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Research Article
Agronomic Performance of Plantain Cultivars (*Musa* spp.) in Efficient Mixing Situation for the Control of Black Sigatoka in Southern Côte d'Ivoire

[1]Tuo Seydou, [1]Amari Ler-N'ogn Dadé Georges Elisée, [1]Chérif Mamadou, [2]Ouédraogo Somgnogdin Léonard, [1]Kassi Fernand, [3]Kouamé Koffi Gaston, [1]Camara Brahima and [1]Koné Daouda

[1]Laboratory of Plant Physiology, Faculty of Biosciences, University Félix Houphouët-Boigny of Cocody-Abidjan, 22 B.P. 582, 22 Abidjan, Côte d'Ivoire
[2]Institute of Environment and Agricultural Research (INERA), 01 B.P. 910, Bobo Dioulasso, Burkina Faso
[3]Department of Biological Sciences, Universtity Peleforo Gon Coulibaly of Korhogo, B.P. 1328, Korhogo, Côte d'Ivoire

Abstract

Background and Objective: Plantain is an important food for many populations in many countries of the humid tropics. However, its production in traditional farming systems by smallholders is threatened by Black Leaf Streak Disease (BLSD) caused by the ascomycete fungus *Mycosphaerella fijiensis* Morelet responsible for significant crop losses. Limitations and disadvantages relating to the methods of chemical and genetic control of this disease suggest the efficient use of tolerant hybrids in reasoned combination between other strategies (such as chemical and biological control) that are available to the producer. This study was conducted in order to compare the agronomic performance of plantain varietal crop combinations for sustainable management of BLSD in the very susceptible cultivar "Orishele" under conditions of natural infestation. **Methodology:** For this purpose, two trials were set up in Azaguie-Ahoua, in Southeastern Côte d'Ivoire, in 2013 and 2014 according to an experimental design of split-plot. Three repetitions each including treatments were assessed. Observations were made mainly on yield parameters in the first cropping cycle. **Results:** Significant differences were observed between the number of functional leaves at flowering and harvest, the bunch weight, the number of fingers of the bunch, the number of fingers, the weight, the length and width of reference fruits of the second and fourth hands. The best values were obtained with "Orishele" in crop combination with seedlings tolerant to BLSD in the different prototypes. However, no difference was observed between cropping cycles (Planting-flowering-harvest). **Conclusion:** These results show that plantain cultivation in combination with sensitive and tolerant varieties in almost equal proportions is a good strategy to slow down the spread of BLSD and ensure a better yield at harvest in cultivars sensitive to this disease.

Key words: Banana, Black Sigatoka, combination, cultivar, *Mycosphaerella fijiensis*, Orishele, plantain, sensitive, tolerant

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Corresponding Author: Tuo Seydou, Laboratory of Plant Physiology, Faculty of Biosciences, University Félix Houphouët-Boigny of Cocody-Abidjan, 22 B.P. 582, 22 Abidjan, Côte d'Ivoire

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Banana (*Musa* spp.) is a plant of great socio-economic and socio-cultural importance, of the *Musa* genus, belonging to the Musaceae family. It is mainly grown for its fruit in humid tropical regions worldwide[1,2]. In those regions, plantain plays a vital role in food security and rural development[3]. Indeed, for 600 million people, banana is the main source of daily energy, while for another 400 million people; banana is an important food supplement[4]. Banana ranks fourth in human food after rice, wheat and corn[5].

Bananas and plantains grown are generally triploid and tetraploid, stemming from interspecific hybridization of two wild species[5] *Musa balbisiana* (BB) and *Musa acuminata* (AA). Sold on local markets, plantain is now-a-days considered as a way of revenue diversification and increase, due to external markets that are developing.

In Côte d'Ivoire, plantain ranks third in terms of food crop yield, with just over 1.6 million tons[6] in 2013. This yield level is still low and does not meet the national and sub regional increasing demand[7]. Indeed, plantain tree is usually produced in crop combination systems either with other food crops or with perennial crops, etc.[8]. Its production in pure culture is rare, as is the case everywhere in Africa[9]. In addition to this, banana like any other crop is facing many diseases and pests including sigatoka, fusarium wilt, bacterial blight, virus diseases, damage caused by weevils and attacks due to nematodes. These constraints significantly threaten the crop by reducing the yield per hectare[10]. Among them, the black and yellow sigatoka, serious foliar diseases caused by *Mycosphaerella fijiensis* Morelet and *Mycosphaerella musicola*, affect all cultivation areas and are considered to be one of the major constraints for banana production[11]. In Côte d'Ivoire, Black Sigatoka (MRN) caused by the ascomycete fungus *Mycosphaerella fijiensis* Morelet appears as the main foliar disease of bananas[12]. It is the most damaging by its virulence and its impact on a wide range of cultivars. It attacks leaves and causes the deterioration of the leaf surface and the decrease of photosynthetic capacities resulting in reduced growth and productivity of plants with early ripening of bananas. Yield losses are estimated between 20 and 50% and may reach 100% as from the second crop cycle[13,14].

The fight against this disease is essential to ensure economic exploitation of banana. It is based on the almost exclusive use of synthetic fungicides, sprayed regularly, at a rate varying with the type of fungicide and conditions of its application. Although efficient, the use of synthetic fungicides is polluting, unsustainable (development of resistance) and inaccessible to smallholders[7]. Thus, the use of resistant varieties (usually hybrids stemming from the genetic improvement of bananas) is considered as the most appropriate and sustainable means of control. However, these hybrids yield fruits whose qualities do not meet the requirements of consumers[7]. Given this situation, it is appropriate to direct research towards other means of control.

The general objective of this study is to compare the agronomic performance of varietal crop combination of plantain trees for controlling Black Sigatoka in the very sensitive cultivar "Orishele" in conditions of natural infestation during the first crop cycle.

MATERIALS AND METHODS

Plant material: The plant material used was made up of sword suckers of banana and plantain from five varieties showing different sensitivities to BLSD. They include: Three local cultivars "Orishele" (AAB), very sensitive; "Corne 1" (AAB), sensitive and "Figue Sucree" (AA) partially resistant and two tetraploid hybrids PITA 3 (AAAB) and FHIA 21 (AAAB) of tolerant cultivars under diffusion to producers[15]. These suckers were selected and collected from the plots of the research station of the National Center for Agronomic Research (CNRA) in Bimbresso, at the experimental site of Azaguie-Abbe. The cultivar "Orishele" was the reference plantain tree cultivar in this study.

Study area: The experiments were conducted in the locality of Azaguie-Ahoua (05°37'N, 04°02'W; 76 m altitude) at about 40 km in the North-East of Abidjan in Côte d'Ivoire. This area of study is an old fallow characterized by a sandy clay soil with a fairly consistent texture[16]. This ferralitic, sandy clay soil is highly desaturated and very gravelly. The climate is tropical humid, characterized by a mixed rainfall with four seasons, including two dry seasons and two rainy seasons: A short dry season (July-August), a long rainy season (March-June), a long dry season (December-February), a short rainy season (September-November).

Average temperatures range between 26 and 29°C, relative humidity is 94% and the rainfall is abundant with an annual average of 1545 mm of water.

Experimental design: The experiment was conducted under natural infestation of banana by *Mycosphaerella fijiensis*. The trial was implemented in 2013 and repeated in 2014. Each trial consisted of pure plots (monovarietal) or controls and plots under varietal combination. These plots were planted with a density of 1,600 suckers ha^{-1}, that is a spacing of 2.5 m over 2.5 m. The experimental design chosen was a split-plot with two factors that are the mixture model also known as prototype (Prototype 1-3) and the variety of banana combined

with cultivar "Orishele" ("Corne 1" "Figue Sucree", FHIA 21 and PITA 3) with three repetitions (3 blocks). The experimental unit was the banana plant. In varietal combination, each block consisted of three prototypes (elementary plots). Each prototype was subdivided into four microplots, each consisting of 24 banana plants stemming from cultivar "Orishele" and one from the 4 other cultivars ("Corne 1", "Figue sucree", PITA 3 and FHIA 21). These microplots were each surrounded by border banana suckers belonging to cultivar "Orishele" so as to favor conditions for stronger pressure of BLSD.

The tested prototypes were different from each other by the succession of banana varieties on the same line and the total number of suckers planted per variety. Thus, these prototypes distinguished themselves by the planting density of cultivar "Orishele" compared to that of the banana variety it was combined with. In each prototype, on a line in the succession of varieties, cultivar "Orishele" was rated "S" while the other cultivars ("Corne 1", "Figue Sucree" PITA 3 and FHIA 21) were represented by "R":

Prototype 1 (P1) showed the succession

1R-1S-1R-1S-1R: In this prototype each microplot had a total of 24 suckers planted including 12 of cultivar "Orishele" and 12 of 1 of the 4 other banana cultivars ("Corne 1", "Figue Sucree" PITA 3 and FHIA 21) that is an average density of 50% "Orishele" rated D50 (800 plants of "Orishele" per hectare).

Prototype 2 (P2) showed the succession

2R-1S-2R-1S-2R: In this prototype each microplot had a total of 24 suckers planted including 6 of cultivar "Orishele" and 18 of 1 of the 4 other banana cultivars ("Corne 1", "Figue Sucree" PITA 3 and FHIA 21) that is a low density of 25% "Orishele" rated D25 (400 plants of "Orishele" per hectare).

Prototype 3 (P3) showed the succession

1R, 2S-1R-2S-1R: In this prototype each microplot had a total of 24 suckers planted including 18 of cultivar "Orishele" and 6 of 1 of the 4 other banana cultivars ("Corne 1", "Figue Sucree" PITA 3 and FHIA 21) that is a high density of 75% "Orishele" rated D75 (1200 plants of "Orishele" per hectare).

The plants were managed in the same way with the standard technical pratices and they did not receive fungicide treatment against BLSD. However, fertilization management was performed using dry, well decomposed chicken manure, taken from farms. It was applied at doses of 2 kg plant^{-1} during sucker planting. Subsequently, five other applications of 2 kg each were carried out monthly from the 4th month after planting, up to a total of 12 kg at flowering.

For the assessment of agronomic and pathological descriptors, for each treatment five plants of cultivar "Orishele" were followed per block (that is 15 plants in total per treatment) during banana trees flowering and harvesting.

Assessment of trial prototypes stages

Phytopathological observations: Phytopathological descriptors were used to assess the seedlings of both trials during the first production cycle in order to select high-performance prototypes. At flowering and harvest, the pathological descriptors of BLSD considered were: The number of functional leaves (NFL) and the relationship between the number of leaves at flowering and harvest stages (NFLH/NFLF).

The leaves were counted from top to bottom for determining the number of functional leaves (NFL) erected. The last fully unrolled leaf (located right after the cigar or bunch formed) bore the number 1. The leaf was considered alive when over one third of its surface was green. Broken or cut leaves at the petiole were not taken into account. The ratio (H/F) between the number of functional leaves at flowering (F) and the number of functional leaves at harvest (H) was calculated. This report helped assess the performance of the tested prototypes.

Agronomic observations: Agronomic descriptors were used as before. The intervals expressed in days (d) between planting and flowering (IPF), between flowering and harvest (IFH) and finally between planting and harvest (IPH) were calculated.

Bunch cutting was carried out when the flower relicts of fruits turned black, fingers were visibly well filled, wrinkle-free and/or first finger turning stage.

At harvest, the assessment of bunches and fruits physical features focused on the following parameters:

- The average bunch weight (BW) of each cultivar was determined by weighing each bunch on precision balance (±1 g) and the yield per hectare was calculated from the average weight of bunches multiplied by the density of plants
- The number of hands (NHB) and fingers (NFB) by bunch were counted
- The mass (MFH), the outer length (ELFH) and grade or class (GFH) of reference fruits (middle fingers) of the second were determined. For these last two parameters, the measurements concerned the distance from the distal end to the proximal end of the outer arc where the pericarp ends and the girth in the middle portion

Statistical analysis of data: The collected data were submitted to analysis of variance (ANOVA) using the Statistica 7.1 software. In case of significantly difference, the multiple comparison tests of Newman-Keuls at the 5% threshold was used to classify the averages in homogeneous groups.

RESULTS

"Orishele" functional leaves at flowering and harvest: For proper filling of fruit, the number of functional leaves on banana between flowering and harvest is very decisive. At flowering, the average number of functional leaves erected on banana of all the treatments performed was higher than 8. Thus, in the control seedlings of the cultivar "Orishele" in pure plots, that number was (9.05) while in varietal crop combination, it was generally between 9.65 and 10.80. Significant differences were observed between the treatments carried out (Table 1). The highest number of leaves was recorded when the cultivar "Orishele" was combined with hybrid FHIA 21 in prototypes 1 (NFLF = 10.80). The overall average for this parameter was around 10.14 living leaves on all banana of the different treatments carried out.

At harvest, differences were also observed between seedlings of the cultivar "Orishele" in pure plots and those of "Orishele" in varietal crop combination. The number of functional leaves was higher (2.75) for "Orishele" seedlings in combination with hybrid FHIA 21 in prototypes 2 and 3. The banana of the cultivar "Orishele" in pure plots had the lowest number of functional leaves (1.00). The number of functional leaves in banana of the cultivar "Orishele" in varietal combination was between 1.35 and 2.75 at harvest (Table 1). The average (2.00) living leaves were recorded at harvest in all treatments.

The ratio NFLH/NFLF reflecting the rate of disappearance of leaves due to black leaf streak disease, expresses the rate of leaves that survived after the production phase. This ratio is less than 0.5 in all banana trees of the different treatments carried out (Table 1). Less than half of the leaves at flowering was present at harvest (NFLH/NFLF<0.50). Banana in pure plots had the lowest values of NFLH/NFLF (0.11). In banana trees under varietal crop combination, the disappearance of leaves was slower compared to controls in pure plots. The ratio NFLH/NFLF ranged from 0.11-0.27. The highest ratio NFLH/NFLF (0.26 and 0.27) was observed in "Orishele" in combination with seedlings of hybrid FHIA 21 in prototypes 2 and 3. The overall average of this ratio was 0.20.

"Orishele" agronomic performance: Banana production cycle in the cultivar "Orishele": The cropping cycles between planting and flowering (IPF) of banana ranged from 294.65-308.25 days (Table 2). The overall average was 300.98 days. No significant differences were observed between treatments for IPF. Banana in pure stand (control) and banana treated (in varietal combination) had IPFs close to each other and flourished at the same time.

Table 1: Functional leaves in the cultivar "Orishele" at flowering and harvest assessed to prototypes

Treatments				
Varietal succession	Plantation density	NFLF	NFLH	NFLH/NFLF
Control	Pure Orishele	9.05±0.22^{d*}	1.00±0.13^{e}	0.11±0.01^{d}
Prototype 1 (1R-1S-1R-1S-1R)	D50 Orishele-D50 Corne 1	9.65±0.20^{c}	1.55±0.14^{cd}	0.16±0.01^{c}
	D50 Orishele-D50 FHIA 21	10.80±0.21^{a}	2.35±0.13^{ab}	0.22±0.01^{b}
	D50 Orishele-D50 PITA 3	10.45±0.20^{b}	2.50±0.22^{ab}	0.24±0.02^{ab}
	D50 Orishele-D50 Figue Sucree	10.15±0.25^{b}	2.25±0.14^{b}	0.22±0.01^{b}
Prototype 2 (2R-1S-2R-1S-2R)	D25 Orishele-D75 Corne 1	9.80±0.21^{bc}	1.35±0.15^{d}	0.14±0.02^{cd}
	D25 Orishele-D75 FHIA 21	10.55±0.21^{b}	2.75±0.12^{a}	0.26±0.01^{a}
	D25 Orishele-D75 PITA 3	10.60±0.23^{ab}	2.10±0.14^{bc}	0.20±0.01^{bc}
	D25 Orishele-D75 Figue Sucree	10.35±0.21^{b}	2.25±0.12^{b}	0.22±0.01^{b}
Prototype 3 (1R-2S-1R-2S-1R)	D75 Orishele-D25 Corne 1	9.85±0.15^{bc}	1.30±0.15^{d}	0.13±0.01^{cd}
	D75 Orishele-D25 FHIA 21	10.15±0.18^{b}	2.75±0.12^{a}	0.27±0.01^{a}
	D75 Orishele-D25 PITA 3	10.10±0.19^{b}	2.10±0.16^{bc}	0.21±0.02^{bc}
	D75 Orishele-D25 Figue Sucree	10.35±0.21^{b}	1.75±0.16^{c}	0.17±0.01^{c}
Overall average		10.14±0.06	2.00±0.05	0.20±0.00
p-value		<0.0001	<0.0001	<0.0001

NB: D25: 25% plantation density, D50: 50% plantation density, D75: 75% plantation density, for each parameter, NLLF: No. of living leaves at flowering, NLLH: No. of living leaves at harvest, NLLH/NLLF: Ratio of No. of living leaves at harvest over No. of living leaves at flowering, *Same column values followed by the same letter are not significantly different at threshold $\alpha = 5\%$ according to the Newman-Keuls test

For the time interval between flowering and harvest (IFH), it ranged from 83.80-92.25 days. The cultivar "Orishele" in pure stand and in varietal crop combination showed no significant difference for the IFH regardless of the treatment (Table 2). The overall average was 88.02 days.

As for the time interval between planting and harvest (IPH), no significant difference was also observed between the treatments. This IPH varied for all the treatments carried out from 378.45-397.90 days for an average of 389.00 days (Table 2). The time interval between sucker planting and banana bunch cut was identical between the control seedlings (pure plots) and those of plots under varietal combination.

Features of bunches and fruits at harvest in the cultivar "Orishele"

Features of bunches of the cultivar "Orishele": The assessment of banana yield at harvest, which is the most important variable for producers showed that the average bunch weight was lower in the control seedlings of the cultivar "Orishele" than in the seedlings of "Orishele" under varietal crop combination. The average Bunch Weight (BW) revealed statistically differences between the treatments (Table 3). For all the treatments, the average bunch weight varied from 6.87 kg for controls to 11.90 kg for seedlings of the cultivar "Orishele" in combination with hybrid PITA 3 in prototype 2. Seedlings of the cultivar "Orishele" in varietal

Table 2: Time intervals between the different phenological stages in the cultivar "Orishele" according to prototypes

Treatments				
Varietal succession	Plantation density	IPF (days)	IFH (days)	IPH (days)
Control	Pure Orishele	301.05±10.18a*	88.20±4.81a	389.25±14.02a
Prototype 1 (1R-1S-1R-1S-1R)	D50 Orishele-D50 Corne 1	301.55±11.36a	87.90±4.34a	389.45±14.18a
	D50 Orishele-D50 FHIA 21	302.75±10.00a	85.65±4.88a	388.40±12.04a
	D50 Orishele-D50 PITA 3	308.25±8.52a	88.80±3.84a	397.05±10.87a
	D50 Orishele-D50 Figue Sucree	297.75±10.66a	84.80±3.18a	382.55±11.81a
Prototype 2 (2R-1S-2R-1S-2R)	D25 Orishele-D75 Corne 1	294.65±11.58a	83.80±1.39a	378.45±11.72a
	D25 Orishele-D75 FHIA 21	300.65±9.45a	87.40±2.91a	388.05±10.41a
	D25 Orishele-D75 PITA 3	290.90±12.34a	92.15±2.29a	383.05±13.62a
	D25 Orishele-D75 Figue Sucree	303.10±8.14a	89.20±2.80a	392.30±9.49a
Prototype 3 (1R-2S-1R-2S-1R)	D75 Orishele-D25 Corne 1	300.75±10.34a	89.75±3.19a	390.50±12.11a
	D75 Orishele-D25 FHIA 21	298.70±11.11a	87.90±2.99a	386.60±12.50a
	D75 Orishele-D25 PITA 3	307.00±10.68a	86.40±2.84a	393.40±12.27a
	D75 Orishele-D25 Figue Sucree	305.65±10.06a	92.25±3.76a	397.90±11.96a
Overall average		300.98±2.83	88.02±0.95	389.00±3.31
p-value		0.998	0.891	0.998

NB: D25: 25% plantation density, D50: 50% plantation density, D75: 75% plantation density, for each parameter, IPF: Interval plantation flowering, IFH: Interval flowering-harvest, IPH: Interval plantation harvest, *Same column values followed by the same letter are not significantly different at threshold $\alpha = 5\%$ according to the Newman-Keuls test

Table 3: Features of banana bunches harvested from the cultivar "Orishele" according to prototypes

Treatments					
Varietal succession	Plantation density	BW (kg)	Yield (t ha^{-1})	NHB	NFB
Control	Pure Orishele	6.87±0.34d*	10.99b	6.05±0.37d	33.45±3.52b
Prototype 1 (1R-1S-1R-1S-1R)	D50 Orishele-D50 Corne 1	8.61±0.40cd	6.89c	6.95±0.18bc	43.30±2.73a
	D50 Orishele-D50 FHIA 21	10.32±0.35b	8.26bc	6.20±0.39c	48.60±1.77a
	D50 Orishele-D50 PITA 3	9.97±0.48bc	7.98bc	6.25±0.29c	40.75±2.82ab
	D50 Orishele-D50 Figue Sucree	10.02±0.27bc	8.02bc	7.65±0.23a	49.30±1.76a
Prototype 2 (2R-1S-2R-1S-2R)	D25 Orishele-D75 Corne 1	8.86±0.22c	5.67cd	7.60±0.20a	49.60±1.60a
	D25 Orishele-D75 FHIA 21	10.33±0.23b	4.13d	7.10±0.10b	39.25±1.94ab
	D25 Orishele-D75 PITA 3	11.90±0.57a	4.76d	7.15±0.27b	42.85±2.96a
	D25 Orishele-D75 Figue Sucree	9.87±0.18bc	3.95e	7.60±0.23a	50.05±2.62a
Prototype 3 (1R-2S-1R-2S-1R)	D75 Orishele-D25 Corne 1	9.27±0.25c	11.12ab	6.75±0.23bc	44.35±2.78a
	D75 Orishele-D25 FHIA 21	9.99±0.32bc	11.99ab	7.40±0.27a	45.80±2.20a
	D75 Orishele-D25 PITA 3	11.40±0.68ab	13.68a	7.25±0.24ab	50.25±2.57a
	D75 Orishele-D25 Figue Sucree	9.15±0.4 4c	10.98b	7.15±0.22b	45.80±2.78a
Overall average		9.73±0.13	8.34	8.34	44.87±0.75
p-value		<0.0001	-	<0.0001	<0.0001

NB: D25: 25% plantation density, D50: 50% plantation density, D75: 75% plantation density, for each parameter, BW: Bunch weight, NHB: No. of hands of the bunch, NFB: No. of fingers of the bunch, *Same column values followed by the same letter are not significantly different at threshold $\alpha = 5\%$ according to the Newman-Keuls test

Table 4: Features of fruits of the 2nd hand of the bunch in the cultivar "Orishele" according to prototypes

Treatments					
Varietal succession	Plantation density	NFH2	MFH2 (g)	ELFH2 (cm)	GRFH2 (cm)
Control	Pure Orishele	7.15±0.65^{c*}	212.00±8.36^{ab}	28.25±0.67^{b}	13.10±0.30^{ab}
Prototype 1 (1R-1S-1R-1S-1R)	D50 Orishele-D50 Corne 1	8.90±0.51^{b}	201.20±4.35^{ab}	27.97±0.46^{b}	13.10±0.38^{ab}
	D50 Orishele-D50 FHIA 21	9.60±0.46^{ab}	240.65±11.55^{a}	29.71±0.38^{a}	12.95±0.24^{ab}
	D50 Orishele-D50 PITA 3	8.25±0.71^{b}	227.10±12.77^{ab}	27.18±0.49^{c}	13.06±0.11^{ab}
	D50 Orishele-D50 Figue Sucree	10.30±0.42^{ab}	231.20±9.00^{ab}	28.20±0.33^{b}	12.35±0.13^{ab}
Prototype 2 (2R-1S-2R-1S-2R)	D25 Orishele-D75 Corne 1	10.50±0.26^{a}	238.60±10.24^{a}	28.11±0.18^{b}	12.70±0.07^{ab}
	D25 Orishele-D75 FHIA 21	8.15±0.23^{bc}	216.35±10.26^{ab}	29.35±0.19^{ab}	12.57±0.10^{ab}
	D25 Orishele-D75 PITA 3	8.45±0.55^{b}	200.70±12.56^{ab}	27.93±0.42^{b}	13.02±0.24^{ab}
	D25 Orishele-D75 Figue Sucree	10.45±0.43^{a}	186.90±12.07^{b}	29.46±0.27^{ab}	12.75±0.13^{ab}
Prototype 3 (1R-2S-1R-2S-1R)	D75 Orishele-D25 Corne 1	9.25±0.49^{ab}	234.20±15.96^{ab}	28.30±0.67^{b}	12.71±0.29^{ab}
	D75 Orishele-D25 FHIA 21	10.05±0.54^{ab}	204.00±7.75^{ab}	27.50±0.52^{bc}	12.05±0.17^{b}
	D75 Orishele-D25 PITA 3	9.60±0.50^{ab}	228.70±14.08^{ab}	29.78±0.44^{a}	12.92±0.33^{ab}
	D75 Orishele-D25 Figue Sucree	8.50±0.48^{b}	210.25±9.57^{ab}	28.20±0.67^{b}	13.36±0.46^{a}
Overall average		9.17±0.15	217.83±3.15	28.45±0.14	12.82±0.07
p-value		<0.0001	0.0075	0.0002	0.0340

NB: D25: 25% plantation density, D50: 50% plantation density, D75: 75% plantation density, for each parameter, MFH2: No. of fingers, MFH2: Mass of reference fruit, ELFH2: External length of reference fruit, GFH2: Grade of reference fruit of hand 4, *Same column values followed by the same letter are not significantly different at threshold $\alpha = 5\%$ according to the Newman-Keuls test

combination with those of hybrid PITA 3 in prototype 2 gave the highest average bunch weight (11.90 kg). The overall average of bunch weight was 9.73 kg. The yields of the cultivars derived from the average bunch weight varied according to the treatment. The highest yield of seedlings was obtained with the seedlings of the cultivar "Orishele" under varietal crop combination, in prototype 3 (Table 3).

As for the number of hands per bunch (NHB), it ranged between 6 and 8 for the different treatments performed. Significant differences between the treatments performed were observed for this parameter (Table 3). The number of hands on the buch was higher with the seedlings of the cultivar "Orishele" combined with those of the cultivar "Figue Sucree" (7.65) in prototype 1, with those of cultivars "Corne 1" and "Figue Sucree" (7.60 respectively) in prototype 2 with those of hybrid FHIA 21 (7.40) in prototype 3. While, in the control seedlings, it was (6.05). The overall average was 7.01 hands per bunch.

The number of fingers (fruits) per bunch (NFB) ranged between 33 and 51 for all treatments. Significant differences were observed between the different treatments (Table 3). The number of fruits per bunch was higher (43.30-50.25) in seedlings of the cultivar "Orishele" under varietal crop combination while it was low (33.45) in seedlings of "Orishele" under pure stand.

Features fruits of the cultivar "Orishele": The features of reference fruits of the 2nd and 4th hand in all treatments showed significant differences. Similarly for the number of fingers (NFH), weight (MFH), the external length (ELF) and grade (GFH). The maximum values were usually recorded in the seedlings of "Orishele" under varietal crop combination. Banana in pure stand (controls) generally presented the lowest values for the parameters assessed (Table 4, 5).

Indeed, the middle fingers of bunches of all banana of the different treatments had masses switching from 174.85-240.65 g at both hands considered with significant differences. For the hands considered, the number of fingers varied from 5-11 from the 2nd to the 4th hand and significant differences were also observed (Table 4, 5).

The outer length and grade showed slight variations from one treatment to the other (Table 4, 5). External lengths varied from 24.87-29.78 cm and the grade from 12.05-13.36 cm, were slightly statistically different.

DISCUSSION

The results of this study on the different phytopathological and agronomic descriptors at flowering and harvest show differences reaction of banana to BLSD especially in the sensitive cultivar "Orishele". The seedlings of the cultivar "Orishele" under cultivation within combined plots had the best response vis-a-vis BLSD. However, the control seedlings of "Orishele" in pure plots (mono-varietal) were more sensitive to this disease.

Table 5: Features of fruits of the 4th hand of the bunch in the cultivar "Orishele" according to prototypes

Treatments					
Varietal succession	Plantation density	NFH4	MFH4 (g)	ELFH4 (cm)	GFH4 (cm)
Control	Pure Orishele	5.90±0.55^{c}*	192.20±11.00^{b}	26.84±0.59^{ab}	12.99±0.21^{a}
Prototype 1 (1R-1S-1R-1S-1R)	D50 Orishele-D50 Corne 1	7.15±0.46^{bc}	189.65±11.19^{b}	28.39±0.46^{a}	12.82±0.20^{ab}
	D50 Orishele-D50 FHIA 21	8.20±0.51^{ab}	194.10±11.03^{b}	28.60±0.28^{a}	13.09±0.19^{a}
	D50 Orishele-D50 PITA 3	6.60±0.51^{bc}	198.40±7.20^{ab}	26.74±0.61^{ab}	12.62±0.10^{ab}
	D50 Orishele-D50 Figue Sucree	7.95±0.47^{b}	221.30±8.15^{ab}	27.72±0.66^{a}	12.41±0.15^{ab}
Prototype 2 (2R-1S-2R-1S-2R)	D25 Orishele-D75 Corne 1	8.50±0.43^{ab}	238.30±9.61^{a}	26.41±0.65^{ab}	12.65±0.09^{ab}
	D25 Orishele-D75 FHIA 21	9.90±0.36^{a}	179.30±12.30^{b}	24.87±1.36^{b}	12.47±0.08^{ab}
	D25 Orishele-D75 PITA 3	7.15±0.64^{bc}	198.70±9.42^{ab}	26.86±0.64^{ab}	12.72±0.23^{ab}
	D25 Orishele-D75 Figue Sucree	8.65±0.45^{ab}	174.85±10.67^{b}	28.26±0.29^{a}	12.52±0.22^{ab}
Prototype 3 (1R-2S-1R-2S-1R)	D75 Orishele-D25 Corne 1	7.45±0.57^{bc}	212.00±15.95^{ab}	28.34±0.66^{a}	12.75±0.29^{ab}
	D75 Orishele-D25 FHIA 21	7.95±0.35^{b}	179.15±5.80^{b}	26.88±0.29^{ab}	12.06±0.14^{b}
	D75 Orishele-D25 PITA 3	8.00±0.43^{b}	221.50±13.03^{ab}	29.26±0.44^{a}	12.83±0.32^{ab}
	D75 Orishele-D25 Figue Sucree	7.00±0.49^{bc}	187.60±6.80^{b}	26.58±0.66^{ab}	13.14±0.18^{a}
Overall average		7.72±014	199.00±3.07	27.36±0.19	12.70±0.06
p-value		<0.0001	0.0002	0.0001	0.0096

NB: D25: 25% plantation density, D50: 50% plantation density, D75: 75% plantation density, for each parameter, MFH4: No. of fingers, MFH4: Mass of reference fruit, ELFH4: External length of reference fruit, GFH4: Grade of reference fruit of hand 4, *Same column values followed by the same letter are not significantly different at threshold $\alpha = 5\%$ according to the Newman-Keuls test

The ratio NFLH over NFLF indicates that the banana of the cultivar "Orishele" in pure stand reached the harvest with less than one functional leaf (R = 0.10). The photosynthetic leaf surface was the smallest during the finger filling process, resulting in insufficient filling. As for the other banana of the cultivar "Orishele" under varietal crop combination with tolerant cultivars, they showed ratio values higher than controls and very close to each other. The low value (0.1) of NFLH/NFLF obtained with banana of the cultivar "Orishele" in pure stand is due to the fact that all functional leaves present on these seedlings showed typical necrosis of the disease, which developed rapidly after flowering. At the time of harvest, banana under varietal combination, having obtained the highest values of NFLH/NFLF performed well face to BLSD even though all their functional leaves at harvest time were bearing typical lesions from that disease. Thus, from flowering to bunch harvest, the number of functional leaves switched from 9.00 to less than one living leaf in the cultivar "Orishele" in pure plots and from around 10 to almost 2 functional leaves in the cultivar "Orishele" in varietal crop combination. This greater number of functional leaves observed in seedlings under varietal crop combination would be attributable to the physical barrier that represented tolerant seedlings to the BLSD[17]. Indeed, according to the studies of Gigot[18], Vidal *et al.*[19] and De Vallavieille-Pope *et al.*[20] on wheat, the low density of sensitive crops on the same plot with tolerant crops, reduces the probability for a spore to be deposited on receptive tissue. For these researchers, the more parasite-sensitive crops are far from each other, the less they are likely to be contaminated. In addition, the presence of tolerant crops forms a barrier between sensitive crops.

However, in general the number of functional leaves on such banana under varietal crop combination, at the time of harvest was less than four as suggested by the study of Lassoudiere[5]. For this author, with the aim of proper fruit development until harvest, need at least 8 functional photosynthesizing leaves at flowering and at least 4 at harvest. For Cohan *et al.*[21] and Sadom *et al.*[22], a high number of functional leaves at flowering is an essential feature to ensure good development of the bunch and quality fruits. Noupadja *et al.*[23] and Boye *et al.*[24] are in complete agreement, while stating that, for obtaining heavier bunches and increased yield, there must be a large number of functional leaves on the seedling from flowering to harvest. The results on phytopathological parameters for which the treatments showed significant variable behaviors are those on the ratio NFLH/NFLF that is to say the number of functional leaves at harvest one the one at flowering. This parameter, which reflects the rate of disappearance of leaves, proves to be a good discriminant of banana tolerance to BLSD during the fingers filling process.

About 335 days of production cycle of the cultivar "Orishele" obtained during our study are in accordance with the 345 days proposed by Kouassi *et al.*[25] and Orellana *et al.*[26], as its production cycle. The analysis of the features of bunches suggests indeed that bunch weight, which highest level is obtained by varietal crop combination of banana is a good yield discriminant. For all the agronomic parameters, generally very similar reaction were observed between the control banana in pure stand and those under varietal crop combination, in particular for the production cycle (planting-flowering-harvest). However, in varietal crop

combination, the incidence of BLSD on the cultivar "Orishele" was low as the best bunch weights were recorded in prototypes. The improvement in average bunch weight harvested from the "Orishele" crops in varietal crop combination could not be explained only by the protection conferred by the associated tolerant crops. It could also due, in part, to the appropriate fertilization of manure applied and having ensured good seedling vigor as well as shorter cropping cycle. The same observations were also made on the features of bunches and in particular the reference fruits of the 2nd and 4th hands. The most profitable varietal crop combination for the cultivar "Orishele" is the one with hybrid PITA 3 partially resistant to Black Sigatoka. The best performance for bunch weight, were observed when the cultivar "Orishele" is under varietal crop combination in prototypes 2 and 3 where it is respectively in low density, that is 25% and in high density that is 75% compared to prototype 1 (medium density). Indeed, the bunch weight of the cultivar "Orishele" in pure plots has almost doubled in prototypes 2 and 3 in combination with hybrid PITA 3. The features of bunches and in particular on reference fruits of the second and fourth hands showed that most of the bunch weight was concentrated on the first four hands which is confirmed by the observation of their length and their size. According to N'Guetta *et al*.[27] and Tomekpe *et al*.[28] the concentration of most of the weight on the 1st hands is a feature of plantain. Furthermore, the seedlings of the cultivar "Orishele" in varietal combination with other cultivars have kept more functional leaves at flowering than in pure plots, which could be one explanation of their higher yield.

The results of this study showed the excellent agronomic performance of the different prototypes in the varietal crop combination of the cultivar "Orishele" sensitive to BLSD and tolerant varieties. Based on the agronomic features recorded according to implanted prototypes, prototype 3 having the strong planting density of the cultivar "Orishele" is likely to be distributed to producers of plantain. Indeed, this prototype 3 proves more profitable for yield at harvest although prototype 2 provides greater reduction in the incidence of the disease.

CONCLUSION

The results obtained at the end of the first cycle of both trials indicate that the combination of cultivars sensitive to varieties of banana more tolerant to BLSD has influenced pest pressure on the cropping plot. This effect was clearly felt on some phytopathological descriptors (number of functional leaves at flowering and harvest) as well as on certain agronomic parameters (bunch weight) especially in the sensitive cultivar "Orishele". The bananas of the cultivar "Orishele" within the prototypes 1, 2 and 3 have a better response to BLSD than banana in pure plots. However, for yield features, the best performances are observed in prototype 2 at low cropping density of the cultivar "Orishele" with more tolerant hybrids FHIA 21 and PITA 3. However, the choice of the most profitable prototype for varietal crop combination of banana can fall on prototype 3, which includes the highest density of the cultivar "Orishele" under varietal crop combination. This cultivar highly sensitive to BLSD shows fruits having organoleptic features very appreciated locally by consumers. This cultivar can be grown in combination with hybrids (FHIA 21 and PITA 3) more tolerant to BLSD and under popularization to producers in Côte d'Ivoire.

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