Agricultures et défis du monde
Collection Cirad-AFD

The agroecological transition

of agricultural systems in the Global South

F.-X. Côte, E. Poirier-Magona,
S. Perret, P. Roudier,
B. Rapidel, M.-C. Thirion,
éditors

éditions Quæ

Chapter 6

The agroecological transition of Cavendish banana cropping systems in the French West Indies

Jean-Michel Risède, Raphaël Achard, Pierre Brat, Christian Chabrier, Gaëlle Damour, Claire Guillermet, Luc de Lapeyre, Denis Lœillet, Steewy Lakhia, Paul Meynard, Philippe Tixier, Hoa Tran Quoc, Frédéric Salmon, François-Xavier Côte, Marc Dorel

The Cavendish banana – a 'dessert banana', as opposed to 'cooking bananas' or to plantains – is cultivated in Martinique and Guadeloupe on around 7000 hectares. In the last few years, the annual marketed volume of this crop has amounted to 320,000 tonnes (Imbert and Lœillet, 2017). Production of the Cavendish banana is a major activity of the economy of the French West Indies, directly employing over 6000 people in the banana chains of these two islands and accounting for nearly 10,000 indirect and spinoff jobs (Global Footprint study). The agri-chain was reorganized nearly ten years ago, following a severe crisis of competitiveness that peaked in the early 2000s. One of the outcomes of that situation was the creation of UGPBAN (General Union of Guadeloupe and Martinique banana growers) to manage the overall strategy for developing the agri-chain and marketing its production. In the French West Indies, this production remains subject to a very strict framework of constraints, in view of the increased competition in the global market and the significant costs it entails. These high production costs are due in particular to much higher salaries than in other production areas, stringent European regulation as concerns standards, and to recurring climatic hazards (hurricanes). Societal expectations are also high in terms of protecting the environment and human health in a context of increasing urbanization. These factors force an approach of continuous innovation on the agri-chain in a permanent effort to improve its competitiveness, as well as its environmental and social sustainability.

Conventional methods of producing the Cavendish banana are being called into question due to physical, chemical and biological degradations, and the unintended pollution they can cause in cultivated and natural environments (Risède and Tezenas du Montcel, 1997). Highly productive in non-limiting soil and crop pest conditions, the Cavendish banana, which represents a single clone encompassing a set of cultivars that are closely related genetically, is in fact demanding in terms of water and mineral inputs, and susceptible to numerous aerial and soil-borne diseases and pests. These diseases and pests have, for several decades now, been managed in many parts of the world, including in the French West Indies, by a sustained use of synthetic pesticides derived from fossil fuels, to which has been added fertilization with synthetic fertilizers. These intensive cropping systems have thus resulted in adverse environmental and health impacts.

Therefore, starting at the end of the 1990s and the beginning of the 2000s, the persisting pollution from chlordecone (an organochlorine insecticide used in the region until 1993 to control the banana weevil, a rhizome boring insect) that led to an unprecedented health crisis in Martinique and Guadeloupe (Cabidoche *et al.*, 2009) was revealed and widely publicized. This pollution has resulted in the long-term fixation of chlordecone in soils and aquatic environments, the contamination of local populations and certain agricultural and livestock products. This crisis was decisive in the way issues were raised amongst all the stakeholders of the banana agri-chain (researchers, producers, public policymakers, civil society) concerning the methods of production of the Cavendish banana in the French West Indies, islands that are rich in biodiversity, and where farmland and residential areas are closely packed.

It is in this particular economic and environmental context that the 'Sustainable Banana' plan was launched in 2007 in the French West Indies to improve the economic, environmental and social sustainability of banana production. This chapter's aim is to discuss the environmental component of this plan and to assess the agroecological transition in the French West Indian cropping systems linked to it. We will, consequently, identify the determinants of this transition, the technical and organizational modalities based on which it was carried out, the related practices that were developed on the field, and the multi-stakeholder intervention frameworks in which it took shape. Finally, the lessons that can be learned from this agroecological transition are presented in a perspective outlook.

The determinants of the agroecological transition

Four major groups of factors were simultaneously involved at the start of the agroecological transition of Cavendish banana cropping systems in the French West Indies.

The consequences of a highly intensified, pesticide-dependent monoculture

In the period between the late 1980s and the early 2000s, there were sharp declines in the productivity of intensive monoculture banana systems (Delvaux *et al.*, 1990; Dorel and Perrier, 1990). The performance of these systems gradually dropped due to recurrent problems of soil fertility loss and soil 'fatigue', caused by an uncontrolled increase in soil-borne parasitism. These systems were affected, in particular, by a range of pests including multispecies communities of endoparasitic nematodes, and a soil-borne fungus that induced root necrosis whose significance was strengthened by the damage caused by these plant parasitic nematodes (Risède and Simoneau, 2004).

The repeated use of synthetic nematicides of the carbamate or organophosphorus families proved inadequate to halt the effects of water and mineral imbalances caused by these soil-borne pests, or to stem the toppling of plants affected by the alteration and necrosis of their root systems. In a similar way, the damage caused by the rhizome weevil *Cosmopolites sordidus* and the size of its population became increasingly difficult to control. In parallel, resistance to benzimidazole fungicides used to control Yellow Sigatoka disease on banana trees, caused by the fungus *Mycosphaerella musicola*, was growing, reducing the range of fungicidal molecules that could be used to control this leaf spot disease. Simply put, it was the production model taken as a whole that began failing in the context of increased biological constraints resulting in yield losses and technical bottlenecks. There was a growing realization that any solution would have to involve a paradigm shift.

Growing societal demand for more sustainable production methods

The risk of a health and environmental crisis due to chlordecone, noted as early as in the late 1970s and early 1980s (Snegaroff, 1977; Kermarrec, 1980), was identified definitively and widely publicized between the late 1990s and early 2000s. This persistent organic pollutant was first detected in several drinking water catchments in 1999, and then in edible tubers (yams, taros, etc.), as well as in other agricultural products and aquatic organisms in 2002. The resulting contaminations drew the attention of local populations, producers, public authorities and policymakers. As a consequence, environmental and health concerns acquired greater importance, which helped in efforts to find alternative solutions to control the banana weevil. They also helped in the implementation of measures to reduce the exposure of local populations to this pollutant. The French government launched a series of plans (national chlordecone action plans) to better understand how the environment was affected and to look for ways to better manage risk (ARS and Ireps, 2016).

Agronomic research already focused on the development of reasoned banana cropping systems

At the end of the 1980s, the French research institution CIRAD had already been undertaking agronomic research on banana cultivation for a long time, and was already very active in the French West Indies. It intensified its research activity in the 1990s and in the early 2000s, with this activity taking the form of a proactive and anticipatory approach intended to develop reference frameworks and sustainable technical packages for producers. These technical packages were based on reasoned practices to limit the systematic use of pesticides and synthetic fertilizers, thus mitigating their environmental impacts. In this way, CIRAD's researchers developed a soil-plant standard to control mineral fertilization on the basis of soil analyses and a foliar diagnostic method that was used from the end of the 1980s. A biological forecasting system to control Yellow Sigatoka disease, developed by CIRAD, was already widely in use at this time and helped to reduce the impacts of the fungicides used against the disease by limiting the number and amount of active fungicide ingredients used per hectare

(1 kg/ha/year in the French West Indies against 30 to 70 kg/ha/year in other parts of the world). The principle of linking soil sanitation against plant parasitic nematodes with the use of healthy banana vitroplants to avoid using nematicides had also been developed, although in practice the bulk of the producers were not yet using this technical itinerary. Similarly, methods were developed for diagnosing banana cropping systems, as also for quantifying populations of soil-borne pests (plant parasitic nematodes, weevils) and for estimating the extent of their damage (in the case of the weevil). Finally, researchers also explored ways to do away with post-harvest fungicides used to control post-harvest diseases (anthracnose and crown rot). In the marketing domain, there are two strategies – push and pull – that determine how innovations are built. In push strategies, it is the invention or innovation that is triggered by the offer. Conversely, in pull strategies, they are driven by demand. Until the 2000s, CIRAD and the research community primarily used a push strategy to come up with innovations. This resulted in the development of a set of diagnostic, prophylactic and reasoned approaches, which however did not at that time engender a coordinated and integrated application, nor lead to widespread adoption by producers.

An institutional environment conducive to a reduction in pesticide use and an ambitious innovation plan

In the early 2000s, environmental issues and sustainable development acquired particular importance at the institutional level in France. Thus 2007 was the year of the *Grenelle de l'environnement* agreements, which aimed at a long-term national mobilization for sustainable planning and development. In 2008, the Ecophyto 1 plan, formulated to reduce the use of pesticides by 50% over a 10-year period, was launched. This occurred in the backdrop of several years of increasingly strict French regulations on active ingredients, which resulted in the gradual withdrawal of and ban on the use of many compounds, including several synthetic insecticides and nematicides used in banana plantations.

This trend was subsequently strengthened at the European level by Regulation (EC) no. 1107/2009 of October 21, 2009, which concerns the introduction of plant protection products in the market, re-specifies their methods of assessment and authorization, and lists the exclusion criteria for substances classified as particularly dangerous for human health and the environment.

It is in this context that an ambitious innovation plan, the 'Sustainable Banana' plan, was launched via the concerted initiative of CIRAD researchers, the Guadeloupe and Martinique Banana agri-chain (BGM) and its different constituents (General Union of Guadeloupe and Martinique banana growers, the grower companies of Guadeloupe and Martinique: LPG and BanaMart), Martinique and Guadeloupe Regions, decentralized government services (Directorate of Agriculture and Forestry), ministries (including the Ministry of Agriculture) and ODEADOM (Office for the development of the agricultural economy in the French overseas territories). This plan was based on a twin objective. On the economic front, it aimed to determine and implement conditions necessary to maintain a high level of production and of employment. To this end, it focused on actions to improve and modernize banana farms and their related infrastructure, and on actions to add value to the banana agri-chain and to diversify it by orienting actors and imparting training to them. On the environmental front, it aimed at developing an alternative production method in the French West Indies based on agroecological concepts. The 'Sustainable Banana' plan was thus the main driver to create a trajectory of innovations for the agroecological transition in the banana production systems of the French West Indies.

Agroecological practices implemented in the field

The change to diversified systems using service plants

Several practices have helped initiate the agroecological transition of banana production methods in the French West Indies. These are mainly practices of prophylaxis, biological or mechanical pest and disease control, monitoring of these pests and diseases in line with reasoned management, as well as those concerning the reinsertion of functional biodiversity in cropping systems in order to strengthen the provision of ecosystem services. These practices combine crop and soil management methods with the deployment of functional biodiversity in cropping systems. Table 6.1, without being exhaustive, lists these practices in terms of the initial objectives assigned to them.

Developed in a partnership innovation framework in which researchers, technical actors and producers interacted, these practices were initially based on relatively specific technical 'building blocks', which were then combined with the help of feedback from different actors involved. Indeed, the agroecological transition developed through a process of a participatory co-design of cropping systems. This process did not unfold linearly over several successive stages, but rather through the coexistence of different strategies with a common thread: protection against plant-parasitic nematodes. Cover crops were initially monospecific, i.e., with only one service plant species used at a time. This species (which could, for example, be *Brachiaria decumbens*, *Neonotonia wightii* or *Crotalaria* spp.) was initially used in rotation with the banana crop. These cover crops then ensured the soil cleansing up of banana parasitic nematodes thus avoiding a resort to spontaneous fallows which include weed species that are hosts to these nematodes. In addition, they also helped restore the overall soil fertility. Gradually, these sanitizing and improved fallows replaced the spontaneous fallows. In parallel, more traditional rotations (banana-pineapple, and especially banana-sugarcane) were practised. Subsequently, cover crops based on service plants began to be associated with bananas, and soon developed into multi-species cover crops, based on a set of service plants specifically developed over time and space (Photo 6.1). In this way, a set of complementary services could be simultaneously targeted, such as biological regulation of pests and diseases, biomass production, erosion control, nutrient recycling, soil structure improvement, carbon sequestration, and atmospheric nitrogen fixation.

A design approach for banana systems based on service plants

To implement these banana cropping systems based on multi-species and multifunctional cover crops of service plants, several generations of prototypes of innovative cropping systems were necessary. They were developed, for the most part,

Photo 6.1. Multi-species cover crop (*Arachis repens* and *Desmodium ovalifolium*) associated with Cavendish banana. © Hoa Tran Quoc/CIRAD.

in the participatory and multi-partnership framework of the 'Sustainable Banana' plan. The general approach was based on a *de novo* co-design with the production of systems that departed from conventional systems, and the creation of prototypes by experts. An important step was to undertake a specific engineering effort in order to learn how to set up cover crops based on service plants, prior to designing any cropping system prototype. Improvement loops based on feedback from the different categories of actors involved (researchers, producers, technicians) on the agronomic and environmental performances of these prototypes were carried out using a step-by-step design. They were informed by the design and the assessment of pre-prototypes of innovative banana cropping systems in real world conditions (exploratory tests of parts of technical itineraries). Figure 6.1 illustrates how generations of prototypes of banana cropping systems based on service plants form part of a gradient of plant complexity and diversity, with the aim of providing multiple agroecological services. These innovative cropping systems were assessed at the beginning mainly on the basis of their agronomic and economic performances. Today, their assessment relies upon a network of Dephy farms (demonstration, experimentation and production of references on plant protection sparing cropping systems) set up in Martinique and Guadeloupe, on the basis of a multi-criteria approach, not only taking into account the economic and environmental dimensions, but also social ones pertaining to the sustainability of these innovative systems (Feschet *et al.*, 2018).

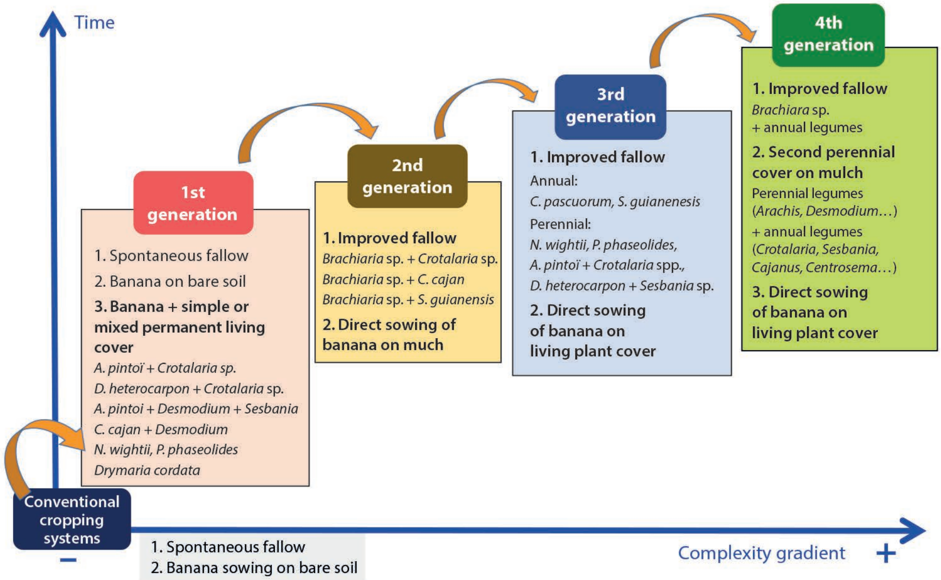

Figure 6.1. Successive generations of prototypes of innovative banana cropping systems including multi-species and multifunctional cover crops of service plants.

Results in the banana cropping systems of the French West Indies

In addition to maintaining the level of production in Martinique and increasing it by 50% in Guadeloupe, one of the key results of this agroecological transition is the substantial reduction in the use of plant protection products in banana cropping systems in the French West Indies. Thus, in accordance with the initial objective of the Ecophyto 1 plan, the quantity of active ingredients (QAI) used between 2006 and 2015 in these cropping systems was reduced by almost 60% on both islands, the reduction being more than 30% between 2008 and 2011 alone (Figure 6.2). If we calculate the quantity of active ingredients (determined by sales of plant protection products to banana producers) per hectare per year, the decrease is also more than 50% between 2006 and 2015. Over the same period, there was a substantial reduction in the use of nematicides and insecticides, amounting to nearly 90% (and a decrease of less than 50% for herbicides alone, while the amount of fungicides showed little variation over the same period).

Finally, farmers have largely adopted crop prophylaxis practices based on the coupling of soil sanitation strategies against soil-borne parasites with the use of healthy planting material (banana vitroplants). At present, more than 80% of farmers use them. The use of nematicides has become sporadic and marginal, as new cropping methods have proven to be particularly effective in limiting the development of major endoparasitic nematodes such as *Radopholus similis*. Synthetic insecticides are no longer used to control the weevil, with the practice having been substituted by biological control methods with Sordidin pitfall traps as a complement to crop prophylaxis.

Regarding Sigatoka diseases, the integrated protection strategy already implemented and then supported by appropriate management of the harvest stage, fruit removal

Table 6.1. Types of practices implemented during the agroecological transition of banana cropping systems in the French West Indies.

	Objectives	
Practice	**Management of plant parasitic nematodes**	**Management of weevils**
Prophylaxis	Destruction of old banana plantations, first by chemical means (herbicides), then using mechanical means or, for small farmers, through cattle grazing. Systematic mechanical elimination of re-growing banana suckers, potential sources of contamination by plant parasitic nematodes and weevils. Coupling of fallows and sanitizing crop rotations with service plants that are not host to the endoparasitic nematodes of the Pratylenchidae family (especially Radopholus similis), using healthy banana vitroplants. Water seclusion ditches to isolate sanitized plots.	
	In nurseries supplying weaned banana vitroplants, use of 30 µm mesh filters to limit the contamination of irrigation water for greenhouses by plant parasitic nematodes of the Pratylenchidae family.	
Biological control	Deployment in the field of a cover crop based on *Crotalaria* species (mainly *Crotalaria retusa, C. spectabilis, C. zanzibarica, C. juncea*) with nematotoxic properties	During the destruction of the plots, mass trapping using pitfall traps in association with an aggregation pheromone (Sordidin). After this step, arrangement of traps on borders of newly planted plots to prevent recontamination from the outside. During banana cultivation, mass trapping using pheromone traps.
Re-injection of functional biodiversity into banana cropping systems	Development of multi-species and multifunctional cover crops of service plants, mostly those that are non-host to the main parasitic nematodes of banana. Their procedures of introduction and management have been specified. Some (such as *Paspalum notatum*) promote biological control and improve the structure of soil food webs.	Cultivation of certain service plants (such as the *Brachiaria decumbens* + *Cynodon dactylon* association) to increase the abundance of certain generalist predators of the weevil (ants, earwigs, etc.) and the biological regulation of the weevil.
Mechanical control		
Monitoring of pest populations	Biological tests to monitor the nematological quality of soil sanitation during the fallow stage. Dynamics of plant parasitic nematode populations in roots. Regular monitoring of the sanitary status of banana seedlings in nurseries using nematological analyses of weaned vitroplants.	Monitoring of populations using Sordidin pitfall traps (private partnerships, INRA, CIRAD). Assessment of damage by rhizome dehulling.

Objectives		
Management of Sigatoka	**Management of weeds**	**Alternatives to mechanical soil tillage**
Rapid elimination of abandoned banana plantations, which are sources of contaminating inoculum. Leaf pruning for sanitary purposes by mechanical ablation of leaves or portions of leaves bearing necrotic lesions. This practice limits the dispersion of the causal fungal agent and the early maturation of banana fruits. It forms part of a broad integrated protection strategy against Sigatoka diseases, which includes: cultivation practices favouring a high rate of foliar emission to compensate for the loss of leaf area due to the disease; a biological forecasting system to limit fungicide treatments.	Installation and maintenance in banana cropping systems of a cover crop of service plants to limit the contamination of plots by weeds, some of which are hosts to plant parasitic nematodes of banana. These service plants compete with weeds through their ability to quickly cover the soil and their allelopathic effects. Setting up of banana cropping systems on litter made from cover crop residues of service plants or various dead mulch (green waste, bagasse, etc.).	
		Biological tillage in the fallow phase using service plants with a deep and fasciculate root system (such as Brachiaria spp.). These plants improve the soil structure (porosity, structural stability).
	Weed control by brush cutter or rotary chopper using a light tractor equipped with low pressure tires.	
Establishment of a regional observatory for monitoring susceptibility to systemic fungicides used to control yellow Sigatoka and black leaf streak disease.		

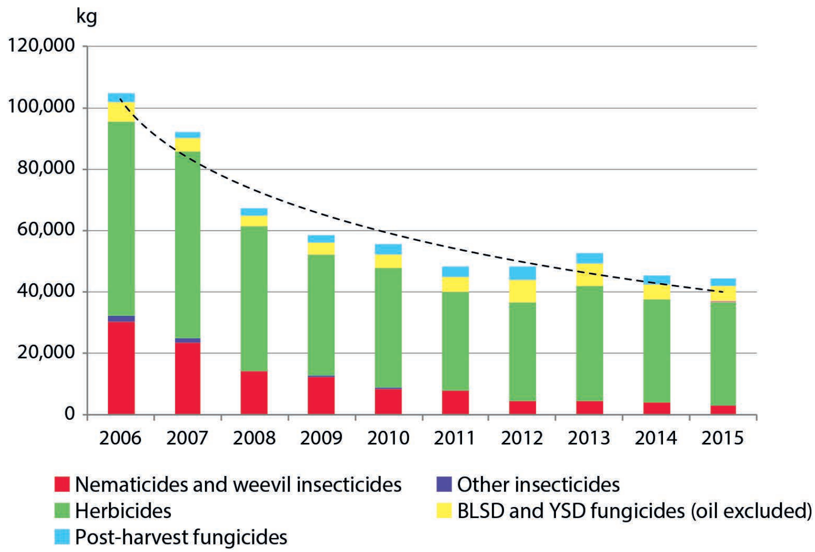

Figure 6.2. Changes in pesticide use as estimated by the quantity of active ingredients (QaI) in banana cropping systems in the French West Indies between 2006 and 2015.

practices, and increasing use of leaf pruning has so far helped to control them, despite the noticeable advent of the black leaf streak disease in the French West Indies (in 2010 in Martinique and in 2012 in Guadeloupe).

The adoption in banana cropping systems of cover crops based on service plants is gaining currency, but is not yet widespread. A joint investigation by CIRAD, the Tropical Technical Institute and the French West Indian banana producer groups is currently being carried out. The first results indicate that around 15% of the area under banana incorporate service plants, but that there is an ongoing process of real adoption, especially in larger farms.

Support by technical actors and public policies for innovation transfer processes

The agroecological transition, supported and strengthened by the 'Sustainable Banana' plan, has defined a trajectory of change and innovation that goes beyond merely technical aspects. Changes have also taken place at the organizational and partnership levels, by strengthening the skills of all the actors and creating spaces of coordination to build and disseminate innovations.

The building up of new capabilities

The creation of the Tropical Technical Institute

The Technical Institute for Banana (ITB) – today renamed as the Tropical Technical Institute (IT2) – was created in 2008 under the umbrella of CIRAD and professionals of the banana agri-chain in the West Indies as part of the 'Sustainable Banana' plan. This institute was created to strengthen the innovation capacities of the research community and producers, and ensure two functions: that of transfer, expected but still partly effected by researchers, and support for producer groups to help them scale up.

The Tropical Technical Institute is a privileged partner and link for researchers and producers in the agri-chain within the framework of the agroecological transition initiated in the banana cropping systems of the French West Indies. It has developed its own capacity to analyse the impacts of production, and has gradually expanded its activities towards the horticultural production sector as part of diversification. In this capacity, it is a member of the innovation and agricultural transfer (RITA) networks of the French Overseas Departments (DOM). With an administrative council and a scientific council, it works with an operational team of a dozen engineers in close proximity with the professionals of the banana agri-chain in the French West Indies, and has recently become a member of agricultural technical institutes and member of the network of technical institutes of the Association for Agricultural Technical Coordination (ACTA).

The launch of two collaborative innovation platforms

The agroecological transition in the banana systems of the French West Indies has also been backed by the launch and activities of two collaborative innovation platforms developed in the framework of the 'Sustainable Banana' plan: a platform for designing innovative banana cropping systems and a platform for breeding and selecting new banana varieties.

The platform dedicated to the design of innovative banana cropping systems is a space of sharing where different categories of actors involved in banana production in the French West Indies (researchers, producers, technical actors, groups, etc.) interact to develop cropping systems that are able to ensure the agroecological transition. Its mode of operation is shown in Figure 6.3. On behalf of an agronomic committee, the platform's actors define the framework of constraints of a model of sustainable banana production, the related specifications and a contract of objectives, based on which a co-design and assessment of innovative banana systems are carried out on the farms of pioneering producers. This platform has helped design banana systems based on multi-species and multifunctional cover crops of service plants. It relies on a toolbox developed by CIRAD researchers, which mainly consists of a collection of service plants, databases on the functional traits of these service plants and the associated ecosystem services, and models standardizing some of this knowledge (models of crop functioning, models of assessment of service plants, simulation and optimization models of cropping practices, etc.) (Dorel *et al.*, 2008; Tixier *et al.*, 2008; Tixier *et al.*, 2011; Ripoche *et al.*, 2012). This platform is also working on multicriteria assessment of innovative systems within the framework of a partnership between CIRAD and the Tropical Technical Institute. It thus benefits from the integration of knowledge and know-how originating from research on the functioning of innovating systems, and from expert knowledge from different disciplinary fields or originating from ecological engineering. In recent years, the actions of the platform for designing innovative banana cropping systems was strengthened by the creation of a dedicated unit to support the setting up of service plant cover crops, in which the Tropical Technical

Institute and CIRAD collaborate with the support of private entities for work on soil preparation, in order to provide assistance and technical solutions to producers willing to set up and manage their service plant cover crops.

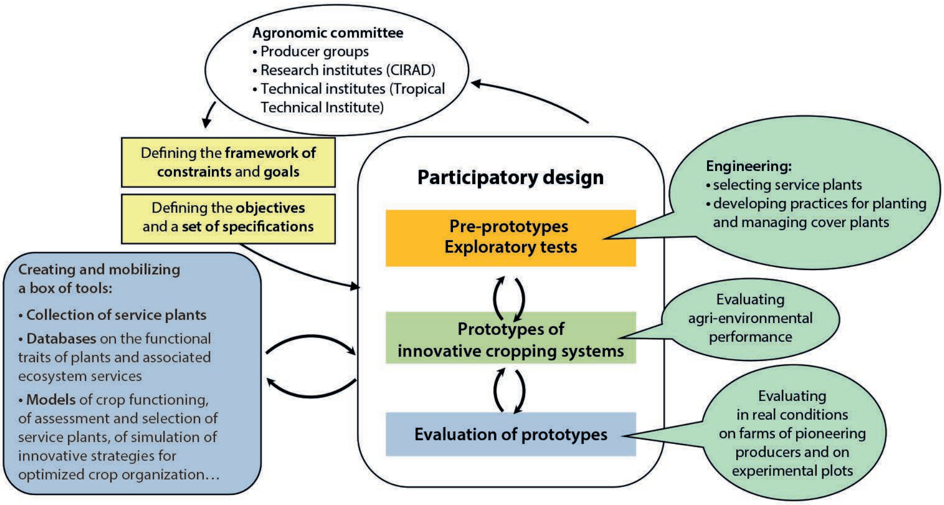

Figure 6.3. Organization of the collaborative platform of innovative banana cropping systems.

From the beginning, the platform for the breeding and the selection of new banana varieties has also functioned in a participatory manner in order to address the needs of producers and consumers. Its objective was to obtain varieties that are tolerant to pests and diseases, especially the black leaf streak disease, that are productive and adapted to the specificities of the French West Indian export agri-chain, and that meet post-harvest quality criteria. Although varietal improvement of banana is a long-term undertaking, it has been included, from the beginning, into the objectives of the 'Sustainable Banana' plan and of the implementation of the agroecological transition. Even though the time taken to develop new varieties is considerably longer than the fine-tuning of new technical itineraries, it was immediately admitted that new varieties would be necessary for the development of technical itineraries that use little or no pesticides. Therefore, acquiring proactive capacities (to be able to breed varieties that will be used in the future) and reflecting on the development of these varieties together in parallel with the development of new cropping systems appeared relevant in terms of tactical choices, improvement targets and speed of implementation. Mobilizing researchers from CIRAD who were specialized in banana breeding and selection, and engineers from the Tropical Technical Institute in charge of varietal development, the platform for the breeding and selection of new banana varieties helped, within the framework of the 'Sustainable Banana' plan, implement an original tool for fine-tuning new varieties (Figure 6.4). It was organized around CIRAD's collection of banana genetic resources (one of the largest in the world, hosted at the Tropical Plant Biological Resource Center of the French West Indies), a plot to crossbreed hybrids that is specially dedicated to the platform, selection plots in the open field in CIRAD's Neufchâteau (Guadeloupe) experimental station, as well as a network of assessment plots set up in the fields of pioneering producers. Structured around a breeding committee involving different actors, this platform has benefited from the inputs of different CIRAD laboratories in the French West Indies and in Montpellier (genetics, physiology, phytopathology, etc.), as well as of the post-production stages and UGPBAN's ripening facilities for pre-industrial testing in agri-chains of products originating from the platform. It has made it possible to optimize breeding strategies and considerably increase the number of hybrids produced annually (800 to 1000 in recent years as compared to just 400 in 2007). Several series of hybrids have been created, but without achieving all the qualities expected and defined in the specifications of the platform. Among these, one hybrid evinced special interest: the 'Cirad 925' hybrid. It exhibits a partial resistance to yellow Sigatoka disease and black leaf streak disease, has low susceptibility to the endoparasitic nematodes *Radopholus similis* and *Pratylenchus coffeae*, and produces good quality bunch structure with a rapid completion of the cycle. The taste of its fruits is comparable to that of the Cavendish banana. CIRAD, the Tropical Technical Institute and some pioneering producers made an attempt in 2015 to produce this variety on a significant scale (6 ha). The attempt failed as it was carried out based on a conventional technical itinerary suitable for the Cavendish. In addition, this variety proved to be much taller than the Cavendish, making it particularly difficult to undertake bunch management and harvest operations. Furthermore, several types of post-harvest limitations not conducive to marketing emerged: a susceptibility of the fruits to chilling injuries and peel splitting, a mismatch between the fruit's peel and pulp during the fruit's maturation, and a browning of the fruit epidermis after export. However, as we will note below, a new situation has emerged in recent years for this variety, with the lifting of the main remaining technical roadblocks.

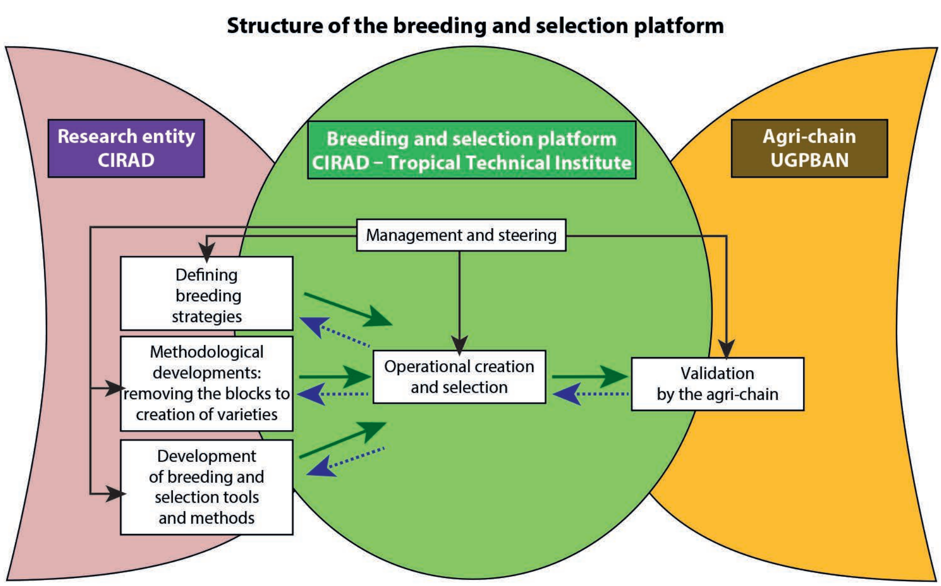

Figure 6.4. Functioning of the platform for the breeding and the selection of new banana varieties at the interface of research and the banana production agri-chain (UGPBAN).

The place of research in the agroecological transition

In addition to its role in the creation of the 'Sustainable Banana' plan and in the development of the two collaborative innovation platforms and the Tropical Technical Institute, CIRAD has been involved in its own advanced research activities, which could help drive the innovations of the 'Sustainable Banana' plan and also anticipate the fine-tuning of solutions allowing the agroecological transition currently under way to continue.

In order to promote ecological intensification through cropping practices, research was undertaken to understand the functioning of the banana agrosystem by focusing on the study of the biological mechanisms and processes involved. The roles of spatial organization of innovative cropping systems on banana pests and diseases were studied. The effects of plant diversity on the structuring, diversity and stability of food webs in banana cropping systems have also been the subject of research to better understand how biological control works (Carval *et al.*, 2016; Chauvin *et al.*, 2015; Mollot *et al.*, 2014; Poeydebat *et al.*, 2017a; Poeydebat *et al.*, 2017b; Poeydebat *et al.*, 2018). Various modelling approaches have been used to try to unravel the processes involved in biological control, and to test the effect of cover cropping practices.

New issues at the juncture of ecology and agronomy have been, and continue to be, addressed. Researchers have, for example, explored an approach based on the observation of the functional traits of plants (individual characteristics representative of the way the plants function) which helps explain the interactions between plants, the agroecological functions they ensure and the ecosystem services provided in banana agrosystems (Damour *et al.*, 2015; Tardy, 2015). This has enabled the determination of the functional profiles of plants that are part of the collection of service plants in the platform dedicated to the design of innovative banana cropping systems in the 'Sustainable Banana' plan (Damour *et al.*, 2016; Tardy *et al.*, 2017). These functional profiles have been matched with identified usage profiles as part of a participatory approach for designing cropping systems that involves producers and the Tropical Technical Institute. These profiles were used to define the spatio-temporal arrangement of service plants in prototypes of innovative cropping systems. This type of work has facilitated the design of innovative functional systems and helped draft practical recommendations concerning service plants (IT2, 2015).

However, researchers at CIRAD also solved new technical constraints encountered by the producers, as and when they deployed the proposed solutions. For example, the agronomists were able to adapt the technical itinerary for cultivating the Cirad 925 variety, thanks to a late selection method of successor suckers and an adaptation of desuckering (suppression of suckers) (Dorel *et al.*, 2016). In addition, a team of fruit physiologists and technologists joined the platform dedicated to the breeding and the selection of new banana varieties and addressed the post-harvest disorders affecting the Cirad 925 variety. The problem of chilling injuries was solved by setting the transport temperature at 15 °C (Bugaud *et al.*, 2016; Luyckx *et al.*, 2016a), that of peel splitting by a better control over the relative humidity in transportation cartons (perforation of polybags) and through the use of flow-packs (Brat *et al.*, 2016). As for the fruits' peel-pulp ripening mismatch, it was solved by reducing, as far as possible, the time interval between arrival in the storage warehouse and the ethylene treatment of the fruits (Luyckx *et al.*, 2016b). There remained the problem of fruit peel browning after export. New results based on non-chemical solutions have recently been obtained but have not yet been validated by tests in the supply chains. Research has also been conducted to determine the best deployment strategies for new varieties in order to limit the risk of future adaptation of pests and diseases to them. A simulation model to support the design of new methods for the control of black leaf streak disease has been developed (Landry *et al.*, 2017). At the same time, work on the phylogenetic organization of diversity, the understanding of the genome structure of banana plants, and the genetic determinism of traits of agronomic interest have also been conducted in support of varietal breeding (Baurens *et al.*, 2017; D'Hont *et al.*, 2012; Perrier *et al.*, 2011).

Support of public policies

Entities at the regional and national political levels were important actors in implementing the 'Sustainable Banana' plan. The decision of the French government and Europe to reduce pesticide use took several forms. The transition that began in the late 1990s and early 2000s was supported by the definition and implementation of various institutional tools such as the Agricultural Orientation Law (LOA) of 1999, the Departmental Agricultural Advisory Commissions (CDOA), and incentives such as territorial farm contracts, sustainable agriculture contracts, and agri-environmental measures, meant for producers to adopt more environmentally friendly practices and reduce dependence on synthetic pesticides. Subsequently, there was a steady increase in the eco-conditionality of public aid. Multi-stakeholder arenas, such as that of the regional group to study pollution caused by plant protection products, have emerged. At the same time, research and research-and-development efforts have allowed funding to be obtained from European structural Docup funds (Single Programming Document). In 2008, the launch of the 'Sustainable Banana' plan, with the consolidation of public aid allocated to the banana agri-chain in the French West Indies as part of Posei (Programme of options specifically relating to remoteness and insularity) and Odeadom, once again consolidated these orientations and was carried out mainly thanks to European (EAFRD), national and regional funds, with the support of the Martinique and Guadeloupe Regions.

Generic lessons learned from the experience and future steps

How to measure the success of the agroecological transition in banana production in the French West Indies? If we use as metric the reduction in the use of pesticides in recent years and the comparison of this level of use in the French West Indies with that in other production areas, the agroecological transition can said to be well underway. Similarly, if the metric is the level of involvement of producers and the governance structures of the Guadeloupe-Martinique Banana agri-chain, we observe a strong encouraging discourse and actions promoting a new way of production that reflect the profession's commitment to this agroecological path.

Some, however, believe that the 'Sustainable Banana' plan, and the agroecological transition associated with it, served as an opportunity for the agri-chain to bounce back following the chlordecone crisis by the maintenance of a high level of subsidies and the cornering of diverse types of aid available to remote French territories from various sources, which could possibly have deleterious results for some food products which can be produced locally, but which are imported into Guadeloupe and Martinique. The researchers' position leads us to avoid rejecting *a priori* these remarks and questions out of hand. This is why we conducted the analysis of the successes and failures of the 'Sustainable Banana' plan based on factual data and with a 'temporal' perspective on the trajectory of the agroecological transition, since this transition cannot be limited to the duration of a single development plan such as the 'Sustainable Banana' plan. We highlight here the steps we think need strengthening in order to consolidate this agroecological transition of banana production in Martinique and Guadeloupe.

The need for multi-criteria assessment of innovative banana cropping systems associated with the agroecological transition

The 'Sustainable Banana' plan has been the subject of regular assessments by various ministerial bodies and by funding entities in general, resulting in a systematic monitoring of the plan's activity. It appears, however, that the assessment of the agri-environmental and socio-economic performances of the new cropping systems created for the agroecological transition, and of their impacts, is also an essential process that needs strengthening. An assessment of this type must take into account the different scales of intervention (plot, farm, watershed, region, territory) and the perception of the actors. It requires the definition of appropriate tools (conceptual frameworks for studying relationships between cropping practices and their impacts, methods, indicators, models, etc.) (Feschet *et al.*, 2018; Lairez *et al.*, 2015). It must also be based on monitoring units for acquiring agri-environmental data (statements on use of external chemical inputs in soil and water, biodiversity, etc.) and socio-economic data (production costs, employment, arduousness of work, new occupations, etc.). In the French West Indies, there already exist such type of monitoring units, which have started compilation of environmental data in the context of projects financed by European funds (Rivage projects, ERDF funds, second phase of the 'Sustainable Banana' plan). They should be able to become clearly labelled reference locations of the agroecological transition that allow the environmental, economic and social value addition of this transition to be objectivized.

Regular reassessments of the framework of constraints to ensure a continued dynamic of agroecological innovations

The agroecological transition of banana production systems in the French West Indies is a phenomenon that spans a long period of time, and which consequently implies a regular reassessment of the framework of production constraints.

At the launch of the 'Sustainable Banana' plan in 2008, the black leaf streak disease had not yet arrived in the French West Indies. It is an air-borne fungal disease whose effects are more marked than those of yellow Sigatoka disease. It was first detected in Martinique in 2010, and in Guadeloupe in 2012. At about the same time, aerial sprayings of systemic fungicides, used in conjunction with the forecasting system, were banned in 2012 and 2013. These elements show to what extent the context can change rapidly (in its various legislative, technical, social dimensions, etc.) and why it is necessary to periodically reassess the framework of constraints of the agroecological transition. Indeed, it is a matter of ensuring the continued relevance of this transition's specifications. In the case of the Sigatoka leaf spot diseases (Yellow Sigatoka disease, YSD, and mainly Black Leaf Streak Disease, BLSD) in the French West Indies, the situation has acquired a marked urgency as new legislative restrictions on the only curative fungicides for a reasoned plant protection were announced to be implemented with very short notice (late 2018 to early 2019). This is forcing technical actors, producers and researchers to completely rethink reasoned control measures for Sigatoka leaf spot diseases by optimizing the techniques and organization of prophylactic deleafing methods, and by linking pre- and post-harvest operations in an integrated manner so as to reduce these diseases' effects and impacts. A new emphasis is thus being laid on the importance of mobilizing, in the short term, all the actors in the value chain (from producers to distributors), and on the relevance of promoting a banana variety that is resistant to black leaf streak disease (BLSD), which is compatible with export requirements and, even if it is unable to completely replace the Cavendish banana, one that could help to control the disease sustainably, especially in areas where the disease pressure is high.

The need for a broader framework for sharing objectives and deploying the agroecological transition

We have seen that there is still only a partial adoption of banana cropping systems based on service plants. The determinants for adopting these systems must be better understood in order to press for a more widespread agroecological conversion. This growth in its acceptance must include both a wider deployment of innovations to all producers, as well as to other actors not involved in production.

At a quantitative level, the modalities of a wider transfer of innovations and alternative solutions co-developed by the actors still need to be organized. This transfer must continue in a participatory and interactive manner between producers, researchers and technicians, supported by training in the use of the co-constructed innovations and by the disseminatory capacities of institutions. The two collaborative platforms, the Tropical Technical Institute, and the technical unit for providing support to growers for setting up service plant cover crops are all essential tools for achieving this goal. While an action plan that relied on the agri-chain and production actors appeared logical and the most likely to succeed, the broadening of the concept of sustainability to the entire agri-chain and the territories in which this plan is implemented becomes the new stage to be executed. From a qualitative point of view, in order to increase acceptance and adoption, it is necessary to move into new arenas of consultation between different actors (producers, groups, technical institutes, researchers, institutions, etc.), with a more prominent role accorded to civil society. It is in this way that the objectives of the agroecological transition will be jointly consolidated and therefore will be better shared. Downstream actors (post-production stakeholders) in the value chain, such as distributors and large and medium-sized retailers, must also be able to appropriate these objectives and participate in definition of the associated specifications, in order to help structure a multi-actor dynamic in space and in time, in line with the expectations of consumers, and to additionally ensure that these production approaches find their true value in new markets.

References

ARS, Ireps, 2016. La pollution par la chlordécone en Martinique, point de situation 2016, 86 p.

Baurens F.C., Martin G., Rouard M., Salmon F., Njembele J.C., Habas R., Ricci S., D'Hont A., 2017. Genome structure and chromosome segregation in triploid interspecific plantain bananas (AAB) and breeding accessions (AAAB), Summary, 1 p.

Brat P., Lechaudel M., Segret L., Morillon R., Hubert O., Gros O., Lambert F., Benoit S., Bugaud C., Salmon F., 2016. Post-harvest banana peel splitting as a function of relative humidity storage conditions. Acta Physiologiae Plantarum, 38 (10), 16 p.

Bugaud C., Joannès-Dumec C., Louisor J., Tixier P., Salmon F., 2016. Preharvest temperature affects chilling injury in dessert bananas during storage. Journal of the Science of Food and Agriculture, 96 (7), 2384-2390, http://dx.doi.org/10.1002/jsfa.7354.

Cabidoche Y.-M., Achard R., Cattan P., Clermont Dauphin C., Massat F., Sansoulet J., 2009. Long-term pollution by chlordecone of tropical volcanic soils in the French West Indies: A simple leaching model accounts for current residue. Environmental Pollution, 157, 1697-1705.

Carval D., Resmond R., Achard R., Tixier P., 2016. Cover cropping reduces the abundance of the banana weevil Cosmopolites sordidus but does not reduce its damage. Biological Control, 99, 14-18, http://dx.doi.org/10.1016/j.biocontrol.2016.04.004.

Chauvin C., Dorel M., Villenave C., Roger-Estrade J., Thuries L., Risède J.M., 2015. Biochemical characteristics of cover crop litter affect the soil food web, organic matter decomposition, and regulation of plant-parasitic nematodes in a banana field soil. Applied Soil Ecology, 96, 131-140, http://dx.doi.org/10.1016/j.apsoil.2015.07.013.

Damour G., Garnier E., Navas M.L., Dorel M., Risede J.M., 2015. Using functional traits to assess the services provided by cover plants: A review of potentialities in banana cropping systems. Advances in Agronomy, 134, 81-133, http://dx.doi.org/10.1016/bs.agron.2015.06.004.

Damour G., Guerin C., Dorel M., 2016. Leaf area development strategies of cover plants used in banana plantations identified from a set of plant traits. European Journal of Agronomy, 74, 103-111, http://dx.doi.org/10.1016/j.eja.2015.12.007.

Delvaux B., Perrier X., Guyot P., 1990. Diagnostic de la fertilité de systèmes culturaux intensifs en bananeraies à la Martinique. Fruits, 45 (3), 223-236.

D'Hont A., Denœud F., Aury J.-M., Baurens F.-C., Carreel F., Garsmeur O., Noël B., Bocs S., Droc G., Rouard M., Da Silva C., Jabbari K., Cardi C., Poulain J., Souquet M., Labadie K., Jourda C., Lengellé J., Rodier-Goud M., Alberti A., Bernard M., Correa M., Ayyampalayam S., Mckain M.R., Leebens-Mack J., Burgess D., Freeling M., Mbéguié-A-Mbéguié D., Chabannes M., Wicker T., Panaud O., Barbosa J., Hribova E., Heslop H.P., Habas R., Rivallan R., François P., Poiron C., Kilian A., Burthia D., Jenny C., Bakry F., Brown S., Guignon V., Kema G.H.J., Dita M.A., Waalwijk C., Joseph S., Dievart A., Jaillon O., Leclercq J., Argout X., Lyons E., Almeida A., Jeridi M., Dolezel J., Roux N., Risterucci A.-M., Weissenbach J., Ruiz M., Glaszmann J.-C., Quetier F., Yahiaoui N., Wincker P., 2012. The banana (Musa acuminata) genome and the evolution of monocotyledonous plants. Nature, 488 (7410), 213-217, http://dx.doi.org/10.1038/nature11241.

Dorel M., Achard R., Tixier P., 2008. SIMBA-N: Modeling nitrogen dynamics in banana populations in wet tropical climate: Application to fertilization management in the Caribbean. European Journal of Agronomy, 29 (1), 38-45, http://dx.doi.org/10.1016/j.eja.2008.02.004.

Dorel M., Damour G., Leclerc N., Lakhia S., Ricci S., Vingadassalon F., Salmon F., 2016. Parent plant vs sucker – how can competition for photoassimilate allocation and light acquisition be managed in new banana hybrids? Field Crops Research, 198, 70-79, http://dx.doi.org/10.1016/j.fcr.2016.08.028.

Dorel M., Perrier X., 1990. Influence du milieu et des techniques culturales sur la productivité des bananeraies de Guadeloupe. Fruits, 45 (3), 237-244.

Feschet P., Lœillet D., Risède J.M., 2018. Multi-criteria assessment of innovative cropping systems in French West Indies. In: Proceedings of the Xth International Symposium on Banana: ISHS-ProMusa Symposium on Agroecological Approaches to Promote Innovative Banana Production Systems (I. Van den Bergh, J.-M. Risède, V. Johnson, eds), ISHS, Louvain, 187-194. Acta Horticulturae, 1196, https://doi.org/10.17660/ActaHortic.2018.1196.23.

Imbert E., Lœillet D., 2017. FruiTrop, Focus Banane : Le guide du commerce international de la Banane, FruiTrop, 272 p.

IT2, 2015. Petit guide pratique des couverts végétaux : Pistes pour le choix et la conduite d'une couverture végétale compagne ou en rotation. Focus sur la culture de la banane en Guadeloupe et Martinique, 71 p.

Kermarrec B., 1980, Niveau actuel de la contamination des chaînes biologiques en Guadeloupe : Pesticides et métaux lourds, INRA Guadeloupe, ministère de l'Agriculture, 155 p.

Lairez J., Feschet P., Aubin J., Bockstaller C., Bouvarel I., 2015. Agriculture et développement durable : Guide pour l'évaluation multicritère, Quæ-Éducagri, Versailles, 232 p., https://www.dawsonera.com/abstract/9782759224418.

Landry C., Bonnot F., Ravigné V., Carlier J., Rengifo D., Vaillant J., Abadie C., 2017. A foliar disease simulation model to assist the design of new control methods against black leaf streak disease of banana. Ecological Modelling, 359, 383-397, http://dx.doi.org/10.1016/j.ecolmodel.2017.05.009.

Luyckx A., Lechaudel M., Hubert O., Gros O., Bugaud C., Benoit S., Leclerc N., Salmon F., Brat P., 2016a. Management of post-harvest fruit quality for ecologically intensified banana cropping systems. Proceedings of the Xth International Symposium on Banana: ISHS-ProMusa Symposium on Agroecological Approaches to Promote Innovative Banana Production Systems (I. Van den Bergh, J.-M. Risède, V. Johnson, eds), ISHS, Louvain, 79-86.

Luyckx A., Lechaudel M., Hubert O., Salmon F., Brat P., 2016b. Banana peel physiological post-harvest disorders: A review. MOJ Food Processing and Technology, 3 (1), 7 p.

Mollot G., Duyck P.-F., Lefeuvre P., Lescourret F., Martin J.-F., Piry S., Canard E., Tixier P., 2014. Cover cropping alters the diet of arthropods in a banana plantation: A metabarcoding approach. PLoS One, 9, e93740.

Perrier X., De Langhe E., Donohue M., Lentfer C., Vrydaghs L., Bakry F., Carreel F., Hippolyte I., Horry J.P., Jenny C., Lebot V., Risterucci A.M., Tomekpé K., Doutrelepont H., Ball T., Manwaring J., De Maret P., Denham T., 2011. Multidisciplinary perspectives on banana (Musa spp.) domestication. Proceedings of the National Academy of Sciences of the United States of America, 108 (28), 11311-11318, http://dx.doi.org/10.1073/pnas.1102001108.

Poeydebat C., Carval D., Tixier P., Daribo M.-O., de Lapeyre de Bellaire L., 2018. Ecological regulation of black leaf streak disease driven by plant richness in banana agroecosystems. Phytopathology, 108, 1184-1195.

Poeydebat C., Tixier P., Chabrier C., De Lapeyre de Bellaire L., Vargas R., Daribo M.O., Carval D., 2017a. Does plant richness alter multitrophic soil food web and promote plant-parasitic nematode regulation in banana agroecosystems? Applied Soil Ecology, 117-118, 137-146.

Poeydebat C., Tixier P., De Lapeyre de Bellaire L., Carval D., 2017b. Plant richness enhances banana weevil regulation in a tropical agroecosystem by affecting a multitrophic food web. Biological Control, 114, 125-132.

Ripoche A., Achard R., Laurens A., Tixier P., 2012. Modeling spatial partitioning of light and nitrogen resources in banana cover-cropping systems. European Journal of Agronomy, 41, 81-91, http://dx.doi.org/10.1016/j.eja.2012.04.001.

Risède J.M., Simoneau P., 2004. Pathogenic and genetic diversity of soilborne isolates of Cylindrocladium from banana cropping systems. European Journal of Plant Pathology, 110 (2), 139-154, http://dx.doi.org/10.1023/B:EJPP.0000015337.54178.c0.

Risède J.M., Tezenas du Montcel H., 1997. Systèmes monoculturaux bananiers et protection de l'environnement : État des lieux et perspectives. Fruits, 52, 225-232.

Snegaroff J., 1977. Les résidus d'insecticides organochlorés dans les sols et les rivières de la région bananière de Guadeloupe. Phytiatrie-Phytopharmacie, 26, 251-268.

Tardy F., Damour G., Dorel M., Moreau D., 2017. Trait-based characterisation of soil exploitation strategies of banana, weeds and cover plant species. PloS One, 12 (3), e017306, 17 p., http://dx.doi.org/10.1371/journal.pone.0173066.

Tardy F., Moreau D, Dorel M., Damour G., 2015. Trait-based characterization of cover plants' light competition strategies for weed control in banana cropping systems in the French West Indies. European Journal of Agronomy, 71 (2015), 10-18, http://dx.doi.org/10.1016/j.eja.2015.08.002.

Tixier P., Lavigne C., Alvarez S., Gauquier A., Blanchard M., Ripoche A., Achard R., 2011. Model evaluation of cover crops, application to eleven species for banana cropping systems. European Journal of Agronomy, 34 (1), 53-61.

Tixier P., Malézieux E., Dorel M., Wery J., 2008. Simba, a model for designing sustainable banana-based cropping systems. Agricultural Systems, 97 (3), 139-150, http://dx.doi.org/10.1016/j.agsy.2008.02.003.