From Science to Field
Banana Case Study – Guide Number 1

Challenging short and mid-term strategies to reduce the use of pesticides in banana production

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Left, top: young tissue culture banana plants on a mulched soil; yellow pitfall traps with a pheromone attractant are set to control black weevils. Left, bottom: legumes such as *Neonotonia wightii* can be used as rotational or associated crops. © Jean-Michel Risède, CIRAD, France. Main photograph: immature banana fingers. © Régis Domergue, CIRAD, France.

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Bananas: Safer production of a major fruit crop

With a total production of about 105 million tonnes, bananas are one of the most popular fruit crops. Two main types of bananas are cropped: dessert bananas, among which the varietal sub-group Cavendish is the best known, and cooking bananas, largely plantains. In 2007, 59 million tonnes of dessert bananas were produced, among which 16.5m tonnes were shipped and traded. Europe is an active hub of the dessert banana trade, as it imports about one-third of the bananas traded worldwide while also producing bananas in some of its outermost regions such as the French West Indies (Guadeloupe, Martinique), the Canaries (Spain), Madeira (Portugal), Cyprus, and Greece (see figure 1).

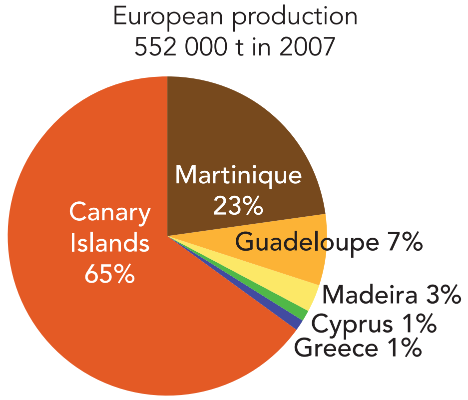
Various pathogens threaten the production of dessert bananas in tropical and sub-tropical environments. This situation is worsened by the poor genetic diversity in banana crops, and it also results from the pure stand cropping methods. Production has been ensured in these agrosystems by protecting, mainly by pesticides, the highly performing - but susceptible to a number of pests and diseases - Cavendish.

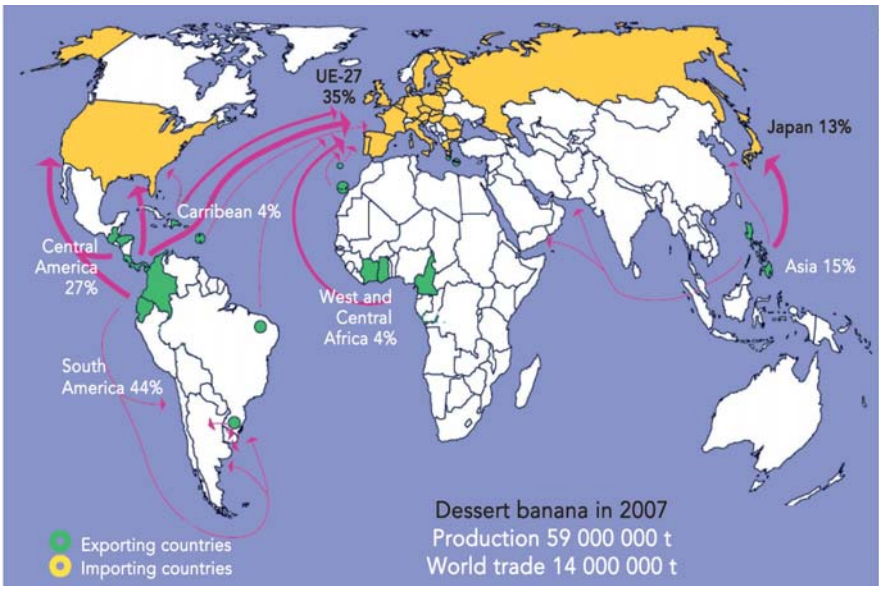
Public demand for safer food and, in this case, the safety of banana crops is increasing. It is a question of protecting the health of all stakeholders (field workers, workers in the packing stations, producers and consumers) by reducing exposure to pesticides both on the production sites and in the importing markets where the banana fruits are consumed. There is also an urgent need to alleviate the environmental injuries linked with excessive use of pesticides (pollution of soils, plants and waters).

Lessons from an analysis of pesticide use in countries producing dessert banana

In 2006-2008, in the framework of the international project 'Pesticide Reduction Programme for Bananas (PRPB)', a global analysis of pesticide use in countries producing dessert banana was launched by four research and/or international development organisations: Bioversity International, CIRAD, the Catholic University of Leuven, and Wageningen University's Plant Research International. Data were collected with a questionnaire completed by grower associations, banana specialists in the countries and extension officers. As part of ENDURE's Banana Case Study, data were further analysed, and completed for Cameroon, the French West Indies

Figure 1: Main dessert banana producing or importing sites throughout the world. © Denis Loeillet and Thierry Lescot, CIRAD, France





(Guadeloupe and Martinique), and the Canary Islands (Spain).

Data analyses yielded four main lessons:

- The total quantity of pesticides used in dessert banana crops is generally linked with the level of annual rainfall (see Figure 2 below). The link is strong for fungicides, with a predominance for those that are sprayed to control the airborne *Mycosphaerella* foliar diseases.
- Fungicides, along with insecticides and nematicides applied to lessen the impact of soilborne pests, are the main pesticides on dessert banana crops (see Figure 2 above).
- In the higher rainfall areas, the repeated use of systemic fungicides (triazoles, strobilurines) resulted in resistance in *Mycosphaerella* populations. Field management of resistance is associated with a marked shift in fungicide use: contact fungicides (dithiocarbamates, chlorothalonil) are increasingly replacing systemic fungicides. Because they have a preventive rather than a curative effect, these contact fungicides are currently sprayed much more frequently and at higher doses than systemic fungicides, in particular to control the very aggressive Black Leaf Streak Disease (BLSD) caused by *Mycosphaerella fijiensis*.
- In the production areas of the European Community, there is a markedly lower level of pesticide use on dessert bananas (see Figure 2), due to:
- The absence of the foliar Black Leaf Streak Disease (note: *When editing this leaflet, we were informed that BLSD was arriving in the French West Indies*). In addition, a forecasting strategy contributes to reducing fungicide use for controlling the Yellow Sigatoka disease in the French West Indies.
- The relevant efforts of producers, in particular during the last decade, to improve the control of black weevil and root-feeding nematodes by using alternative cropping methods.
- The impact of European regulations on agrochemical use. In the European Community, current restrictions on pesticides strongly contribute to reducing their use in banana agrosystems. For example, no insecticide remains authorised, only one chemical nematicide is still used, and aircraft spraying to control Yellow Sigatoka will probably be prohibited in coming years. Elsewhere, legislative constraints and regulations on pesticide use in bananas vary widely due to the institutional and environmental policies of countries. They include aspects that

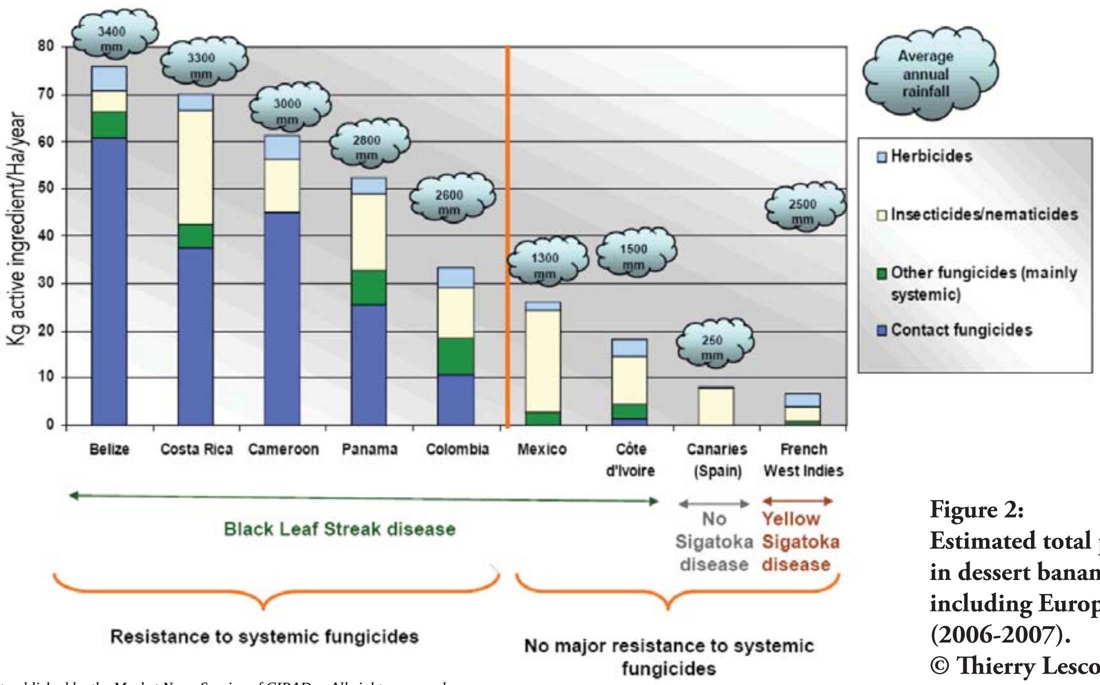
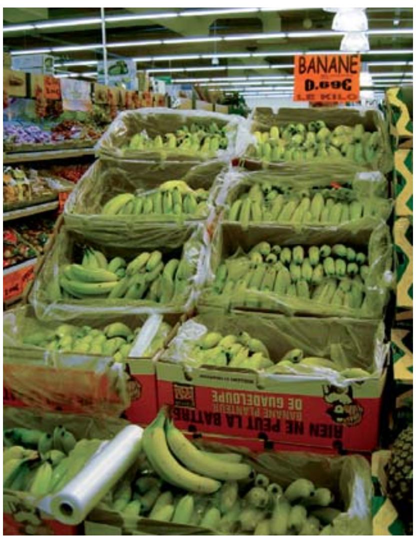


Figure 2:
Estimated total pesticide quantities used in dessert bananas in some countries, including European Community areas (2006-2007).
© Thierry Lescot, CIRAD, France

impact producing countries (rules and restrictions on aerial spraying, timing and formulations for spraying, permitted toxicological and ecotoxicological profiles of active ingredients to be applied, local environmental protective measures) as well as importing countries (Maximum Residue Levels of fungicides in dessert bananas for the European market). Different trading requirements or specifications also exist on the international market, for example GlobalGAP, but legislation appears to be the critical force reducing pesticide use in European banana-producing countries. It hence drives the search for alternatives to pesticide use.

Landmarks for short and mid-term sustainable strategies to decrease pesticide use in bananas

Alternative and innovative solutions to decrease pesticide use in bananas are currently being developed by growers, researchers, and other stakeholders. Here we focus only on short and mid-term solutions, although long-term solutions exist, aiming at a better understanding of the banana agrosystem, along with an in-depth analysis of banana and pathogen genomes to unravel their relationships.



Legislation appears to drive reduced pesticide use in European banana-producing countries. EC citizens consumed an average of 10.7kg per head of bananas in 2007. © Thierry Lescot, CIRAD, France.

Short-term solutions are already being adopted in certain dessert banana-producing countries, but still at limited scales. They represent achievable alternatives to reduce pesticide inputs in banana agrosystems and need to be extended at larger scales.

Mid-term solutions bring together innovations designed for reaching integrated crop management of the concerned diseases. They include compatible and challenging solutions that are being tested in banana research programmes and are also based on prototypes of banana cropping systems that are evaluated by growers, extension officers and researchers. They include modelling as a relevant tool to achieve integration of innovative solutions.

Short and mid-term solutions are reviewed here for providing control of the four major types of banana diseases or pests: *Mycosphaerella* foliar diseases, the black weevil, plant-parasitic nematodes, and weeds. Reference is also made to the use of biocontrol agents and the requirements to sustain their development in the European Community (see page 7).

Control of *Mycosphaerella* foliar diseases

Short-term solutions

• Use forecasting strategies to reduce fungicide inputs based on disease incidence. This is possible mainly in regions with low disease pressure and no existing fungicide resistance, and in newly cropped areas.

• Promote prophylactic de-leafing of bananas in the field: this mechanical ablation of lesioned leaves bearing infectious conidia and ascospores restricts inoculum dispersal within and among plots.

• Allocate banana production without fungicide inputs to climatic zones that are unfavorable for *Mycosphaerella*, such as low rainfall regions. Banana should preferentially be organically produced in these regions.

- Use of biofungicides and natural organic products. Recent data indicate that some could favorably be combined with reduced doses of contact fungicides.

Mid-term solutions

- Complete integrated management of *Mycosphaerella* foliar diseases by growing dessert banana cultivars with resistance to *M. fijiensis* and/or *M. musicola*. Conventionally bred hybrids are currently under evaluation. GMOs could also be an alternative. In any case, disease-resistant banana cultivars should not be cropped in pure stands, but rather through spatial arrangements with other cultivars or other plant species, to reduce disease development and minimise chances to break down resistance to *Mycosphaerella*.

Mycosphaerella **foliar diseases (mainly Black Leaf Streak Disease caused by *M. fijiensis*, and Yellow Sigatoka disease caused by *M. musicola*) severely alter the photosynthesizing leaf surface and induce premature ripening of fruits. These leaf spot diseases are usually controlled by aerial fungicide sprays.**
© Jean-Michel Risède, CIRAD, France.

Control of the black weevil *Cosmopolites sordidus*

Short-term solutions

- Mechanical destruction of contaminated rhizomes (with a machete, or a towed mechanical device).
- Use of pheromone-pitfall traps for monitoring populations and for mass-trapping within plots, at farm and landscape scale. Alternatively, bits of banana pseudostems (large pieces laid on soil, or pre-cut slices that are replaced in the mother pseudostem) can be used. Although less efficient than pheromone-pitfall traps, this technique is cheap and therefore of interest for smallholders.

Mid-term solutions

Short-term solutions contribute to an Integrated Pest Management strategy by implementing:

- Mass trapping with 'attract and kill systems'. These systems couple pheromones and entomopathogenic nematodes (*Steinernema carpocarpsae*) or fungi *Beauveria* spp.
- Bioprotection of banana root tissues with entomopathogenic fungi such as *Beauveria bassiana*, and/or non-pathogenic *Fusarium oxysporum*.
- Models to predict the dynamics and dispersal of the black weevil.
- Spatial arrangements within banana agrosystems to disrupt dispersal of the black weevil.

Here you can see a portion of banana corm heavily damaged by larval stages of *Cosmopolites sordidus*. Black weevil has long been controlled by polluting insecticide treatments, which are now banned.
© Jean-Michel Risède, CIRAD, France.

Control of plant-parasitic nematodes

Short-term solutions

- Start after crop rotation or fallow (see below), with new nematode-free plantlets derived from tissue culture. Smallholders can, alternatively, use *in vivo* mass multiplication techniques to sanitize planting material. However, this should be done in a collective process (grower association, nematological laboratory etc) to ensure dissemination of nematode-free plantlets.

- Sanitize plots from major banana parasitic nematodes, in particular *Radopholus similis*, by rotating banana crops with locally diagnosed non-host crops (such as pineapple, different cultivars of sugarcane, some forage grasses such as *Digitaria decumbens* or *Brachiaria humidicola*, some legumes such as *Neonotonia wightii, Macroptilium atropurpureum* or *Crotalaria* spp.), or by one/two year fallows. All volunteers (re-growing suckers) must be systematically removed.
- Systematically diagnose duration and effectiveness of soil sanitation against plant-parasitic nematodes with potted biotests using in vitro banana plants as traps.
- Surround nematode-sanitized banana plots (or banana field sectors) with 50-80cm deep ditches, to restrict *R. similis* dissemination by water run-off from contaminated plots.

In addition to alterations they cause in water and nutrient uptake, root-feeding nematodes induce a range of symptoms such as growth reduction and root breakage, resulting in toppling over of mature banana plants. Nematodes are controlled in many areas by two to four nematicide treatments per year. © Jean-Michel Risède, CIRAD, France.

Mid-term solutions

Short-term activities will support longer term integrated and more ecologically-based banana agrosystems by adopting:

- Deployment of above-ground diversity (plant diversity), to ensure ecological stability, including beneficial cover crops and nematode-resistant or tolerant banana cultivars.
- Modification strategies to improve the soil biota with target strains of micro-organisms (arbuscular mycorrhizal fungi, other fungal endophytes such as beneficial *Fusarium oxysporum* strains) and organic matter to strengthen plant and soil health.
- Models to predict nematode population dynamics in banana agrosystems and to assess and sort innovative cropping practices.

Weed control

Short-term solutions

- Mechanical weeding with soil tillage devices such as spading machines or Rome plough or mowers such as rotary engines for mechnisable lands, and hoeing or bush cutters for sloping lands.
- Set up new banana crops in mulches from a previous rotational crop, which will avoid or reduce pre/post emergence herbicide applications.
- Control weeds from heavily infected plots by a single herbicide application before planting the new banana crops.
- Cover inter-row space of banana plots by mulching with dead banana leaves or other organic residues (such as pieces of pseudo-stems) from harvest to cover the soil surface.
- Cropping other plants in the large inter-rows, such as the shade-tolerant *Impatiens* spp. (balsaminaceae), the perennial soybean *Neonotonia wightii*, or short-lived vegetable or cash crops (tomato, watermelon etc).

Heavy weed pressure in a banana plot. Weeds can strongly compete with banana plants. Until now weeds have been generally controlled by frequent sprays of herbicides. © Jean-Michel Risède, CIRAD, France.

Mid-term solutions

Targeting Integrated Weed Management (IWM) in bananas by:

- Improved mechanical weeders adapted to new vegetation arrangements in banana plots.
- Effective low-dose herbicides, to help mulch installation before setting new banana crops.
- Planting annual cover crops that die naturally without herbicide applications, while being non-hosts to banana pathogens.
- Planting weed competitors (in space and in time) that still satisfy bananas by providing drainage, nutrients and beneficial organisms.

What are the requirements for promoting the development of biocontrol techniques in banana producing areas of the European community?

Biocontrol methods exist for black weevil and pathogenic nematodes and to a lesser extent for post harvest fungal diseases. They still have to be developed against the main foliar disease of bananas, Black Leaf Streak Disease (BLSD). Available biocontrol agents (BCA) belong to various classes of Plant Protection Products:

- Pheromones (agents modifying insect behavior): They are chemical but not biocidal.
- Microbials such as fungi for insect or nematode control.
- Macrobials such as Entomopathogenic Nematodes (EPN) for nematode control.
- Natural products for facilitating the Systemic Activated Resistance (SAR) for naturally induced resistance to pathogens.

To further promote the development of biocontrol techniques in European banana-producing areas, four conditions are required:

- Pest control: Pest or disease control must first be effective and validated. To control the black weevil, mass trapping with pheromone traps is effective, but also 'attract and kill' systems (coupling pheromone traps and EPN or EPF). Chemical insecticides are therefore no longer required in European banana production. Control of nematodes feeding on banana roots by pathogenic fungi is not yet satisfactory in areas that are highly infested, and additional work is required to improve efficacy. Control of BLSD is still under R&D as no SAR process has been found for Musa sp. As a consequence, organic bananas can therefore be grown only in areas where BLSD pressure is not high.
- Quality control of Biocontrol agents: In Europe, only standardised material can be registered (and then used). Production of BCA, their formulation and quality control are under strict legislation.
- Registration trials: Any biocontrol method has to be tested in multi-local field trials with officially approved protocols, and conducted by Good Laboratory Practices (GLP)/Good Field Practices (GFP) certified teams.
- Education of growers: As use of BCA requires 'non-chemical' specific usage rules, development of these new sustainable production systems needs technical training and support for growers, in order to make this technique workable and understandable.

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Challenging short and mid-term strategies to reduce the use of pesticides in banana production - Summary

One of the most traded fruits in Europe and worldwide, dessert bananas have long been produced with a marked recourse to pesticides to control the various pathogens that threaten the crop. New ways are being developed to grow banana that rely less upon pesticides but rather upon agroecological measures and Integrated Pest Management strategies.

These operational solutions are continuously refined by researchers, growers and other stakeholders fully implied in ensuring more sustainable banana cropping systems, and further assuring human food and health.

This guide, the first of a series of five, starts by examining the lessons taught from an overall analysis of pesticide use in countries producing dessert banana, including representative European ones. Then, it goes through the main alternative or innovative solutions to reduce, in the short and mid- term, pesticide use in bananas.

In particular these solutions are highlighted to alleviate fungicide, nematicide and insecticide use, which are the main pesticides used in dessert banana farming. Four following guides complete, or more specifically, exemplify the solutions recommended in this first guide.

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About ENDURE

ENDURE is the European Network for the Durable Exploitation of Crop Protection Strategies. ENDURE is a Network of Excellence (NoE) with two key objectives: restructuring European research and development on the use of plant protection products, and establishing ENDURE as a world leader in the development and implementation of sustainable pest control strategies through:

> Building a lasting crop protection research community

> Providing end-users with a broader range of short-term solutions

> Developing a holistic approach to sustainable pest management

> Taking stock of and informing plant protection policy changes.

Eighteen organisations in 10 European countries are committed to ENDURE for four years (2007-2010), with financial support from the European Commission's Sixth Framework Programme, priority 5: Food Quality and Security.

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From Science to Field
Banana Case Study – Guide Number 2

Mycosphaerella foliar diseases of bananas: towards an integrated protection

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Assessing Black Leaf Streak Disease on banana leaves. © Charles de Wulf

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Mycosphaerella foliar diseases, the major threats to the banana industry

Severe defoliation induced by Sigatoka Disease. © Luc de Lapeyre de Bellaire, CIRAD, France.

Black Leaf Streak Disease (BLSD, caused by *Mycosphaerella fijiensis*) and Sigatoka Disease (SD, caused by *Mycosphaerella musicola*) are the main constraints of export dessert banana production. These foliar diseases threaten the major banana-producing countries in the world as all export banana cultivars (Cavendish cultivars) are highly susceptible. *Mycosphaerella fijiensis,* which is more aggressive than *M. musicola,* has totally replaced the latter in countries where it has been introduced. Today, virtually all banana- exporting countries suffer from BLSD, with the exception of some islands of the Caribbean (such as Guadeloupe and Martinique) where *M. fijiensis* has not yet been reported, and the Canary Islands where very dry conditions prevent the development of these fungal foliar diseases.

Infection results in substantial necroses of the foliage and consequently yield loss, but - most importantly - in immature ripening that renders the fruits unfit for export. Hence, protection of the crop is critically important for the entire industry. In these production environments with conducive tropical humid conditions for *Mycosphaerella* diseases, the only current practice is chemical control. In addition, to be highly cost effective, the high frequency of sprayings is a constant worry because of the development of fungicide resistance, and also because of the potential effects on both the environment and workers. This situation represents a technical, economical and environmental impasse. Hence, alternatives to chemical control are urgently required to provide sustainable solutions for the management of *Mycosphaerella* foliar diseases.

Important leaf spotting caused by Black Leaf Streak Disease on a commercial farm. © Josue Ngando, CARBAP, Cameroon

Premature ripening as a consequence of important Mycosphaerella leaf spotting, which renders bananas unfit for export. © Josue Ngando, CARBAP, Cameroon

A forecasting strategy for rational chemical control

In most countries exporting bananas, traditional disease management strategies rely on weekly applications (40-60 treatments/year) of fungicides. Nevertheless, in some countries, a forecasting strategy has enabled growers to reduce the number of applications to only 5-6 treatments/year for SD control in the French West Indies, and to 12-14 treatments/year for BLSD control in Cameroon and Ivory Coast. This biological forecasting system is based on early detection of the disease through the calculation of a Stage of Evolution of the Disease (SED).

SED: Ten plants in a plot are observed weekly to monitor continuous disease development. The most advanced stage of the disease is scored on the youngest leaves of the banana tree (leaves 1 to 5 for SD and 2 to 4 for BLSD). Leaf number/disease development associations are expressed in coefficients (Cs). The SED is derived from multiplying the sum of all Cs with the Foliar Emission Rate (FER), and its graphic representation is used for timing of decisions (See figure 1).

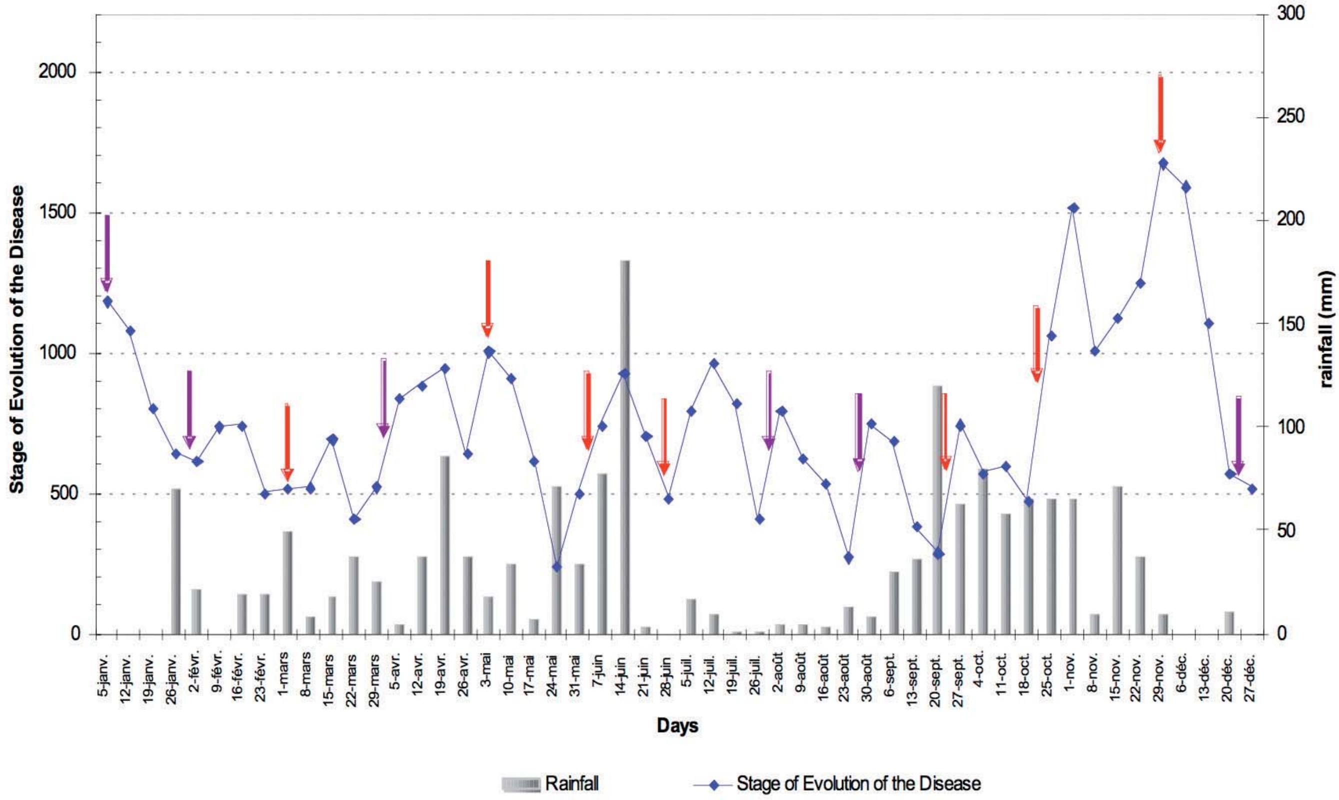

Figure 1. Example of Black Leaf Streak disease forecasting. Aerial spraying (purple arrow: antimitotic product; red arrow: DMI fungicide) was decided according to the Stage of Evolution of the Disease (blue line). © Luc de Lapeyre de Bellaire, CIRAD, France.

The reliability of this forecasting strategy depends on very specific technical requirements:

- The time between decision and spraying should be minimised and requires appropriate logistics for aerial applications
- Strong curative effect of systemic fungicides (100g a.i./ha) mixed in pure mineral oil
- Apply chemicals with different mode of action to reduce development of fungicide resistance
- Collaborative and centralized action of banana growers to delimit the aerial distribution of the disease.

Evolution to an integrated strategy

Chemical control of SD and BLSD is unsustainable due to the continuously increasing fungicide resistance that drives up the frequency of applications. Where fungicide resistance is established, control relies on weekly applications of contact fungicides. However, legislation also contributes to pesticide reductions as shown under European conditions, for example there are two authorised fungicides in the French West Indies (FWI) versus more than 25 in West Africa and Latin America. In the FWI, requirements for buffer areas around urbanised areas and rivers reduce aerial applications that could probably be banned soon. So, even where forecasting strategies are performed, disease control becomes increasingly difficult (Figure 2 on following page). Hence, alternatives should be developed and applied. Such alternatives should be integrated with other agronomic measures such as field sanitation to manage inoculum dispersal (for instance, the mechanical ablation of lesioned leaves).

Short-term solutions

Forecasting strategies should be devoted and implemented in areas where specific conditions are fulfilled: (i) areas free of fungicide resistance, (ii) new banana areas, (iii) low disease pressure areas. Where fungicide resistance is established, the reintroduction of forecasting strategies relies on possible fungicide resistance reversion and incoming of new mode of action fungicides with a high curative effect. Possible fungicide resistance reversion requires a better understanding of gene flow between unsprayed and sprayed areas and of the competitiveness of resistant strains.

The development and introduction of fungicides with low negative environmental effects is a necessity. Recently, various bio-fungicides have been tested. Unfortunately, none of these bio-fungicides enables alone a good control of BLSD under high disease pressure. Nevertheless, recent data show that their combination with contact fungicides could result in significant reductions of these latter which are currently sprayed at high rates (1000 g/ha versus 100 g/ha for systemic fungicides).

Mid to long-term solutions

In the long term, the introduction of resistant cultivars in banana cropping systems should ensure a sustainable control at low cost. Currently, there are no resistant cultivars that can commercially replace Cavendish bananas, and banana breeding is complicated by sterility.

However, new dessert banana cultivars with partial resistance to BLSD and SD, produced through breeding programmes, do exist and are presently being evaluated (pictured right). A potential brake on their widespread adoption is that they will have to be accepted in the market and their post-harvest processing adapted to an export industry that is currently adjusted mainly for Cavendish bananas. The adoption of new cultivars released by conventional breeding programmes, or that of genetically modified bananas, could thus be a very long process that should also take into account innovative ways to preserve sustainability of resistance.

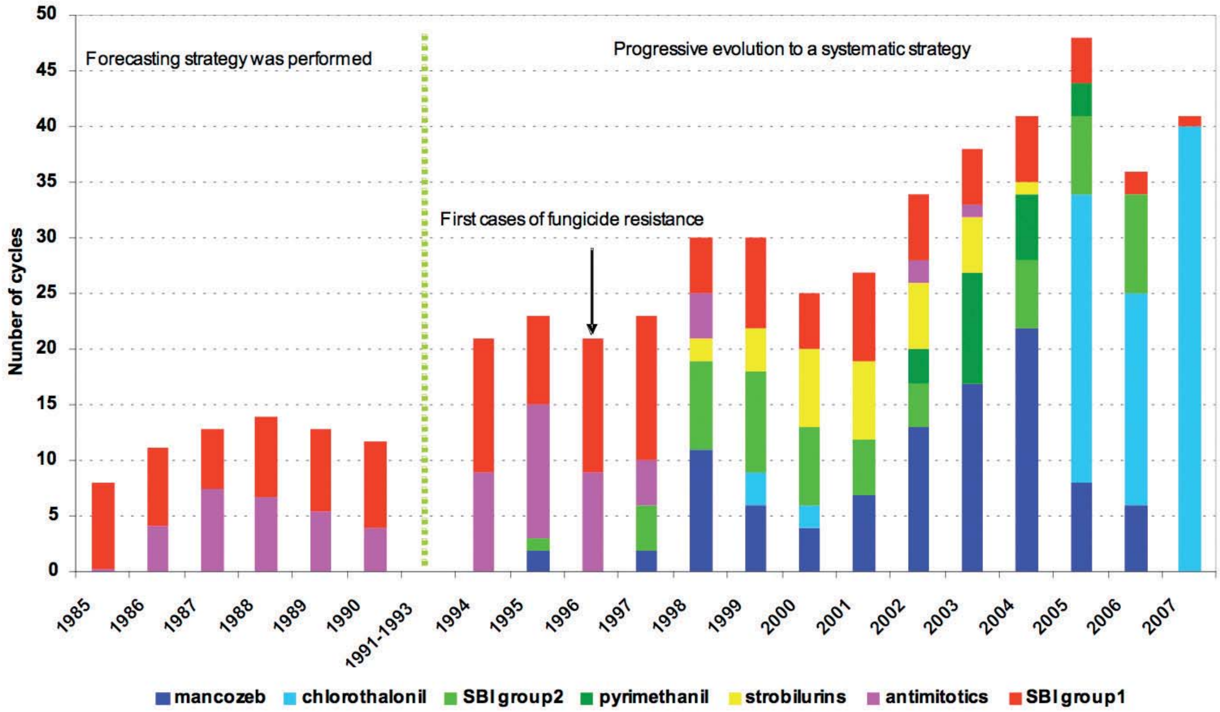

Figure 2. History of fungicide use for BLSD control in a representative commercial banana farm.
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Acknowledgements. Thanks to Inge Van den Bergh of Bioversity.


New banana varieties produced through the CIRAD breeding programme in the FWI showing partial resistance to Sigatoka. © Catherine Abadie, CIRAD, France.

Mycosphaerella foliar diseases of bananas: towards an integrated protection - Summary

Mycosphaerella foliar diseases, Black Leaf Streak and Sigatoka diseases caused respectively by *Mycosphaerella fijiensis* and *M. musicola*, are by far the main parasitic constraints for export bananas. They result in substantial necrosis of the foliage and consequently yield loss, but - most importantly - in immature ripening that renders bananas unfit for export. In the absence of commercial resistant varieties, banana exports can only be achieved through intensive chemical control. In most countries, fungicides are applied systematically following a fixed-schedule treatment programme (40-60 applications/year) to protect the young leaves against infection. In some places, forecasting systems are used to schedule treatments in function of the stage of evolution of the disease (5-14 treatments/year). In all countries chemical control has to face increasing difficulties in terms of efficacy, cost and environmental impact. This situation results mainly of two major events: (i) the development of fungicide resistance to systemic fungicides that lead to a systematic use of protectants and (ii) the evolution of the legislation which becomes increasingly restrictive. New alternatives that must be associated with basic prophylactic measures such as the mechanical ablation of lesioned leaves are needed for a sustainable control of these diseases. They are presented as (1) short-term solutions: implement the forecasting strategy where it is feasible or introduce fungicides with low negative environmental effect where this forecasting strategy is impeached by fungicide resistance; (2) mid-to-long-term solution: develop and introduce resistant cultivars in the cropping system.

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From Science to Field
Banana Case Study – Guide Number 3

Integrated Pest Management of black weevil in banana cropping systems

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**Innovative options to control the black weevil Cosmopolites sordidus in banana fields include the management of pitfall traps with pheromones, along with that of fallows (seen here in Guadeloupe, French West Indies). © CIRAD, France
From top: the black weevil is a crawling insect. At the larval stage it bores into the banana corm, causing plants to topple. © Philippe Tixier, CIRAD, France. Pitfall trap with pheromone attractant. © Philippe Tixier, CIRAD. Disc-on-stump trap used in Cameroon. © Justin Okolle, CARBAP, Cameroon. France.**

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Pheromone trapping as a short-term alternative to insecticides in banana fields

The black weevil *Cosmopolites sordidus* Germar (Coleoptera: Curculionidae) is a major pest of bananas and plantains in most production areas. Female *C. sordidus* lay eggs in the corm of banana plants. After egg hatching, larvae bore inside, which damages the points of insertion of primary roots and leads to plant snapping and toppling. Yield losses are important both in industrial plantations for export and in traditional smallholder farms: 25% corm infestation reduces the yield by 30%. In the past, insecticides were massively used worldwide to control the banana weevil, but their use is now decreasing, in particular in European banana producing areas. As an example, 2kg of insecticide active ingredient were used per hectare in 2008 in Martinique in the French West Indies, compared to 7kg in 1999 (source: CIRAD, France). The weevil *C. sordidus* contaminates banana fields through infested planting material, residual populations from the previous planting, or colonisation (crawling) from neighbouring fields. Traditionally, banana pseudo-stem pieces laid on the soil were used to trap and control populations of *C. sordidus* adults. However, the effectiveness of these traps varies with their age, location and environmental conditions. Moreover this trapping method is laborious and has been progressively replaced by pheromone-pitfall traps. In Cameroon, a disc-on-stump trap is also used by smallholders and some larger plantations.

Pheromone-pitfall traps effectively control populations of *C. sordidus***.** The pheromone Sordidine is specific to *C. sordidus* and attracts both sexes. Nevertheless the spatial and temporal organisation of trapping is a key factor in its success because of the patchy distributions of weevils within the field. The most common and effective strategy consists in:

- Monitoring the population with a regular network over the farm (4 traps per hectare)
- Mass trapping in highly infested fields (16 traps per hectare are recommended, placed 20m apart) or on the periphery of the field to limit its colonization with a barrier of traps (see Figure 1 on following page).

Fallows can be managed to control black weevil

Fallows are primarily used in banana cropping systems to sanitize fields against plant-parasitic nematodes and to renew soil fertility. Fallows also have a strong effect on *C. sordidus* populations by suppressing their resource (banana crop residues). As a consequence, after some weeks, when the resource has become very low, *C. sordidus* populations seek new banana plants and may contaminate neighbouring fields in production. To prevent this dissemination throughout the farm, complementary strategies can be implemented:

- Early crushing (by hand with a machete, or mechanically) and elimination of the banana corm residues issued from the previous crop.
- Mass trapping using pheromone-pitfall traps, in and around fallows, to provide better sanitation of banana plantations. The pheromone-pitfall traps prevent a large part of *C. sordidus* populations from moving from fallows to other banana plots. Therefore, fallows must not be located next to new banana plantations in order to avoid massive damage to the young plants. The control of *C. sordidus* should be managed at the farm and landscape scales rather than at the field scale, with special attention on the location of fallows and associated trapping.
- Setting up new banana crops with tissue culture plants to avoid the dissemination of weevil-infested planting material.

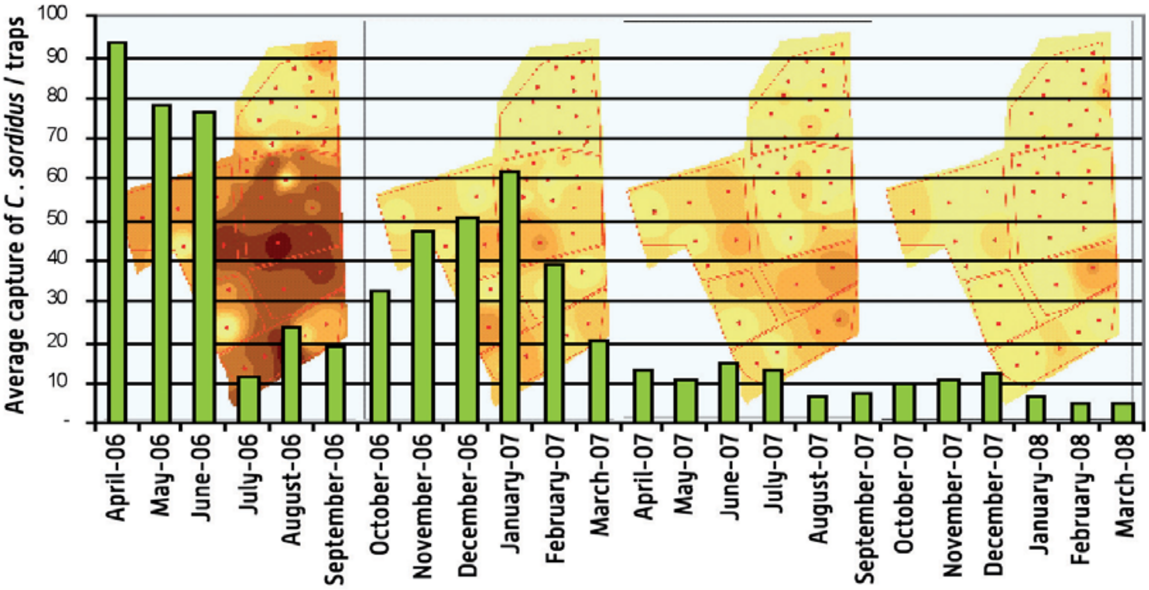


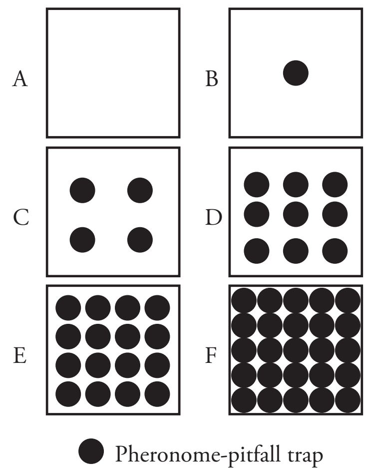
Figure 1. Population dynamics of *Cosmopolites sordidus* in a banana plot with mass pheromone trapping over two years in the sub-tropical con-ditions of the Canary Islands. © Ángeles Padilla Cubas, ICIA, Spain

The mid-term: Use of biocontrol agents and modelling tools to promote IPM

To achieve control of *C. sordidus* in the mid-term by promoting a strategy of Integrated Pest Management, two additional strategies are being evaluated:

- **Challenging options with biocontrol agents:** In the near future, trapping systems should be enhanced with biocontrol agents such as the entomopathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* or the entomopathogenic nematode *Steinernema carpocapsae* and *S. feltiae*. Another attractive approach currently being tested is to confer bioprotection to banana vitro plantlets with endophytic fungi such as non-pathogenic *Fusarium oxysporum*.
- **Designing new cropping system scenarios with modeling tools:** Simulation models, such as COSMOS (Fabrice Vinatier, CIRAD), calibrated from bibliographical and experimental data, allow testing of the effects of the location and the density of pheromone-pitfall traps on the epidemiology of *C. sordidus*. Figure 2 shows the simulation of different densities of pheromone-pitfall traps over a one-hectare field. These simulations help determine the optimal density for traps: *C. sordidus* populations decrease strongly when the trap density is increased, but control is not improved when there are more than 16 traps per hectare. Models can also provide relevant information to find the best compromise between the effectiveness and the cost of the control method. The COSMOS model is also well designed for Integrated Pest Management of *C. sordidus*, including the use of more tolerant varieties, spatial arrangement of banana plantations, and heterogeneity of crop residues and trapping.

Tested trapping patterns



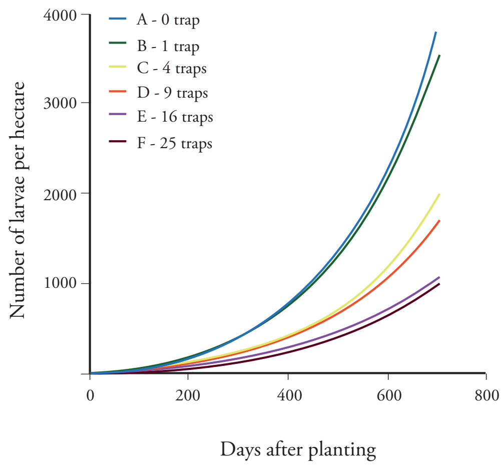


Figure 2. Simulation with the COSMOS model of the number of larvae of *C. sordidus*, on a one-hectare plot for six patterns of trapping, from zero to 25 pheromone-pitfall traps per hectare. Infestation is initialised from a clustered contami-nation by adults. © Fabrice Vinatier, CIRAD, France

Integrated Pest Management of black weevil in banana cropping systems - Summary

The black weevil, *Cosmopolites sordidus* (Coleoptera: curculionidae) is a major pest of banana in export farms and for smallholders in developing countries. New Integrated Pest Management strategies include the implementation of prophylactic cropping practices and the use of pheromone-pitfall traps.

The combined use of pheromone-pitfall traps and fallows reduces the number of *C. sordidus* adults in the field and has significantly reduced insecticide use in the French West Indies and in the Canary Islands.

Because of the patchy distribution of *C. sordidus* and the capabilities of weevils to invade neighbouring fields, these methods should be deployed at the farm and landscape scale, with special focus on their spatial and temporal organisation.

To further refine the Integrated Pest Management of this pest in the longer term, we are evaluating biocontrol agents and modelling tools developed to simulate the spatial organisation of traps at the plot and landscape scales.

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From Science to Field
Banana Case Study – Guide Number 4

Integrated management of banana nematodes: Lessons from a case study in the French West Indies

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Association of bananas with the perennial legume *Neonotonia wightii*. © Jean-Michel Risède, CIRAD, France.

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Integrated management of banana nematodes: Lessons from a case study in the French West Indies

Plant-parasitic nematodes are tiny worms that live mainly in soil and roots. In the case of banana plants, the most damaging species spend most of their life cycle in root and corm tissues. Their mouth cavity contains a hollow stylet with which they puncture the cell and remove the contents. Plurispecific communities of millions of individuals can develop in corm and root tissues of which they alter the physical and functional integrity. Nematode proliferation can disrupt nutrient and water uptake, delay growth and cause banana plants to topple over. In the French West Indies, toppling over is the main damage caused by nematodes.

As in many other banana-producing regions around the world, 10 years ago in the French West Indies methods for the control of nematodes in export bananas relied on the use of synthetic carbamate and organophosphate nematicides. For the most part classified as toxic or highly toxic, in recent years many of these products have gradually been banned. Alternative integrated plant-parasitic nematode management has consequently been developed in banana cropping systems in the French West Indies with the support of different stakeholders (growers, researchers, extension officers etc).

Plant toppling caused by burrowing nematodes in the French West Indies. © Jean-Michel Risède, CIRAD, France.

Soil sanitation is a key step in preventing the build-up of the burrowing nematode *Radopholus similis*

The main banana parasitic nematodes do not develop a resting stage for long-term persistence in soils. Consequently, in most cases soil prophylaxis is efficient in slowing down their population dynamics, especially in the case of the worldwide endoparasitic species *Radopholus similis*. In the French West Indies, recommendations for soil sanitation against nematodes are usually based on a twofold strategy:

Improved fallow to cleanse the soil of *R. similis*: This type of fallow relies on the destruction of nematode-infested banana plots by injecting a reduced quantity of herbicide into the pseudostems. When the plot is replanted after using this technique, only 10-15% of plants are reinfested after 9-12 months as oppose to 75-80% with mechanical destruction. It is essential to systematically remove - by hand or mechanically - all spontaneously regrowing suckers ('volunteer plants') as they can host and multiply residual nematode populations. If necessary, the ground should also be weeded by hoeing or mechanically to prevent the growth of host weeds for *R. similis*. Species belonging to several families including Poaceae, Euphorbiaceae, and above all Solanaceae and Urticaceae, can harbour *R. similis* populations.

Water isolation ditches to delay the recontamination of fallows and plots that have already been sanitized: Run-off water from nematode-infested banana plots can disseminate *R. similis* and re-contaminate sanitized plots. As a consequence, fallows being sanitized and plots that are already sanitized must be protected against incoming water from nematode-infested plots. Digging 50-80cm deep ditches around plots efficiently prevents the dispersion of *R. similis*. In this way, re-infestation of banana fields by parasitic nematodes can be reduced and delayed by more than three years.

Female of the burrowing nematode Radopholus similis.
© Jean-Michel Risède, CIRAD, France.

Non-host crops also contribute to soil sanitation and prophylaxis against nematodes

A way to complete soil sanitation and prophylaxis against plant parasitic nematodes in banana agrosystems is planting nematode-resistant plants as rotational or associated crops. Such cropping practices are most effective against the burrowing *R. similis*, but less effective against the lesion nematode *Pratylenchus coffeae*, which has a wider ecological niche.

Various types of plants can be used as rotational crops thanks to their non-host status for *R. similis*:

> Cash crops including certain varieties of sugarcane and pineapple.

> Pasture grasses such as Pangola grass (*Digitaria decumbens*), creeping signal grass (*Brachiaria humidicola*) and Guinea grass (*Panicum maximum*); and also legume grasses such as perennial soybean (*Neonotonia wightii*), Stylo grass (*Stylosanthes hamata*), and Siratro (*Macroptilium atropurpureum*).

> Other cover crops such as *Crotalaria* species.


Pasture rotation with Pangola grass (*Digitaria decumbens*); grass is being mowed. © Jean-Michel Risède, CIRAD, France.

Cover crops that are not hosts for *R. similis* can also be associated with banana to favour below-ground biodiversity in banana cropping systems and to promote more beneficial soil biota. Two crop associations are currently being developed in the French West Indies:

> Banana-*Impatiens* association: *Impatiens* spp. are shade-tolerant Balsaminaceae that do not compete with banana. This type of association is being developed in the highlands of Guadeloupe. In addition to being unsuitable for build up of *R. similis* populations, *Impatiens* species may lessen or even avoid herbicide applications.

> Banana-perennial soybean association: perennial soybean (*Neonotonia wightii*) is a legume with a strong tap root that penetrates vertically into the deep soil layers, while banana roots grow horizontally in the shallower soil layers. As a consequence, the two plants do not compete. In addition to avoiding the need for herbicides in banana plots, perennial soybean provides a key ecosystemic service, i.e. fixing and supplying nitrogen for plant productivity.

***Crotalaria* species are promising annual legumes that are not only resistant to *R. similis* but can also be used to sustain soil fertility. © Jean-Michel Risède, CIRAD, France.**

Shade-tolerant *Impatiens* do not compete with banana and are being tested in the highlands of Guadeloupe. In addition to being unsuitable for the build up of *R. similis* populations, *Impatiens* species may lessen or even avoid herbicide applications. © Jean-Michel Risède, CIRAD, France.

Monitoring soil sanitation before banana planting is essential

Potted biotests to monitor the progress of cleansing the soil of *R. similis* in commercial banana plots can be performed by a nematology laboratory. Such biotests are a decision tool that should be used to monitor the effectiveness of a soil sanitation process before planting a new plot. The basic principle is to trap and multiply residual nematode populations present in soil samples of the plot to be diagnosed using *in-vitro* micro-propagated plants of a nematode-susceptible banana variety. After two months, banana plants are uprooted and their root system analysed to estimate the percentage of nematode-infested plants.

Healthy planting material must be used when planting new banana crops

As a basic precept, it is essential to increase the value of as yet uninfested soils or already sanitized soils, by planting healthy material. It is a fact that banana corms have long been the major source of nematode dissemination throughout fields, countries and continents. Today, tissue culture banana plants represent an opportunity to use clean planting material. Even so, such material must be periodically checked for the presence of nematodes. The water used in weaning and hardening nurseries of tissue culture banana plants must also be checked for nematode contamination. Nematodes can be spread by river water and introduced into nurseries by pumping and it may thus be necessary to equip pumping material with 5µm sieves to prevent contamination of irrigation water.

Five-week-old tissue culture banana plants under weaning conditions.
© Jean-Michel Risède, CIRAD, France.

Nematode tolerant or resistant varieties: a promising complementary solution

Although Cavendish bananas are susceptible to both *R. similis* and *P. coffeae* species, they exhibit different levels of susceptibility to these nematodes. These differences can be exploited if producers of tissue culture plants single out the less susceptible Cavendish lines, as it was the case for the MA13 line, a Cavendish selection obtained by CIRAD and Vitropic S.A. In addition, the selection of banana hybrids that are resistant to nematodes is a promising medium-term solution that has already been launched by the CIRAD breeding programme, and is currently being further developed in the framework of the '*Plan Banane Durable*'

(Sustainable Banana Plan), a new participatory project bringing together researchers, growers and other stakeholders dealing with pesticide reduction. Conventionally bred, such banana hybrids have the key advantage of displaying strong partial resistance to both Black Leaf Streak Disease and Yellow Sigatoka Disease, the most damaging airborne diseases of banana. These hybrids are currently being released for joint evaluation by growers and researchers. Some are showing promising resistance to *R. similis.*

Integration of management and reintroduction of biodiversity: a further step towards sustainable control of nematodes

The stricter regulations on the use of chemical nematicides alongside the combination and then the adoption of the prophylactic measures and monitoring procedures described above has led to reductions of up to 60% of nematicide inputs in banana cropping systems. To enable disruption of the spatial, temporal and genetic homogeneity characterising banana plant covers, and to create new below-ground biological balances that reduce the abundance and mitigate the effects of nematodes parasitic to bananas, a major step will be the complete integration of current nematode management techniques, and the re-introduction of biodiversity in banana agrosystems, to ensure a variety of ecological services that sustainably support soil and plant health.

Banana hybrids under field conditions. © Jean-Michel Risède, CIRAD, France.

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Integrated management of banana nematodes: Lessons from a case study in the French West Indies

Summary

Plant-parasitic nematodes are tiny worms that live in soils and roots; in the case of banana plants, they spend most of their life cycle in root and corm tissues. Their proliferation mainly disrupts nutrient and water uptake, delays growth, and may cause the banana plants to topple over. Until recently, most methods for the control of banana nematodes relied on the use of chemical nematicides, many of which are gradually being banned in Europe. This guide reviews the main steps of alternative integrated plant-parasitic nematode management in banana cropping systems in the French West Indies. This includes i) soil sanitation measures such as improved fallow to cleanse the soil of the burrowing nematode *Radopholus similis*, water isolation ditches to delay recontamination of fallows and already sanitized plots, along with the use of non-host plants including cash crops, pasture grasses, and legumes; ii) monitoring of soil sanitation before planting new banana crops; iii) use of healthy planting material, mainly tissue culture banana plants; iv) use of nematode tolerant banana varieties, and in the medium-term, nematode resistant varieties; and v) further integration of management strategies and the reintroduction of biodiversity to ensure sustainable control of nematodes.

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From Science to Field
Banana Case Study – Guide Number 5

Banana production under Integrated Pest Management and organic production criteria: the Canary Islands case study

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Banana crops in the agricultural landscape in the Canary Islands. © Juan Cabrera Cabrera, ICIA, Espagne

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Banana production in the Canary Islands

In the Canary Islands, commercial production of bananas started at the end of the 19th century and today it is the largest banana producing region in Europe. Banana production structures the agricultural landscape and supports the economy. The banana growers are mostly smallholders with less than one hectare and have profound knowledge of crop management in subtropical conditions. Unlike bananas produced in the humid tropics, bananas from the Canary Islands are not affected by *Mycosphaerella* diseases, but other pests and diseases do require sustainable control.

The need for further adjustments to promote sustainability

New European Community directives restricting the use of synthetic agrochemicals, protecting the environment, and preserving food safety and human health mean that technical knowledge needs to be updated to maintain the economic viability of banana farms. With the support of different administrations, the banana growers' association of the Canary Islands (ASPROCAN, Asociación de Organizaciones de Productores de Plátanos de Canarias) decided to promote controlled production, chosen to fit their production and trading systems, to comply with the new European standards. As a result, banana growers have now adopted various certifications such as AENOR (UNE 155202), GLOBALGAP, Integrated Production and Ecological Production, thus offering consumers a safer fruit of higher quality. At the same time, they aimed to satisfy environmental considerations as well as improving traceability and working conditions throughout their production and trading processes.

In the Canary Islands, bananas are produced mainly by smallholders. © Juan Cabrera Ca-brera, ICIA, Spain

Integrated production/ecological production

The combined use of adapted cropping practices and spraying with alternatives to conventional synthetic pesticides has already allowed some growers to meet the standards of integrated or ecological production. However, to extend such innovative strategies and promote sustainable production of high quality bananas, new tools must be refined, validated and then transferred to growers to ensure harmlessness for the environment, producers and consumers.

Inputs of exogenous organic matter

This traditional practice in the Canary Islands is regaining importance in both integrated and ecological production systems. Inputs of organic matter during land preparation or periodically to the banana crop maintain a well balanced soil for nutrients and biota. Various studies in the Canary Islands have shown that organic inputs improve the biological activity in the rhizosphere zone, thus increasing populations of arbuscular and mycorrhizal fungi, favouring plant growth, promoting rhizobacteria, actinomycetes and beneficial free living nematodes, and inducing better plant tolerance to biotic or abiotic stresses.

Inputs of organic matter are critical for the banana crop in the Canary Islands. © Juan Cabrera Cabrera, ICIA, Spain

Use of banana vitroplantlets

Widely used by producers, healthy banana plantlets developed through tissue culture considerably reduce the spread of pests and diseases through planting material in new plantations. They also facilitate periodic renewal of banana crops and allow alternative production systems to be introduced, such as one-cycle cropping systems, new plantation arrangements and new plantation densities.

Soil mulching with plant residues

Once planting has been completed, covering the soil surface with plant residues reduces soil warming and thus helps reduce nematode damage and slow weed colonisation, without requiring intensive herbicide use. In addition, mulching the soil with plant residues favours moisture retention and reduces water evaporation, thus decreasing the need for irrigation.

New plantation spacing: crop mechanisation

New plantation spacing with broad alleys allows many cultural practices to be mechanised and consequently helps rationalise crop management. These alleys enable spraying machines to pass and facilitate bunch harvesting. In addition, following harvest, machines can cross over the banana fields to slice and chop pseudostems, thus strongly perturbing the habitat of *Cosmopolites sordidus*.

Selective removal of leaves and floral remnants

Selective deleafing (dead leaves and green leaves obstructing the emerging inflorescence) along with the removal of floral remnants improves the control of insect pests and diseases such as *Dysmicoccus grassii* (Leonardi), *Thrips florum* (Schumtz), *Opogona sacchari* (Coger), *Aleurodicus sp.*, and *Verticillium theobromae* (Turconi).

New plantation spacing allows mechanisation to be introduced.
© Juan Cabrera Cabrera, ICIA, Spain

Cropping under greenhouse conditions

In bananas cropped in greenhouses, plastic sheets that cover greenhouses strongly reduce UV radiation and prevent invasions by the white flies *Aleurodicus dispersus* (Russell) and *Aleurodicus floccissimus* (Martin *et al.*). They also slow the entry of owlet moths into the greenhouses.

Release of pest natural enemies and conservation of native auxiliary fauna

Inundative releases of natural enemies and protection of the native auxiliary fauna are helpful for managing banana pests in the Canary Islands. For example, biological control of the spider mite *Tetranychus urticae* (Koch) is successfully achieved by releases of the predatory mite *Phytoseiulus persimilis* (Athias-Henriot) (see photograph on following page). In-depth knowledge of the lifecycles and population dynamics of the organisms involved allows for rational and efficient management of these processes.

Use of pitfall traps with attractants

These types of traps are designed for monitoring and controlling insect pests. They can be used with an aggregation pheromone for population monitoring and for mass trapping within plots of the black weevil *Cosmopolites sordidus* (Germar). They maintain populations under acceptable levels for the crop, thus reducing or even removing the need to spray with the specific synthetic insecticides which are used against this pest. Also, traps with sexual attractants are deployed to monitor caterpillars of the moths *Chrysodeixis chalcites* and *Spodoptera littoralis.* Coloured sticky traps capture white flies (yellow traps) or thrips (blue traps). Sticky paper strips are also laid on pseudostems or on bunch stalks for delaying ant walking, as an additional means to control the cotton mealy bug.

Spraying with alternatives to synthetic pesticides

A variety of products replacing conventional synthetic pesticides are currently used in the Canary Islands, including Azadirachtin, *Bacillus thuringiensis*, oils, sulphur, potassium salts of fatty acids from plants, and microorganisms from soil microbial flora which are antagonists of plant parasitic nematodes. Various strains of entomopathogenic fungi native to the Canary Islands are also being tested against white flies and the black weevil. These alternatives are expected to help manage banana pests, and some are already undergoing accreditation.

***Phytoseiulus persimilis*, a predator of phytophageous spider mites.**
© Estrella Hernandez Suarez, ICIA, Spain

Adult white fly parasi-tized by the fungus *Paecilomyces fumosoroseus*.
© Ángeles Padilla Cubas, ICIA, Spain.

Widespread alternative cropping practices and control measures contributing to the reduction and rationalisation of synthetic pesticides in the Canary Islands

Cropping practices/control measures	Targeted pests	Reduction of :
Inputs of exogenous organic matter	Banana parasitic nematodes	Nematicides
Use of banana vitroplantlets	Banana parasitic nematodes *Cosmopolites sordidus*	Nematicides Insecticides
New plantation spacing/ drop-by-drop irrigation/crop mechanisation	All in general	Nematicides Insecticides Acaricides
Soil cover with dead or living mulch	Banana parasitic nematodes	Nematicides Herbicides
Removal of floral remnants (terminal tapered bud, bracts etc)	Thrips spp., *Opogona sacchari*, *Verticillium theobromae*	Insecticides Fungicides
Selective deleafing (green and dead leaves)	*Dysmicoccus grassii*, *Aleurodicus dispersus*, *Aleurodicus floccissimus*	Insecticides
Cropping under greenhouses - UV	White flies (*Aleurodicus* spp.), moths	Insecticides
Slicing and chopping of banana plant residues	*Cosmopolites sordidus*	Insecticides
One-cycle cropping systems	*Cosmopolites sordidus*	Insecticides
Spreading of calcium amendments around banana pseudostems	*Cosmopolites sordidus*	Insecticides
Use of pitfall traps with attractants	*Cosmopolites sordidus*, moths, thrips, white flies (*Aleurodicus* spp)	Insecticides
Inundative releases and protection of natural enemies	*Tetranychus urticae*, *Dysmicoccus grassii*, *Chrysodeixis chalcites*, *Spodoptera littoralis*, *Aphis gossypii*, *Aspidiotus nerii*	Acaricides Insecticides
Spraying with alternatives to synthetic pesticides	All in general	Insecticides Acaricides Nematicides

Banana production under Integrated Pest Management and organic production criteria: the Canary Islands case study

Summary

Pioneers in the cropping of commercial banana in Europe, the growers of the Canary Islands have more than a century of experience in banana production. Combining new cropping technologies and traditional practices gives them the opportunity to maintain productivity. Good agricultural practices that preserve the environment have evolved rapidly. With the support of various administrations, the banana grower associations of the Canary Islands (ASPROCAN) decided to promote controlled production, making the choice to fit their production and trading systems to the new standards of the European Community. The combined use of a variety of cropping practices and of spraying with alternatives to conventional synthetic pesticides is currently allowing various growers to successfully crop bananas under the standards of integrated or ecological production. These strategies are reviewed in the present guide. Some of the new tools still need to be refined, validated and then transferred to growers, in order to produce bananas of high quality that are harmless for producers, consumers and the environment.

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