# Multidisciplinary assessment of two organic banana production systems in Martinique

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***Abstract***

**A drastic reduction in pesticide use over the last 20 years in Martinique has been possible thanks to the deployment of banana in vitro plantlets, fallow rotations and cover crops, but this agroecological transition entails additional costs for growers. Certified organic production could provide access to higher prices, but technical challenges for organic production in humid zones need to be addressed. In 2018, the BANABIO research programme set up two organic systems: 1) a bio-intensive banana monoculture (BI), and 2) a bio-diversified banana-cocoa-legume service tree association (BD) compared with a conventional system (CO). This trial, set up in a complete randomized block design, was assessed by a panel of specialists who examined yield, nutritional status of the soil and bananas, soil biodiversity, pest and disease pressure, and production costs. The results after three harvests showed a 16% gross drop in yields under organic farming conditions. More specifically, the gross agronomic yield was 42.1 t ha$^{-1}$ for the CO system, as opposed to 35.1 t ha$^{-1}$ for the BI system. In addition, the cycle length was on average 6 weeks shorter in the CO system. Black Sigatoka pressure was more intense in the organic systems as indicated by the number of leaves at harvest averaging 2.1 in the CO system versus 1.4 in the BI system. Nonetheless, soil biological processes and biodiversity were promoted in the organic systems. Due to weed restitution, the BD and BI systems had higher levels of C returned to the soil and our results showed that soil carbon concentration and earthworm biomass increased by 13 and 230%, respectively. The organic systems entailed very high production costs (€ t$^{-1}$) of around +37% when comparing the BI system with the CO system over the first three cycles. Mechanical weeding (cost × 2.4) and organic fertilizers (cost × 2.4) were the main reasons for increased expenditure. quantifying the increase in income that could be derived by the producer from selling organic bananas is still to be assessed but given the important extra cost linked to organic banana production, organic farming is likely to be unprofitable in the current regulatory and economic context of the French West Indies.**

**Keywords:** agroforestry, banana yield, conventional farming, French West Indies, organic farming, production costs, soil biology

## INTRODUCTION

Some 8,000 ha of bananas are cultivated in Martinique and Guadeloupe. The volume exported in 2015 was around 265,000 t, mostly to Europe (Fruitrop Focus, 2017). These two islands, located in the Caribbean Basin and close to some Central and South American countries that figure among the largest banana exporters in the world have several particularities: 1) the French West Indies are part of the European Union and, as such, the regulatory context is very demanding/restrictive; 2) the cost of living and incomes there are high, which implies high labour costs and; 3) civil society exerts considerable pressure for a

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reduction in pesticide use. This tendency is mostly driven by the chlordecone scandal, which is still centre stage in the media today. This highly restrictive context makes the French West Indies a very innovative territory and a driving force for developing and implementing agroecological practices in banana cultivation.

Despite many efforts to reduce pesticide use in these two territories (Risède et al., 2019), bananas from the French West Indies struggle to fetch a better price and are unable to provide higher incomes for growers, despite all their efforts.

Conversion to organic farming may be a way for some growers to increase their income and thereby derive some tangible benefits from the efforts made to reduce pesticide use over the last 20 years.

Such a strategy might be all the more relevant in that organic banana sales are steadily increasing. In 2020 sales reached record levels with 1.3 million t worldwide, i.e., 7% of the world export banana market (Dawson, 2021). Although the development of organic farming is not always linear, it nonetheless seems to be driven by a general tendency towards healthier food, for consumers and the environment. It therefore appears to be a strategy for the future.

However, growing organic bananas in the French West Indies still faces some technical challenges. Although organic banana cultivation in certain irrigated dry zones has produced some success stories (Ecuador and the Dominican Republic), such production in a humid tropical environment still faces some technical drawbacks, such as: weed management, nitrogen fertilizer management, especially just after planting, pest and disease management, especially black Sigatoka. In addition to these agronomic aspects, economic factors like insufficient availability of local raw materials, imports of inputs in small quantities and/or high prices resulting from the small island economy are potential constraints.

Thus, despite the clear advantages that organic banana production could have for the environment, it is necessary to assess its feasibility in terms of farming techniques, and to precisely quantify the extra costs associated with organic production. Such an assessment would help to determine whether the current context is suitable for organic production in the French West Indies, would serve as a reference, and would provide food for thought for implementing possible ways of promoting such production.

As part of the national Ecophyto Plan, under the DEPHY Expé Call for Projects, we launched the BANABIO project (site web) with a view to testing two novel prototype cropping systems for the organic production of dessert bananas.

The restrictive framework of each system was established at the outset of the project with partners in the banana supply chain in Martinique. The two types of organic systems envisaged corresponded to a transition from current references to ecologically intensive organic systems. The 1st system assessed was based on the idea of a framework of "bio-intensive" constraints (BI), taking the form of a banana monoculture and the substitution of conventional inputs by organic inputs. The 2nd system, called Biodiversified (BD), also respected organic farming specifications, but went further than the BI system as it combined several crops (banana and cocoa) and service trees (*Cajanus cajan*, *Indigofera zollingifera* and *Inga ingoides*) in an agroforestry system. These systems were assessed by comparing them with a "reference" system (CO), which was based on the average conventional practices existing in Martinique.

These three systems have been tested at the CIRAD experimental station in Martinique since the end of 2018 and are currently being assessed by a multidisciplinary team of researchers. The trial is set to be extended up to the end of the useful life of the banana plantings. The results presented here are the first data to be analysed over the first three production cycles.

## MATERIALS AND METHODS

### Experimental site

The trial is located at CIRAD's Rivière Lézarde research centre (14.66°N, 60.00°W, 46 m a.s.l.). The soil is classed as a Nitisol (WRB classification). The texture of this soil type is dominated by clays (59% clays, 20% silts, 21% sands) (Venkatapen, 2012). The chemical properties of the plots were analysed prior to setting up the trial and are presented in Table 1. The climate is humid tropical with a mean temperature of 26.4±0.1°C and cumulative rainfall of 2,413±252 mm (average data over the 1997-2017 period). Seasonality is low, with February being the driest (95 mm) and October the wettest (313 mm). Prior to setting up the BANABIO trial, pineapple had been grown for 25 years in the plot, without rotations. The previous plant cover was destroyed first using a rotary slasher, followed by tillage with a spader down to a depth of 20 cm, followed by subsoiling, then a different fallow was installed depending on the cropping systems.

Table 1. Soil chemical properties of the experimental plots before banana planting.

| | **Mean (*n*=9)** | **Standard deviation** |
|---|---|---|
| Organic matter (%) | 2.54 | 0.13 |
| Total nitrogen (%) | 0.15 | 0.01 |
| C:N ratio | 10.01 | 0.34 |
| Soil pH ($H_2O$) | 5.31 | 0.15 |
| CEC Metson (meq. 100 $g^{-1}$ soil) | 15.87 | 0.86 |
| Exchangeable Ca (meq. 100 $g^{-1}$ soil) | 4.47 | 0.78 |
| Exchangeable K (meq. 100 $g^{-1}$ soil) | 1.84 | 0.24 |
| Exchangeable Mg (meq. 100 $g^{-1}$ soil) | 2.19 | 0.17 |
| $P_2O_5$ Truog method (mg P $kg^{-1}$ soil) | 7.67 | 1.34 |

For this trial, the three cropping systems assessed (CO, BI and BD) were each replicated in three plots of around 500 $m^2$ arranged randomly in a randomized block design, with the whole trial occupying a total cultivated area of 4,500 $m^2$.

## Crop management sequences for the three systems

Although differentiated, the three systems were managed according to a common set of practices. The practices common to the three systems were: 1) installation of the banana plantation in simple rows spaced 2.85 m apart with 1.95 m between plants along the row (Figure 1); 2) management of soil-borne pests using in vitro plantlets on a soil sanitized by fallow, which is effective in preventing plant-parasitic nematodes. Weevils were uniformly controlled throughout the plots by trapping with pheromones (sordidin); 3) banana black Sigatoka disease, caused by *Mycosphaerella fijiensis* Morelet, was managed by weekly sanitary leaf removal, identically in the three cropping systems. At the same time as sanitary leaf removal, a biological warning strategy adapted from Fouré and Ganry (2008) was applied to optimize the use of different types of phytosanitary treatment. This was done by establishing observation posts, selecting five young banana plants of uniform height and age, bearing 8 to 10 leaves, spread throughout each of the trial plots of the three cropping systems. The five banana plants making up each observation post were monitored up to flowering of at least one of the plants, then five new banana plants were selected according to the same criteria. The treatments carried out differed depending on the systems and are indicated below; 4) irrigation was managed uniformly throughout the experimental design, with all plots being irrigated at the same time, with 2 to 3 irrigation sessions per week so that the water resource was non-limiting; 5) decision-making rules common to the three systems were applied for fruit care and the choice of harvest date. For each cropping cycle, paint sprays were used to mark the banana plants with the week number at the time of flowering, defined as the switching of the fingers in the fourth hand to the horizontal stage. At this stage, the green leaves on each plant were counted. The first six hands in each bunch with fewer than nine leaves and the first seven hands in each bunch with nine leaves or more were kept. Subsequent hands and the male flower were removed, taking care to leave two “sap-drawer” fingers on the third hand after the last hand kept. The bunches were deflowered and covered with polyethylene bags. The physiological age of the fruit, expressed in degree-days (°D), was calculated from the date of flowering using the method described by Ganry and Meyer (1975). Bunches were harvested at a physiological age of between 700°D and 1,100°D, and the harvesting dates were adjusted to the calibre of the bananas located on the outside of the last hand (32 mm). Residues produced after sanitary leaf removal and harvesting of bunches are left randomly in the field.

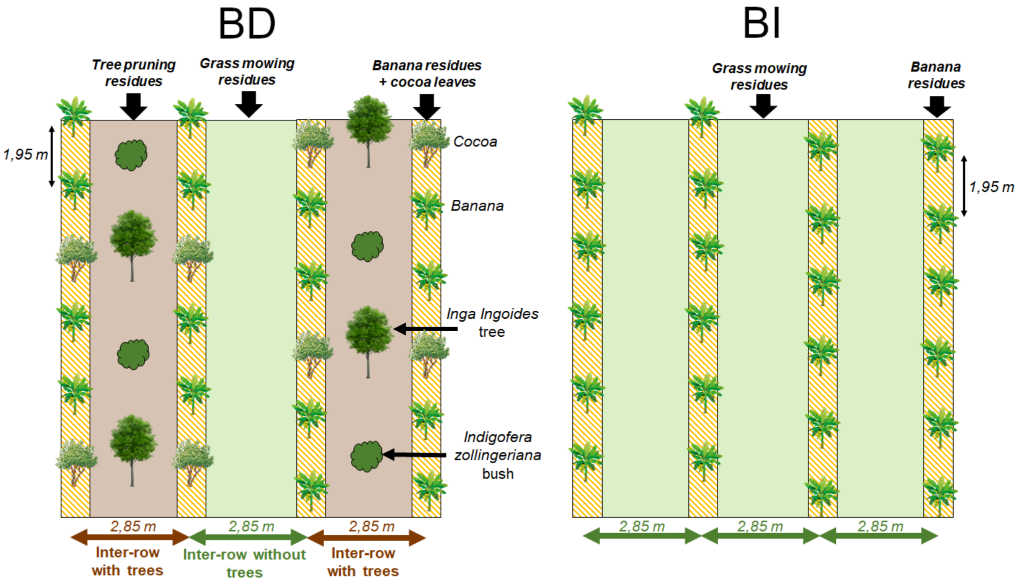

Figure 1. Diagram showing the planting arrangement in the two AB systems (BD and BI). In the BD system (left), cocoa trees have replaced pigeon peas. The CO system was planted with the same spacing between banana plants as the BI system.

The farming practices that differed in the three systems studied involved soil tillage and fallow (before planting), fertilization and amendment, along with weed and black Sigatoka management. The practices specific to each system are detailed below.

**CO system**

After destruction of the previous plant cover, the vegetation was left to develop freely (spontaneous fallow). Prior to banana planting, the vegetation was destroyed with a rotary slasher. The soil was then tilled by two crossed passes with a rotary spader to a depth of 20 cm and two crossed passes with a subsoiler to a depth of 60 cm.

The CO system was fertilized with various synthetic mineral fertilizers. The main two types of fertilizers used had the following formulation: 14N-5P-25K or 15N-5P-15K. Based on 1,800 plants ha$^{-1}$, the average amount of nutrient added for each cycle was 440 kg N ha$^{-1}$, 185 kg $P_2PO_5$ ha$^{-1}$, 488 kg $K_2O$ ha$^{-1}$ and 152 kg MgO ha$^{-1}$.

Weed cover was mainly managed with herbicide. To date, the average number of herbicide rounds has been 2 year$^{-1}$ and the molecules used are Fluazifop-P (Fusilade Max) and Glyphosate (Touchdown S4) at 2 L ha$^{-1}$. Mechanical brush clearing (backpack brush-cutter and manual border removal) are carried out occasionally in addition to the herbicide treatments.

Black Sigatoka was managed by occasional applications of a paraffin mineral oil (Banole®, Total) in a mixture with Sérénade Max (2 kg ha$^{-1}$, *Bacillus subtillis* QST 713, 5.4 treatments year$^{-1}$ on average) or in a mixture with Sico® (difenoconazole, Syngenta; 2.5 treatments year$^{-1}$), Tilt®250 (propiconazole, Syngenta; 0.4 treatments year$^{-1}$), and Luna Privilège® (fluopyram, Bayer SAS; 0.4 treatments year$^{-1}$) at respective doses of 20, 0.4, 0.4 and 0.2 L ha$^{-1}$. After homogenization, the mixtures were sprayed in the trial plots with a backpack sprayer (series M3A, CIFARELLI, Voghera, Italy) at a rate of 20 L ha$^{-1}$. On each application, anti-drift nets were used between the CO trial plots and the BI and BD trial plots to prevent any drifting of the treatments into adjacent plots.

### BI system

After destruction of the previous plant cover, a multi-species fallow comprising two legume service plants (*Crotalaria juncea* and *Pueraria phaseoloides*) was sown. Prior to banana planting, the vegetation was destroyed with one pass of a rotary slasher. The soil was then prepared by two crossed passes with a rotary spader to a depth of 20 cm, and two crossed passes of a subsoiler to a depth of 60 cm. At the same time as the banana plants were planted, a new service plant cover was sown with the two species already mentioned.

The BI system was mostly fertilized with organic fertilizers of the AB'FLOR® brand, the type of fertilizer most applied having the following formulation: 7N-5P-7K. Based on 1,800 plants ha$^{-1}$, the average amount of nutrient applied for each cycle was 514 kg N ha$^{-1}$, 307 kg $P_2O_5$ ha$^{-1}$, 584 kg $K_2O$ ha$^{-1}$ and 106 kg MgO ha$^{-1}$.

Weeds were mostly controlled using a mechanical backpack brush-cutter. The average number of brush-cutting rounds was 7 year$^{-1}$ with border removal varying between once and twice a year.

Black Sigatoka was managed by occasional applications of a paraffin mineral oil (Banole®, Total) in a mixture with Sérénade Max (2 kg ha$^{-1}$, *Bacillus subtillis* QST 713, 9.6 treatments year$^{-1}$ on average), sprayed in each of the trial plots with a backpack sprayer (series M3A, CIFARELLI, Voghera, Italy) at a rate of 20 L ha$^{-1}$.

### BD system

After destruction of the previous plant cover, a multi-species fallow comprising two legume service plants (*Crotalaria juncea* and *Pueraria phaseoloides*) was sown. In addition to the banana plants and the herbaceous service plants, the BD system incorporated 4 tree species, including an intercropped cultivated species, cacao (*Theobroma cacao*). "Pois Doux" (*Inga ingoides*), a tree of a fast-growing legume family, was planted 4 months before the bananas were planted along the future banana plantation interrow (Figure 1). In preparation of planting the banana plants, just the planting row was mechanically tilled with one pass of the rotary spader to a depth of 20 cm, which amounted to around 40% of the area of the plots. The same planting row was tilled with a single pass of a subsoiler to a depth of 60 cm. At the same time as the bananas were planted, a new service plant cover was sown with the two herbaceous species already mentioned, along with the planting of Zollinger's indigo trees (*Indigofera zollingeriana*), between the "Pois Doux" in the interrow. Every third banana plant was replaced by a pigeon pea (*Cajanus cajan*), so the banana planting density was 1,200 plants ha$^{-1}$ in the BD system (Figure 1). Six months later, the pigeon peas were destroyed and the cacao trees planted in the mulch resulting from their destruction. The cacao tree planting density was 600 plants ha$^{-1}$.

The BD system was mostly fertilized by organic fertilizers of the AB'FLOR® brand, the type of fertilizer most applied having the following formulation: 7N-5P-7K. Based on 1,200 plants ha$^{-1}$, the average quantity of nutrient applied for each cycle was 342 kg N ha$^{-1}$, 205 kg $P_2O_5$ ha$^{-1}$, 389 kg $K_2O$ ha$^{-1}$ and 71 kg MgO ha$^{-1}$. Although the total quantity of nutrients applied was lower than in the BI system, the fertilization applied to each plant was identical, the differences being due to the planting density.

Weeds were mainly managed with a mechanical backpack brush-cutter. So far, the average number of brush-cutting rounds has been seven per year, with border removal varying between once and twice a year.

Black Sigatoka was managed by occasional applications of a paraffin mineral oil (Banole®, Total) in a mixture with Sérénade Max (2 kg ha$^{-1}$, *Bacillus subtillis* QST 713, 9.6 treatments year$^{-1}$ on average), sprayed in each of the trial plots with a backpack sprayer (series M3A, CIFARELLI, Voghera, Italy) at a rate of 20 L ha$^{-1}$.

### Assessments and measurements carried out in the BANABIO trial

All the samples and measurements were taken in the central area of the trial plots, i.e., excluding a strip of around 4 m (2 rows of bananas), which was considered as a border potentially affected by the practice in the neighbouring plot. Measurements were taken on 10 banana plants per plot over cycle 1, then on 15 banana plants per plot over the following cycles, i.e., 45 banana plants per system and 135 banana plants in total.

On each flowering, the height and circumference of these banana plants were measured, and the number of fruits per hand was counted. The number of leaves and portions of leaf remaining without necrotized tissues was recorded weekly on each of the monitored banana plants between the flowering date and the harvesting date.

On each flowering, the main nutrients contained in the soil and in banana leaves were analysed in each of the nine plots. The nutrients contained in the leaves were analysed on a composite leaf sample taken from 10 banana plants in the central zone of the trial plots. Soil nutrients were analysed on a composite sample made up of eight samples taken with an auger in the 0-30 cm horizon in a radius of 40 cm around a banana plant.

At harvest time, the number of remaining leaves was counted, and the bunch and peduncle of each banana plant monitored since flowering were weighed on field weighing scales. Two central fingers of the third hand were removed and their diameter, length and weight were measured using a calliper, a tape measure and weighing scales, respectively. Agronomic yield was obtained by multiplying the average fruit weight per bunch in each plot by the number of banana plants harvested and extrapolating to 1 ha (t $ha^{-1}$). Each sampled fruit was treated with an application of Ortiva (azoxystrobin, 250 g $L^{-1}$, Syngenta) in a bath at 2.4 mL $L^{-1}$ of water, as per the usual practice in the profession, and banana green life duration was measured according to the protocol described by Chillet et al. (2008). The damage caused by the banana weevil was estimated by Vilardebo infestation coefficient (1973). The method consists in attributing a score of infestation following a visual examination of the galleries created by the larvae in the cortical zone of the banana corms.

Soil biology was monitored by studying earthworms, which are a good indicator of the biological activity of soil and have proven to be sensitive to the conversion to organic farming (Coulis, 2021; El Jaouhari et al., 2022). The spade test was therefore used, which consisted in excavating a 30×30 cm monolith then carrying out manual sorting of clods. The individuals collected were counted and identified in the laboratory to determine the density (ind $m^2$) and biomass, by image analysis, in the three systems. One sample was taken per cycle at a rate of three measurement replications per plot, i.e., 27 spade tests per date in total. The cycle 1 samples were taken in August 2019, the cycle 2 samples in March 2020 and the cycle 3 samples in September 2020.

The aboveground biomass of weeds was measured on 4 dates in the different systems prior to their destruction (with herbicide in the conventional system and by brush-cutter in the organic system). The average amounts of organic matter returned to the soil were then multiplied by the number of destructions actually carried out in each system to estimate the amount of aerial organic matter returned to the soil from the herbaceous cover in the three systems.

The production costs analysis (from planting to harvesting) focused on labour costs (hours worked × hourly cost) and the cost of inputs (quantities × price). It was carried out using the Excel database, where the technicians entered the operations carried out at the experimental site (date, description of the operation, the plots involved, area, number of hours devoted to the operation, quantity and type of inputs applied and equipment used). The operations were grouped by system, by production cycle and by task (e.g., fertilization, fruit care, etc.). The data concerning the three trial plots in each system were summed to obtain the costs for the entire system. For the operations undertaken over the entire experimental site, with no distinction between systems, the area or number of banana plants was used to attribute the number of hours worked and quantities of inputs applied to the different systems on a pro rata basis. In addition, the working hours needed for bunch harvesting were estimated from the average work output for a banana farm in Martinique. Lastly, input prices mainly came from the trial accounts. When not available, it was those of the Martinique producer group, as for the effective hourly labour cost (average rate plus end-of-year bonus). The cost of installing the irrigation system was estimated for the first cycle, but for subsequent cycles the costs of operation and maintenance were not considered. We assume that these costs are low in the first years of a plantation and that they should not vary between cropping systems.

## RESULTS

On average, over the three cropping cycles, the gross agronomic yield was 42.1 t ha$^{-1}$ for the CO system, as opposed to 35.1 and 21.7 t ha$^{-1}$ for the BI and BD systems, respectively (Figure 2). When comparing the CO and BI systems, which had identical planting densities (1,800 plants ha$^{-1}$), the gross yield of the BI system was 16% lower than that of the CO system. Over the first three production cycles, the most notable differences between the systems were recorded in cycle 2 (Figure 2). In cycle 3, the differences between BI and CO tended to decrease. The first two production cycles were shorter in the CO system (9.1 and 8.1 months) than in the two organic farming systems (9.6 months on average for the first two cycles in BI and BD); these differences in cycle duration were greatest in cycle 2, decreasing in cycle 3, but the CO system currently maintains its advance accumulated in the first two cycles (Figure 2).

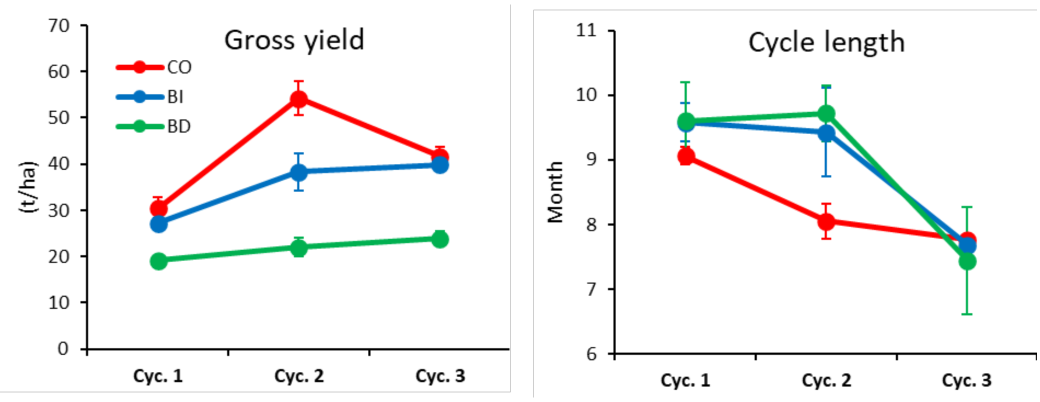

Figure 2. Graph showing average gross yield and average cycle length as a function of production cycle for each system (for both graph, *n*=10 for the first cycle and *n*=15 for cycle 2 and 3, ±SD).

The average number of leaves at harvesting over the first three cycles was 2.1 for the CO system as opposed to 1.4 and 1.1 for the BI and BD systems (Figure 3). The number of leaves at harvesting varied considerably depending on the production cycle, with large differences being observed in cycle 2 with 3.4 at harvesting in the CO system, as opposed to 1.2 and 0.9 in the BI and BD systems, respectively (Figure 3). The banana green life duration data are currently being analysed and the results cannot be presented here, but the preliminary results seem to indicate no difference between the three systems.

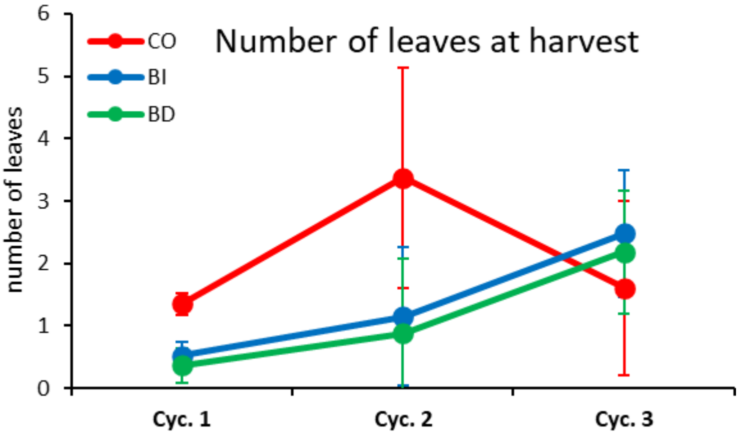

Figure 3. Graph showing average number of leaves at harvest as a function of production cycle for each system (*n*=10 for the first cycle and *n*=15 for cycle 2 and 3, ±SD).

The nutrient analysis data for the soil and banana leaves at flowering did not display any clear tendency. We chose not to present the results here, except for the analysis of carbon in the soil, which tended to increase in the BD system in cycle 3 (1.8%), with the BI and CO systems having similar and stable values (1.6%) over the 3 cycles (Figure 4). The average earthworm biomass in the conventional system was 8 g m$^{-2}$, as opposed to 18 and 19 g m$^{-2}$ for the BI and BD systems, respectively, amounting to a 230% increase, on average, for the two organic farming systems compared to the CO system (Figure 4).

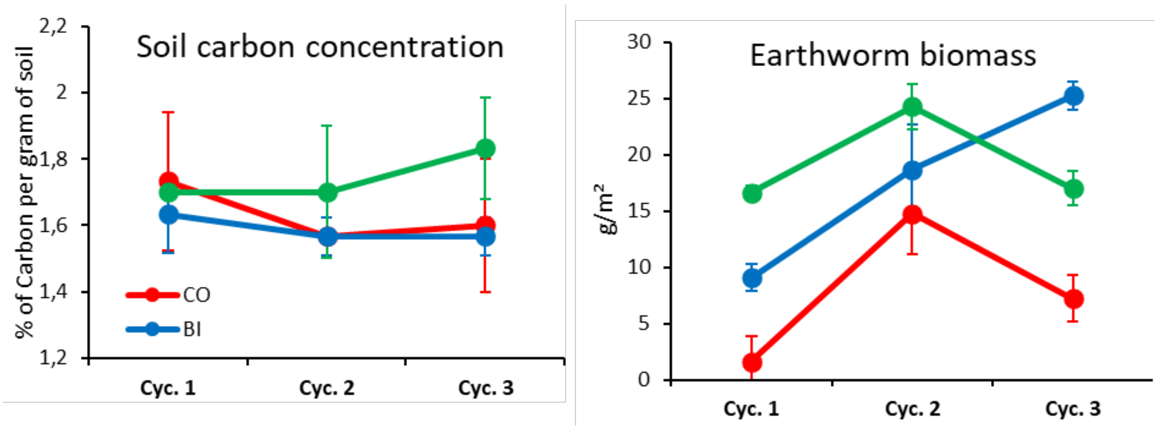

Figure 4. Graph showing average soil carbon concentration (*n*=3, ±SD) and average earthworm biomass as a function of production cycle for each system (*n*=9, ±SD).

The cover crops were gradually replaced by spontaneous weeds and quickly disappeared after fallow. Weed management was therefore conducted more like the management of a spontaneous herbaceous cover than the management of cover crops. The assessments of the organic matter returned to the soil from the herbaceous cover amounted to 4 t ha$^{-1}$ on average for the CO system, as opposed to 9 and 8 t ha$^{-1}$ in the BI and BD systems, respectively, hence around 212% greater in the two organic farming systems than in the CO system (raw data not shown but see synthesis in Figure 5). Weevil damage to the banana corms estimated by the Villardebo index showed average scores over the first three cycles of 15 for the CO system, as opposed to 4 and 6 for the BI and BD systems. Weevil damage was therefore 66% less, on average, in the two organic systems than in the CO system (raw data not shown but see the synthesis in Figure 5).

At the end of the three production cycles, the production costs ha$^{-1}$ for the CO system were 16,470 euros, as opposed to 21,331 and 23,651 euros for the BI and BD systems, respectively. These costs correspond to data gathered at a research station, so their interest lies in a comparison of relative values between the systems rather than in an analysis of absolute values. When the yield data are integrated into these costs, the total cost of producing 1 t of bananas in the conventional system is estimated at 542 euros, as opposed to 744 euros in the BI system and 850 euros in the BD system. For the three systems as a whole, the total was very high for the first cycle due to the costs related to planting and soil preparation (Figure 6). Those costs fell considerably in the second cycle. The two expenditure items that widened the difference between the CO and BI systems were fertilization and weed management, each costing 2.4 times more in the BI system than in the CO system. The item making the BD system more expensive than the BI system was intercrop management, especially in cycle 1 (Figure 6).

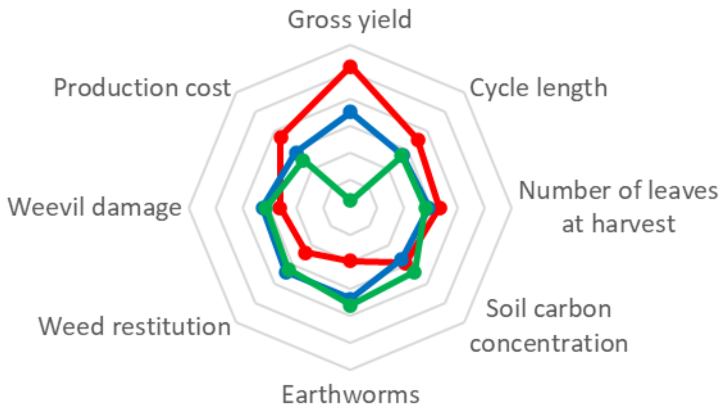

Figure 5. Radar plot of the main quantitative variables assessed in this work. The variables were transformed (centred and reduced) to be represented on a single axis. The sign of several variables was also modified so that high values always correspond to a beneficial effect. In the end, the sign was reversed for the following 3 variables: cycle length, weevil damage and production cost. Therefore, long cycle length, high weevil damage and high production cost are represented by a low value on the graph and vice versa. Because the interest lies mainly in the relative differences between the systems, the scale of the axis is not shown on the graph. The raw data have all been presented and interpreted previously in the text or in a figure, the values averaged over the 3 production cycles are used. The cost of production variable was calculated using cost ha$^{-1}$ data, which was chosen over cost t$^{-1}$ data because the latter already incorporates yield data.

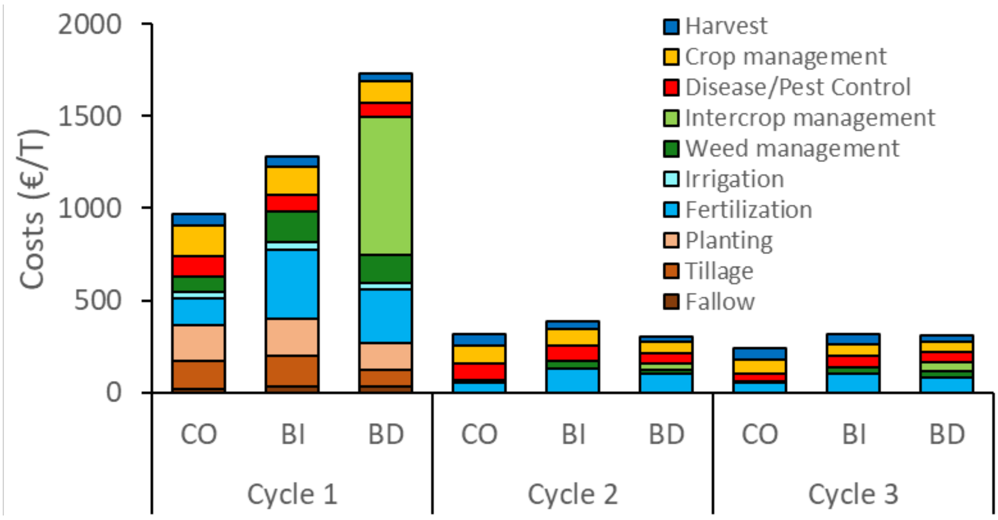

Figure 6. Stacked bar graph showing production cost estimates for the three systems.

## DISCUSSION

One of the main criticisms aimed at organic farming is its lower productivity than conventional farming. The drop in yield attributable to a conversion to organic farming is variable but is generally between 35 and 5% with an average effect of around 20% (Röös et al., 2018). However, that effect largely depends on the type of crop and there are few references concerning a formal comparison of yields between a conventional Cavendish banana crop and an organic one. Our results showed a 16% gross drop in yields under organic farming conditions. These differences may be due either to the effect of fertilization or to an effect of pests (notably black Sigatoka) but for the moment, without further analysis, it is difficult to attribute a precise cause to this yield decrease. However, the differences between the systems were more marked in the first cycles and tended to fade from the 3rd cycle onwards. It is therefore possible that over the entire lifespan of a plot (6 to 8 years in the French West Indies), the difference between the conventional and organic systems could decrease or even be cancelled out. However, even though the gross yield per cycle tends to decrease over the production cycles, the length of the cycle is shorter in the CO system. It is therefore possible that, if that advance were to increase, the CO system would enable an additional harvest compared to the organic system over the total lifespan of a plot. Continued assessment over the coming production cycles of the BANABIO trial will provide answers to this question.

According to the study by Jimenez et al. (2007) on organic Cavendish banana cultivation in Ecuador, yields fell from 42 to 23 t $ha^{-1}$ after conversion to organic farming; these data were obtained on two working farms. That amounts to a drop in yields of 45%, hence much greater than in our trial. Yet the number of leaves at harvesting was larger in that study (between 8.5 and 9.7) than in our study (between 1.1 and 2.1). The context is very different between Martinique and Ecuador, plus these differences might also be due to less fertilization. In the BANABIO trial, the fertilization of the two AB systems was important, the total nitrogen inputs were 514 kg N $ha^{-1}$ in BI against 440 kg N $ha^{-1}$ in CO. This choice was made to compensate for the lower availability of nutrients in organic fertilizers. However, no fertilization data were indicated in the study by Jimenez et al. (2007), which might explain the differences.

Aside from its yield advantages, the conventional system accumulated disadvantages in other respects, as shown by our multidisciplinary analysis (Figure 5). Firstly, biological activity in the soil was lower in the CO system than in the two organic systems. In addition, carbon concentration in the soil was lower in the CO system. This result may have been due to mineral fertilizers and weed management by herbicides, resulting in less organic matter being returned to the soil in the CO system. All this suggests that current conventional practices will probably not enable sustainable maintenance of soil fertility. In addition, it cannot be ruled out that these practices may also have an impact in the medium term by reducing the lifespan of the plot. Evaluations on these experimental plots will continue to address this issue in the future.

Another interesting aspect of our results was the larger number of galleries, hence the damage caused by weevils to the banana corms in the CO system. This result can be interpreted as greater bioregulation in the organic systems (biological control by conservation), which would seem to have led to a reduction in weevil populations. However, this point calls for more in-depth measurements to confirm.

Despite a fairly moderate decrease in yields, and advantages from other points of view, the organic systems entailed very high production costs (euros $t^{-1}$) of around +37% when comparing the BI system with the CO system over the first three cycles. This extra cost was mainly due to weed management and fertilizer purchases. In terms of weed management, new technical solutions, such as using sheep or robots for automatic weed control, could help to reduce costs. For fertilizer purchases, development on a territorial scale of the organic waste recycling sector could improve this situation by reducing the cost of fertilization. A way to mitigate the difficulty of transition to organic production should be to initiate conversion from an established banana field. Since the yield gap is more pronounced during the first cycle of a field it could be good solution to reduce the yield loss in organic.

The preliminary results we obtained seemed to show a similar banana green life duration between the organic and conventional treatments (results not shown). However, in order to be sure that organic banana can be exported without the risk of ripening during shipment by boat, packaging and exporting trials need to be carried out under real conditions. This is one of the priority perspectives of this work. In addition, despite a considerable extra cost linked to organic banana production, we did not go as far as quantifying the increase in income that could be derived by the producer from selling organic bananas. Yet, this aspect is decisive for getting farmers to commit to organic production. Despite these gaps, our results enabled precise costing of the potential yield losses that growers can expect if they convert to organic production in the French West Indies and also made it possible to target the particularly sensitive items of expenditure that "drive" the increase in organic production costs. These results will provide food for thought and guide possible future public aid policies intended to promote conversion of the banana supply chain in the French West Indies to organic farming.

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