that these drivers of change would lead to two contrasting agricultural development pathways, one where Guadeloupean agriculture is on the decline because the farming sector has failed in adapting to change (and in particular, the need for more sustainable agricultural practices) and the other where a thriving farming sector has achieved a successful agroecological transition.

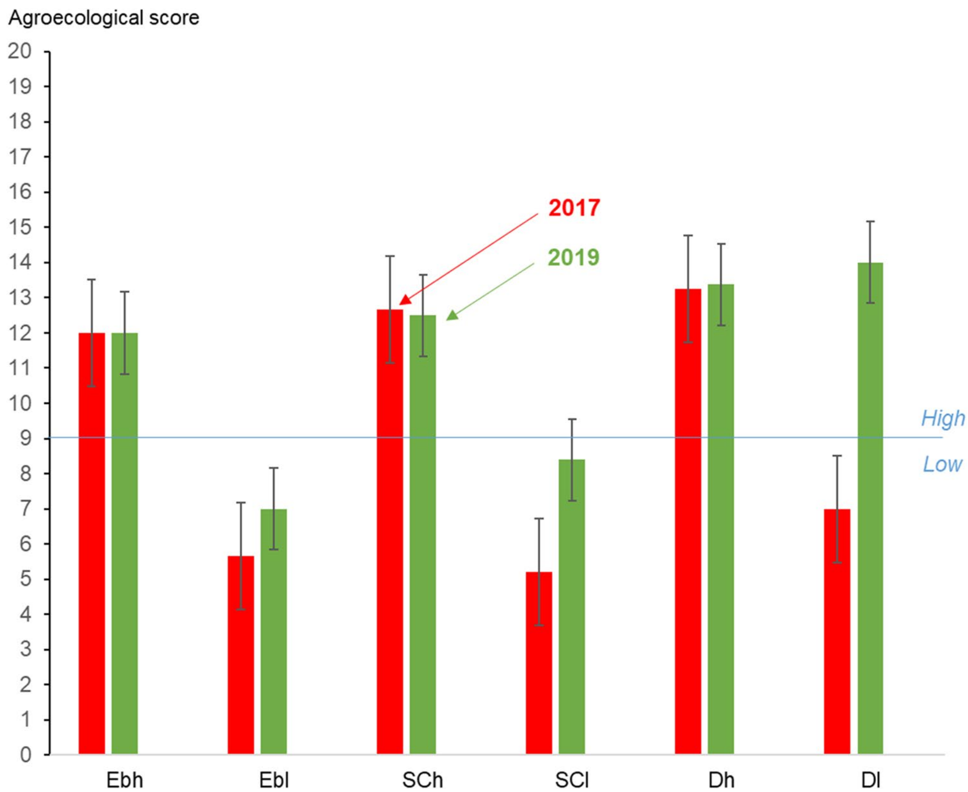


**Fig. 4** Evolution of plantain practices between 2017 and 2019. The agroecological score of plantain practices between 2017 and 2019 evolved in different ways according to each type: farms having an export banana strategy with a high agroecological score (EBh) (three farmers), farms having an export banana strategy with a low agroecological score (EBl) (six farmers), farms with a sugarcane strategy with a high agroecological score (SCh) (six farmers), farms with a sugarcane strategy with a low agroecological score (SCl) (five farmers), farms with a diversified strategy with a high agroecological score (Dh) (eight farmers), and farms with a diversified strategy with a low agroecological score (Dl) (one farmer). It increased for EBl, SCl, Dh, and Dl; decreased for SCh; and stagnated for EBh. The error bars correspond to the standard error wich is the standard deviation divided by the square root of the total number of samples (number of farmers). The standard deviation is calculated from the agroecological score of each practice

**Table 5** (A) Wilcoxon signed rank test of the differences between 2017 and 2019, regardless of the strategy. (B) Wilcoxon signed rank test of the differences between 2017 and 2019 for each practice and for each type. The differences are not statistically significant for five types: farms having an export banana strategy with a high agroecological score (EBh), farms having an export banana strategy with a low agroecological score (EBl), farms with a sugarcane strategy with a high agroecological score (SCh), farms with a diversified strategy with a high agroecological score (Dh), and farms with a diversified strategy with a low agroecological score (Dl). The differences are statistically significant for the weed management for farms with a sugarcane strategy with a low agroecological score (SCl). Significant differences are marked by an asterisk (*). NA corresponds to the values not available (when the data are ex aequo between the 2 years)

| A. Practices regardless of strategy | *P*-value | | | | | |
|---|---|---|---|---|---|---|
| Fertilizer | 0.08 | | | | | |
| Weed management | 0.17 | | | | | |
| Pest and disease management | 0.22 | | | | | |
| Crop diversity | 0.62 | | | | | |
| Irrigation | 0.42 | | | | | |
| B. Practice | *P*-value EBh | *P*-value EBl | *P*-value SCh | *P*-value SCl | *P*-value Dh | *P*-value Dl |
| Fertilizer | 0.37 | 0.05 | 0.87 | 0.13 | 0.82 | 1.00 |
| Weed management | 0.20 | 0.65 | 0.23 | 0.02* | 0.61 | 1.00 |
| Pest and disease management | NA | 0.65 | 0.24 | 0.66 | 0.35 | NA |
| Crop diversity | 0.11 | 1.00 | 0.40 | 0.91 | 0.59 | 1.00 |
| Irrigation | 1.00 | 0.59 | 0.34 | 1.00 | 0.70 | NA |

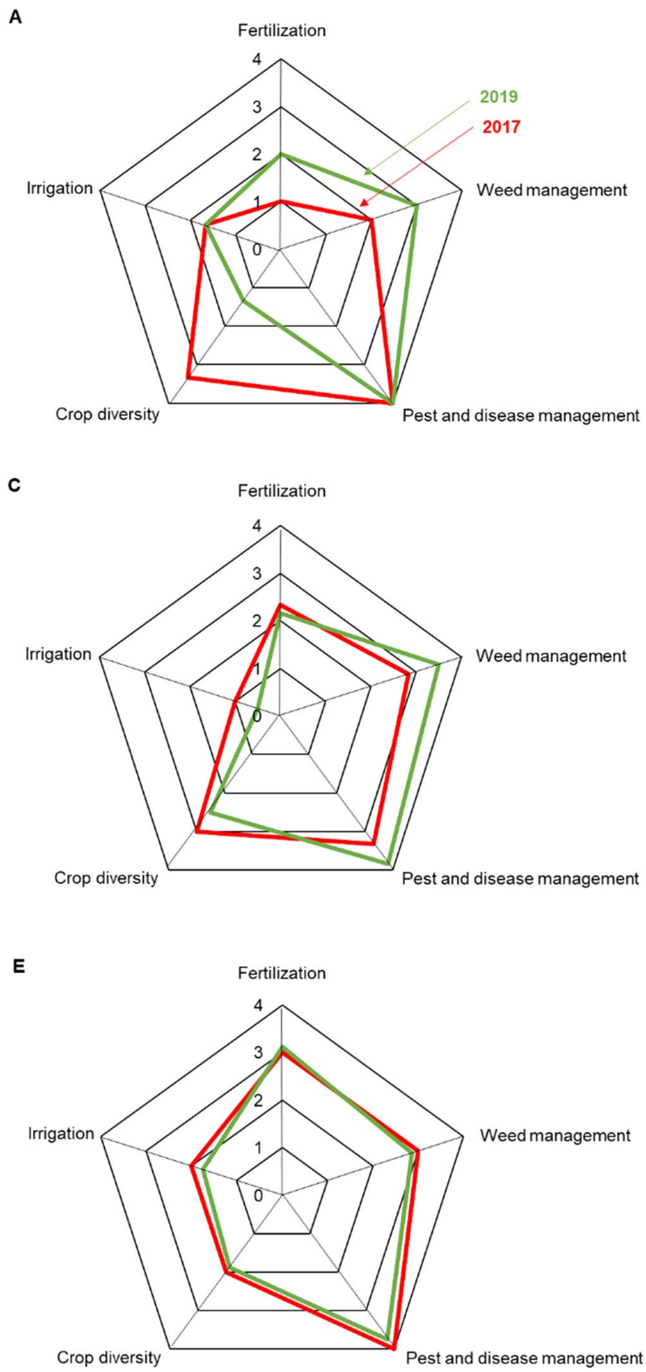


**Fig. 5** Evolution of agroecological score of plantain practices between 2017 and 2019. The agroecological score evolved in different ways according to each practice (fertilization, weed management, pest and disease management, crop diversity, and irrigation) of each type: **A** farms having an export banana strategy with a high agroecological score (EBh), **B** farms having an export banana strategy with a low agroecological score (EBl), **C** farms with a sugarcane strategy with a high agroecological score (SCh), **D** farms with a sugarcane strategy with a low agroecological score (SCl), **E** farms with a diversified strategy with a high agroecological score (Dh), and **F** farms with a diversified strategy with a low agroecological score (Dl). The radar chart represents the evolution over time of the score of all studied quantitative variables (agroecological score) on individual axes (corresponding to all studied practices) starting from the same central point

The results also showed that the cause of the changes is explained differently by the farmers according to their type and, therefore, their trajectory.

## 3.3 Innovative plantain systems either part of strong or weak agroecological transition

### 3.3.1 Four innovative cropping systems

The first two rounds of focus groups held in three different locations led to the collective definition of four plantain cropping systems. Cropping systems 1 and 4 were the product of a consensus in the group that defined one system. In one group (the one held in North Basse-Terre), they defined two distinct cropping systems: cropping systems 2 and 3 (Table 6).

In the group that proposed the first cropping system, composed in a majority by EB-strategy farmers, they discussed the opportunity to compare the performances of vitroplants and the PIF (Plant Issus de Fragments de tige) method (Kwa 2003), which is a technique for on-farm sanitation and multiplication of plantain plants. This method was assessed in Cameroon, and results showed that the plants produced with the PIF technique had the same agronomic quality as vitroplants (Sadom et al. 2010). The PIF technique has very low production costs, but vitroplants guarantee a lower health risk (Sadom et al. 2010). Vitroplants are commonly used in export banana systems, and EB-strategy farmers are accustomed to use this kind of material. However, the use of vitroplants in plantain systems was new in 2019 in Guadeloupe, although adopted in other countries such as Cameroon (Youmbi et al. 2005). Eleven pilot farms were testing plantain vitroplants as part of a research project conducted between 2017 and 2019 that assessed plantain yields during four successive plantain production cycles after vitroplant introduction. One farmer involved in the experiments was present at this focus group and able to share the results. Using the PIF method was suggested by the D-strategy farmers of the group. The method was new for these farmers but was already being implemented by other farmers of Guadeloupe who were not present in this group. This comparison between PIF and vitroplants was also discussed in the group that proposed cropping system 4. In this case, farmers wanted to compare a method already implemented by “banana professionals” (vitroplants), which they never used themselves with another method that, according to them, could respond locally to a lack of healthy plants (PIF method).

In the four plantain cropping systems, farmers associated other marketable crops (such as peas, malanga, sweet potatoes, cucumbers, and peppers) with plantain. The rationale was to ensure a quick cash flow while waiting for the plantain bunches to be harvested and to cope with the uncertainty of commercialization (due to uncertain markets or climatic hazards), a barrier common to all of the farming system types and specifically critical in crops that take almost a year to produce. Associating crops was not an innovative practice for Dh farmers who already do so in their systems, but it was an innovative practice for EB-strategy farmers (especially the EBl type) whose cropping systems are mostly based on monocropping. This latter group of farmers probably maintains conventional monoculture systems today; since as Barbosa et al. (2016) showed in Brazil on Prata Ana banana (*Musa* spp., AAB), these systems have the highest yields and the best economic viability. However, they do not allow quick cash flow, which is an important criterion for many farmers to secure their income.

In terms of spatial design, farmers chose a double row system with one wide row spaced far enough apart to maximize yield and production costs, as done in export banana systems (Kesavan et al. 2002). Farmers who proposed cropping system 2 (mainly D-strategy farmers) chose to increase the space between rows, mostly to facilitate weed management with tractors. This practice was new for farmers who use herbicides, but not for those who use a compact tractor on their farms.

The type of nutrient supply chosen during the co-design was also linked to the type of farmers present in the group. In three of the cropping systems, farmers chose local organic fertilizers. In cropping system 4, because all participants

**Table 6** Main characteristics of the four cropping systems defined collectively. The Blanche variety corresponds to the French Clair type and the Corne, Mbouroukou, and the Domenico-Hartón Enano to the Faux Corne type (Scherschel 2017). The PIF (Plant Issus de Fragments de tige) method is a technique for on-farm sanitation and multiplication of plantain plants

| System | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Plantain variety | Blanche | Blanche/Corne/Mbouroukou | Blanche/Corne/Domenico-Hartón Enano | Blanche |
| Plant preparation | PIF vs. vitroplant | PIF | PIF | PIF vs. vitroplant |
| Crop association | Yes | Yes | Yes | Yes |
| Rows | Double | Simple | Double | Simple |
| Fertilizer | Mineral | Local organic | Local organic | Local organic |
| Irrigation | Yes | No | No | Yes |

had livestock, the choice was manure. For cropping systems 2 and 3, farmers chose manure as an amendment and vermicompost as a fertilizer. Using vermicompost was new. The proposal to produce and use vermicompost was a recurrent topic mostly proposed by the research center and associations promoting agroecological practices in the Caribbean to have access to fertilizers at local level. However, in Colombia, the second-largest plantain producer in the world, the use of vermicompost is more related to nematode management (Bautista M. et al., 2015; Martha Marina Bolaños Benavides et al. 2020) than to fertilizer application. In cropping system 1, farmers chose mineral fertilizers that they already mostly use.

In the group that proposed cropping system 4, the participants chose to irrigate to cope with a lack of water. This choice to include an irrigation system was linked to the drought intensity in the area (Mantran et al. 2017). The group that proposed cropping system 1 also chose irrigation, but in this case, it was related less to a proven constraint in their cropping area than to the fact that they already had access to irrigation.

The cropping systems proposed by farmers considered the structural characteristics of farms (*e.g.*, presence or not of animals in the farm), biophysical constraints (*e.g.*, disease or drought), technical constraints (*e.g.*, space for weed management), environmental constraints (*e.g.*, soil leaching), but also economic constraints (*e.g.*, uncertainty of commercialization), highlighting the systemic vision they had in the design process.

Discussions between farmers with the research team made it possible to identify innovative practices, such as the use of animals for weed management. However, such innovative practices were not chosen in the final designs presented in Table 6. During the consensus-building process that aimed to select the most promising alternative plantain cropping systems, farmers mostly chose practices and designs they believed would be both successful (with an almost certain probability of success based on their personal experience and/or their exchanges with other farmers) and able to alleviate the constraints identified. Relying on farmers' knowledge and experience to weight the available options and select the one with the highest chances of success and/or the most able to address the identified constraints is characteristic of a rule-based design as defined by Meynard et al. (2012). It can lead to fixation effects (Jeuffroy et al. 2022), but putting together farmers from diverse types engaged in various pathways toward agroecology limited these effects.

Among all of the groups, the one that proposed a cropping system that differed most from the farmers' current practices was the group that proposed cropping system 4. Farmers decided to introduce trees into the system to limit soil leaching. Meanwhile, the group that proposed cropping system 1 was very inspired by changes implemented in the banana export systems. Angeon and Bates (2020) highlighted the technology package logic that was encountered with the EB-strategy farmers with this preference for imported resources that may be eligible for subsidies such as vitroplants. However, over the past decade, the banana export sector has implemented its own agroecological transition due to the scandal (Risède et al. 2018) associated with the decade-long use of chlordecone. It consequently makes sense to replicate some of the agroecological practices that are used in Cavendish systems in plantain cropping systems. Furthermore, at territorial scale, synergies could be found with Cavendish systems and the various plantain systems to close possible nutrient gaps.

In this process, the cropping systems designed were mostly a mix of common practices and new ones already implemented by innovative farmers. Trust in personal experience and in other farmers considered as "experts" played a central role in the choice of these practices. The central place of trust in innovation adoption, linked to geographic proximity, was identified by Ramírez-Gómez et al. (2020).

Farmers were able to ask their own questions regarding the performances of these practices to these experts. Montenegro de Wit and Iles (2016) argue that non-academic knowledge and expert testimony should be better valued in protocols aiming to produce evidence in agroecology. Due to the lack of research on plantain cropping systems in Guadeloupe, scientists were not always able to answer certain questions. The research team specifically provided scientific knowledge on how to implement PIF. Additionally, the research team proposed methods and tools to evaluate existing practices along an agroecological gradient, facilitate knowledge exchanges between farmers, and support them to design by themselves innovative cropping systems addressing their constraints. For Chizallet et al. (2020), the role of scientists in such processes is to equip (with frameworks and tools) the farmer, who is a non-professional designer. Here, the research team equipped farmers already engaged in an agroecological transition. According to the ladder of participation defined by Arnstein (1969) and Geilfus (2008), that goes from a passive posture to a personal development posture, this process was between functional participation, as the objective of the project was pre-established (co-designed agroecological plantain systems), and interactive participation, as the farmers themselves evaluated the systems.

#### 3.3.2 Barriers and solutions to implementing agroecological cropping systems

The last focus group made it possible to focus on the barriers to implementing agroecological cropping systems and consequently on constraints not always considered in the design of the four cropping systems.

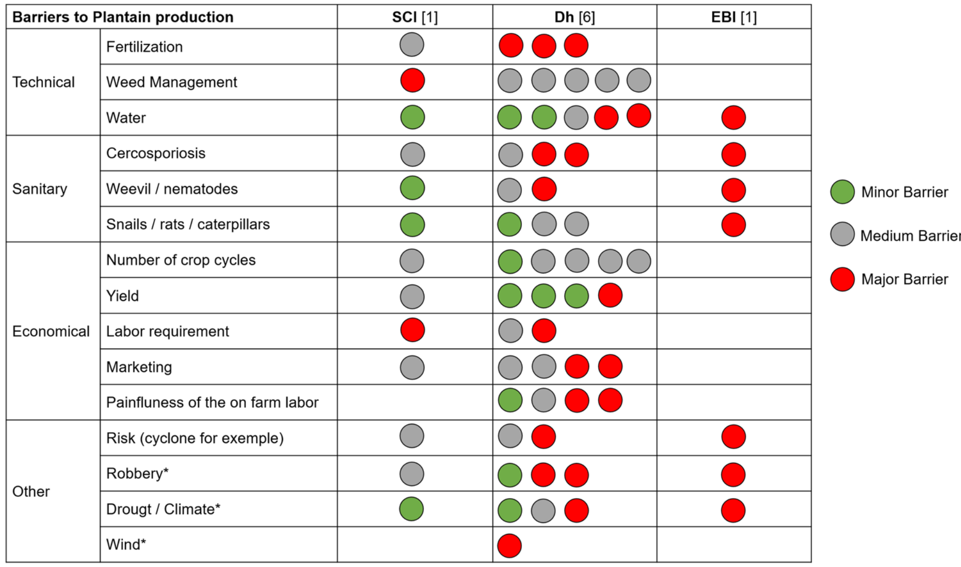


**Fig. 6** The participants of the 2021 focus group prioritized barriers. The barriers with * correspond to the barriers added by the farmers before the prioritization: farms with an export banana strategy and a low agroecological score (EBl), farms and sugarcane strategy with a low score (SCl), and farms with a diversified strategy and high score (Dh). Labor requirement corresponds to the working duration while the painfulness of the on-farm labor corresponds to the hardness of the task

The commercialization/marketing barrier was common to the three focus groups but appeared as a major barrier for D-strategy farmers who are less involved in structured organizations. The EB-strategy farmers who were mostly members of a cooperative of farmers that supports commercialization did not see marketing or commercialization as a barrier even though this was mentioned in 2019 (Fig. 6).

As for commercialization, constraints related to weevils (*Cosmopolites sordidus*) and nematodes (*Radopholus similis*) were common to all focus groups because they depend on the sanitary state of plants and the soil (Gold et al. 2001; Haegeman et al. 2010). In Guadeloupe, nematodes were identified as the major pest on plantain (Rhino et al. 2010) associated with the lack of production and access to healthy plants (Delone 2014). However, weevil and nematode constraints appeared to be greatest for diversified (Dh) and export banana type (EBl) farmers (Fig. 6). Possible reasons why this is not a major barrier for the sugarcane type (SCl) may be explained by (i) the recent introduction of plantain in their cropping systems, and therefore probably low weevil pressure, and (ii) the sanitizing character of sugarcane, which leads the crop rotation, in relation to soil pests.

Nutrient supply was another common barrier for all of the focus groups in 2019. As for the commercialization/marketing barrier, it was not mentioned by the EB-strategy farmers in 2021, for the reasons explained above, and appeared as a major barrier for the D-group farmers. EB-strategy farmers' better access to inputs via the cooperative also probably explains why this was not a barrier.

Some of these barriers were specific to a given location, and this is the case for irrigation in North Grande-Terre and cercosporiosis, which is a disease only mentioned in the Basse-Terre groups where the humidity is high (Mantran et al. 2017). It is caused by *Mycosphaerella fijiensis*, a fungus that spreads quickly under high humidity conditions (Kwa and Temple 2019).

A gradient of agroecological solutions was mentioned, ranging from those favored by export banana type farmers interested in technological packages (vitroplants, commercial imported inputs, etc.) eligible for subsidies, to those favored by farmers who were very committed to transforming their farms based on agroecological principles (local compost, knowledge of the environment, etc.). The most agroecological systems were those that relied the most on local resources and which were the least subsidized and/or technically supported. This gradient was also present in the marketing channels, ranging from marketing via cooperatives for those implementing technological package systems to direct sales on farms for the most agroecological systems. Various authors highlight the importance of territorial anchorage to move toward more agroecological systems (Duru et al. 2015b; Thénard et al. 2021).

The type with the highest agroecological score (Dh) also proposed the most agroecological solutions (redesign solutions). A set of redesign solutions involving the entire cropping systems or farming system was mentioned by D-strategy farmers (Fig. 5), such as the PIF method (Kwa 2003) and the use of *Commelina diffusa*, a cover crop, to cope with weed management. These were also mentioned by SC-type farmers, but not by EB-type farmers.

The number of substitution solutions mentioned was almost equivalent to the number of redesign solutions (Fig. 7). The solution that was the most frequently mentioned (6 times) was the use of a brushcutter to deal with weeds, a technique increasingly used in various cropping systems, including Cavendish banana systems. It was mentioned by the D and SC-strategy farmers. D-strategy farmers identified the choice of other plantain varieties as a solution

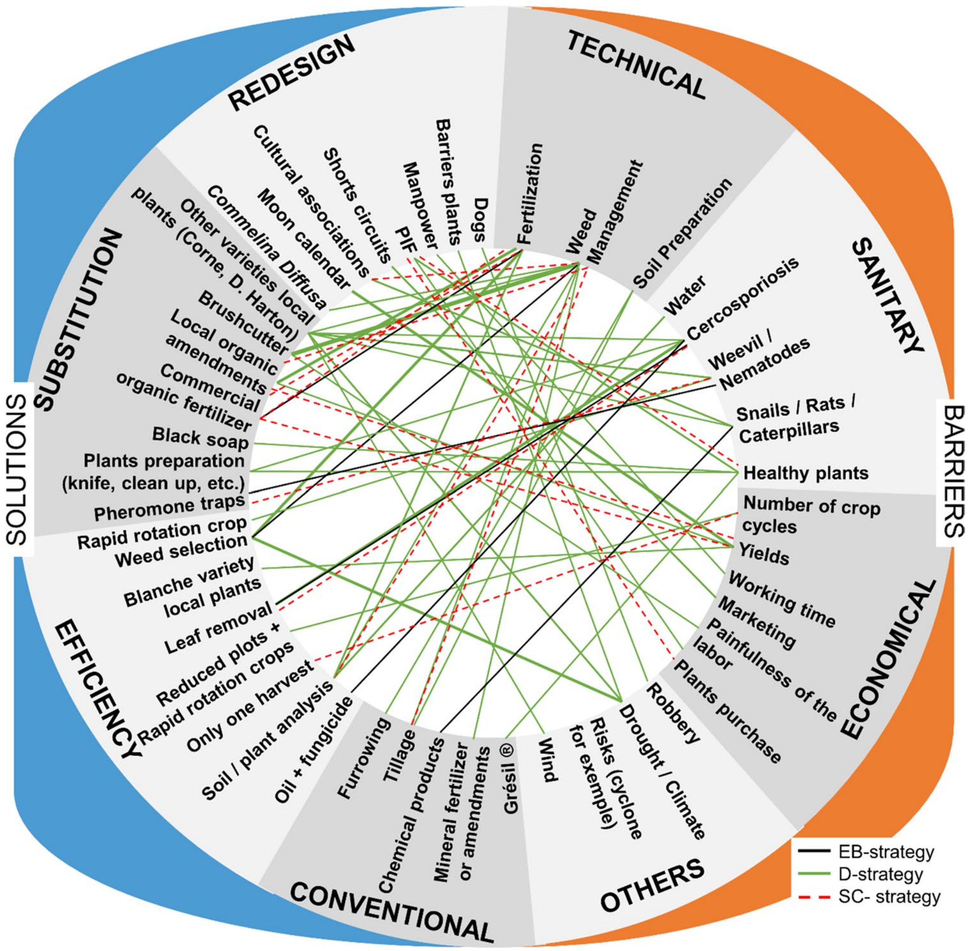


**Fig. 7** The links between the agroecological barriers (in orange), the solutions (in blue), and the types of plantain farming systems were analyzed in the efficiency-substitution-redesign ESR framework (Hill and MacRae 1996). The intensity of the link corresponds to the number of times the lever was mentioned to cope with a barrier (the more farmers chose it, the thicker the link). The EB-strategy corresponds to the export banana strategy (black line), the D strategy to the diversified strategy (green line), and the SC-strategy to the sugarcane strategy (red dashed line). In the redesign solutions, PIF corresponds to the PIF (Plant Issus de Fragments de tige) method, a technique for on-farm sanitation and multiplication of plantain plants

to cope with three groups of health barriers, namely cercosporiosis, telluric parasites (weevils and nematodes), and other pests (snails, rats, and caterpillars). The other substitution solutions were the use of local organic amendment for supplying nutrients (mentioned by all three strategy groups) and to address low yields (mentioned by D and SC-strategy farmers); the use of black soap that is currently tested by farmers to cope with cercosporiosis (mentioned by D-strategy farmers) and the plant preparation (mechanical cleaning and soaking, mentioned by D-strategy farmers) to cope with the lack of healthy plants and the use of pheromone traps to control weevil populations/infestation (mentioned by the SC and EB-strategy farmers).

None of the EBl types mentioned solutions corresponding to the redesign of the farm (production system). The difference in the choice of more or less agroecological practices by different farm types was highlighted by Fanchone et al. (2020) in Guadeloupe and Martinique, with farms mainly oriented toward export (sugarcane and Cavendish banana) that were subsidized and more interested in a weak agroecological transition based on existing practices, and farms from diversified systems already engaged in agroecological practices moving toward a strong transition. With this work, Fanchone et al. (2020) highlighted the need for innovations in these various types of farms.

This specific step of the method was complementary to the design workshops, highlighting additional technical alternatives known by farmers to address the barriers they identify. It showed that the farmers knew a range of technical solutions. However, not all of these solutions had been implemented. Therefore, it highlighted the need to better understand the flows of knowledge and of material and financial resources between plantain farmers and other actors within the innovation system to identify those currently promoting or locking these technical solutions at the territorial scale, especially the most influential actors. Such knowledge would facilitate the design of organizational innovations found to be the key to support the agroecological transition.

## 4 Conclusion

This work aimed to co-design innovative agroecological plantain farming systems that integrate knowledge held by farmers on plantain cropping systems, in order to (i) strengthen the scant scientific research on plantain cropping systems and (ii) address the increasing demand from policiy makers and civil society to develop under-research crops dedicated to local diet following agrocecological principles. We highlighted that plantain production practices and marketing/commercialization strategies in Guadeloupe are very diverse, and this diversity is reflected in the observed agroecological transition of farmers, with some systems close to strong agroecological transition, while others are closer to weak agroecological transition. The co-design of innovative systems helped plantain farmers to define agroecological solutions for innovative plantain production in Guadeloupe capable of addressing the specific barriers that they face. Farmers identified solutions to overcome these barriers, and in so doing improved their contribution to agroecological transition. In a context where scientific research on plantain cropping systems of Guadeloupe is lacking, the role of research scientists in this process was to facilitate exchanges of a diversity of endogenous knowledge held by farmers. A system experiment is now in place on an experimental station and will allow scientists to evaluate the performance of the proposed cropping systems. In addition to biotechnical indicators, economic indicators of these systems could be evaluated. This work may be continued in the future by improving scientific knowledge on some specific constraints highlighted, particularly around marketing channels, which were identified as a major barrier for the agroecological transition.

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**Authors' contributions** Marie Bezard, Jean-Louis Diman, Valérie Angeon, and Raphael Morin contributed to the study conception and design. All authors contributed to the development of the methodology. The data collection was performed by Marie Bezard and Raphaël Morin. The data visualization was prepared by Marie Bezard, the first draft of the manuscript was written by Marie Bezard, and all authors commented on earlier versions of the manuscript. All authors read and approved the final manuscript.

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**Data availability** The data and material are available upon demand to the corresponding author.

**Code availability** The datasets analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Ethics approval** Informed consent was obtained from all individual participants included in the study.

**Consent to participate** Participants have been informed of the purpose of the research and have been given the opportunity to ask questions and withdraw from the study in which case their data would not be used. All participants to the surveys and the focus groups had access to a non-opposition information sheet ("Fiche d'information non-opposition") informing them of their rights.

**Consent for publication** The research conducted complies with the General Data Protection Regulation (RGPD, Reglement pour la protection des données personnelles), and all participants consented to participate in the study.

**Conflict of interest** The authors declare no competing interests.



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