Journal of Agriculture and Crops
ISSN(e): 2412-6381, ISSN(p): 2413-886X
Vol. 9, Issue. 4, pp: 427-440, 2023
URL: https://arpgweb.com/journal/journal/14
DOI: https://doi.org/10.32861/jac.94.427.440

Academic Research Publishing Group

Original Research | Open Access

Productivity Performance of *Musa* AAA Under Diferents Planting Densities and Two Cultivars (Grand Nain and Williams) in Banana Intensive Agrosystems in the Agneby-Tiassa Region, Côte D'ivoire

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Article History
Received: 10 May, 2023
Revised: 23 July, 2023
Accepted: 26 July, 2023
Published: 29 July, 2023

Abstract

The study was conducted on Agro-industrial farm of Brimbo, property of S.C.B, located in the Agneby-Tiassa region. The study aimed to contribute to the sustainable production of dessert bananas in Côte d'Ivoire through the development of new technical itineraries. The Grand Nain and Williams cultivars were planted in a block design with total randomisation, comprising eight treatments. During plant growth, the effect of density and cultivar on phytopathological parameters of Black Leaf Streak Disease and on growth and production parameters of the banana plant were evaluated. The results showed that planting density influenced the rank of YLS in both cultivars with the highest mean values at 1550 ; 1600 ; 1650 and 1700 plants/ha, with 7.0 ; 7.1 ; 7.0 ; 7.2 for Grand Nain and 7.2 ; 7.0 ; 7.1 ; 7.1 for Williams respectively. The height of the banana plants ranged from 216.9 to 227.1 cm in Grand Nain and from 228.6 to 237.0 cm in Williams. A significant difference was observed for the pseudotruncular circumference with values between 67.5 and 71.5 cm in the cultivar Grand Nain and between 70.6 and 75.5 cm in the cultivar Williams. NLF was significantly influenced by density and cultivar. The best bunch weights were obtained at 1900 plants/ha for Grand Nain and 22.6 kg for Williams at 1550 plants/ha. This study showed that the removal of immature lesion-bearing areas combined with planting density had varying effects on Black Leaf Streak Disease status, growth and productivity of banana plants of the Grand Nain and Williams cultivars.

Keywords: Production performance; Banana plants; Densities; Grand nain and Williams; Côte d'Ivoire.

How to Cite: N'GUESSAN Patrick Henri, KOUAME Konan Didier, YAO Kouadio Jacques Edouard, KASSI Koffi Fernand Jean-Martial, KANGA N'guessan Martial, KOUAME Koffi Gaston, KONE Daouda, 2023. "Productivity Performance of Musa AAA Under Diferents Planting Densities and Two Cultivars (Grand Nain and Williams) in Banana Intensive Agrosystems in the Agneby-Tiassa Region, Côte D'ivoire." *Journal of Agriculture and Crops*, vol. 9, pp. 427-440.

1. Introduction

Banana (*Musa spp.*) is a widely consumed crop in Central and West Africa [1]. It is an essential contributor to food security, employment creation, income diversification in rural and urban areas, gross domestic product (GDP) and, in so doing, to poverty alleviation [2]. Despite the importance of this crop, it is threatened by numerous abiotic and biotic constraints at both the smallholder and industrial plantation levels. In all production areas of the world, Black Leaf Streak Disease (BLSD) or Black Sigatoka caused by the fungus *Mycosphaerella fijiensis* is the most important parasitic constraint in banana farming [3, 4]. Black Sigatoka is one of the major threats to dessert banana production. The pathogen attacks the leaves of banana plants by deteriorating the leaf surface, thus reducing the photosynthetic capacity of the leaves, which affects the growth and development of the plants [5, 6]. The disease causes a more or less generalized drying of the leaf system. It directly affects photosynthetic activity, growth and development of the plants. It can cause yield losses ranging from 30 to 80% and even 100% in the second cycle if no phytosanitary treatment is applied [7]. These yield losses could have significant economic consequences if preventive measures are not adopted by farmers. In Côte d'Ivoire, black Sigatoka was reported in 1985 in the Sud-Comoé region [5, 8]. Several studies are being conducted for sustainable production of banana productivity by controlling black Sigatoka [9-11]. These studies have focused on fungicide treatments based on natural substances. However, the disease continues to spread in the plantation. In view of this situation, it's necessary to propose other control methods in order to reduce the impact of black sigatoka in areas of high dessert banana production. The present study aims to contribute to the sustainable production of banana dessert in Côte d'Ivoire by developing new technical itineraries. Specifically, the effects of eight planting densities and two cultivars will be evaluated:

- on the control of black sigatoka,
- on the evolution of banana growth parameters,
- and on the evolution of banana production parameters.

2. Materials and Methods

2.1. Materials

2.1.1. Plant Material

The studies were carried out on two main cultivars, Grand Nain and Williams. Grand Nain is a short banana tree (2.00 m to 2.50 m), with a large, cylindrical, slightly curved, upward-pointing fruit cluster of up to 240 fruits. The main stem (pseudo stem) has dark brown, red or black spots. Williams is a medium-sized banana tree (2.40-3.70m) with a large, cylindrical-shaped diet of up to 300 fruits of the same size (about 20cm), slightly curved and pointing upwards.

2.2 Methods

2.2.1. Study Area

The study was conducted in the department of Tiassalé located 135 km northwest of the city of Abidjan and geographically located at 4°49'41" W longitude and 5°53'53" N latitude (Figure 1). It is part of the Agneby-Tiassa region. The agro-industrial farm, which hosted the trials, is located at latitude 4°51'29.6" West and longitude 6°00'16.7" North. It's a banana dessert production area of the S.C.B Company. The rainfall regime at this site is bimodal with 4 seasons. The major rainy seasons start from March to June and a minor rainy season occurs from September to November; the dry season consists of a major (December to February) and a minor (July to August) dry season. Annual rainfall in this area varies between 1250 and 1620 mm. The average annual temperatures are around 28°C. The soils are hydromorphic with a sandy clay loam and clay loam texture. They have an average gravelly surface horizon and induration at shallow depth due to the presence of lateritic armour [12].

2.2.2. Experimental Design and Treatments

The banana plants were planted in a block design with total randomisation, including two non-repeating factors, planting density and banana cultivar (Figure 2). Eight densities were evaluated and constituted the eight treatments for each of the two selected cultivars (Grand Nain: and Williams). The planting densities, D1: 1900 plants/ha (2.13 x 2.47 m), D2: 1850 (2.16 x 2.5 m), D3: 1800 (2.19 x 2.54 m), D4: 1750 (2.22 x 2.57 m), D5: 1700 (2.26 x 2.61 m), D6: 1650 (2.29 x 2.65 m), D7: 1600 (2.33 x 2.68 m), and D8: 1550 plants/ha (2.36 x 2.73 m) were selected (Table 1). In total, 16 elementary plots of 645 m2 (12.9 x 50 m) were used. The number of plants varied according to the spacing between the banana trees in each experimental plot. Data collection was carried out on 20 banana plants per treatment for the production observations and 10 banana plants per treatment for the BLSD phytopathological observations. Planting took place on banana fallow aged of 6-month. Vitroplants, whose characteristics and selection criteria were based on the dark green colour of the leaves with anthocyanin spots in places, were selected. After the weaning and nursery phase, these in vitro plants had to have at least 5 leaves and a distance of 25 to 30 cm between the bulb and the intersection of the last two leaves was respected. Holes were drilled with spades with a size of 20 x 20 x 24 cm regardless of the density.

2.2.3. Plantation Layout

The staggered planting method was used (Figure 2). The in vitro plants were planted on 5 November 2013. Before planting, soil preparation work (ploughing, subsoiling, amendment with crushed limestone, creation of beds and soil bulging), and installation of the irrigation network, drainage and guy wires were carried out. An application of systemic herbicide (Glyphosate) at 3 l/ha was applied to the different plots one week before planting. After planting, a network of cableways was installed. The plots were regularly weeded and herbicide treatments with Glufosinate-ammonium at 2 l/ha were carried out 4; 8; 12; 16 weeks after planting in order to control weeds and promote good growth of the banana plants. At planting, each plant received 150 g of dolomite divided into 3 applications at a rate of 50 g per application. Calculations of fertiliser quantities were made after soil analyses. Thus, a monthly contribution of complete NPK (25.3 - 4.3 - 23.5) at the rate of 95 g/plant was made. Also 115 g/plant of urea and 129 g/plant of potassium sulphate were applied homogeneously on the plots during the vegetative development of the banana plants. 15,000 g of organic matter in the form of cocoa parchment was applied to each plant in the 8th week after planting.

2.2.4. Determination of the Effect of Density and Cultivar on the Phytopathological Parameters of Black Leaf Streak Disease

Control of Black Leaf Streak Disease (BLSD) was started in 3rd week, by weekly removal of infested leaves at stages 4; 5; 6. Aerial applications of fungicides against BLSD were made from the 8th week after planting. They were applied homogeneously and under the same conditions on the plots during the production cycles. The control strategy was mainly composed of contact fungicides, mancozeb applied at 8 to 10 day intervals. When the infestation level increased, spot interventions were made with difenoconazole combined with Fenpropimorph in a mineral oil mixture. In each elementary plot, 10 central banana plants were identified and observed weekly. The Youngest Leaf Spotted (YLS) and Youngest Leaf Necrosed (YLN) were observed. YLN shows the development of the disease, i.e. the appearance of the early stages of BLSD. During the observation, the youngest symptomatic leaf of the 3 observed leaves counting from the top outside the candle was noted. If none of the 3 leaves observed are symptomatic, the next leaf is observed until symptoms are obtained, then the YLS is equal to the rank of the symptomatic leaf. When there are no symptoms on the observed leaves of the banana tree, in this case the YLS is estimated equal to the number of functional leaves of the banana plant plus one. The YLN is the rank of the youngest leaf with visible necrosis counting from the top outside the cigar. When there is no necrosis on any leaf of the observed banana plant, in this case the YLN is estimated to be equal to the number of functional leaves of the banana plant plus one leaf.

2.2.5. Determination of the Effect of Density and Cultivar on Banana Growth Parameters

The growth parameters evaluated were the height of the banana plant (from the collar to the V formed by the last two leaves) and the circumference of the pseudo-trunk at 1 m from the ground. On 20 banana plants identified since planting, measurements were taken every week until flowering using a tape measure. The number of living leaves at flowering (NFF) and the number of leaves at harvest (NFR) were counted.

2.2.6. Determination of the Effect of Density and Cultivar on Production Parameters

The main objective for the "export banana" is to preserve the quality of the fruit throughout the production process until it is sold on the markets. The harvested bunch must meet standard criteria for weight and grade. Grade is the measurement, expressed in millimetres, of the diameter of a cross-section of the fruit. In this study, the production data analysed were grade (GR), number of hands (NM), and average weight of the bunch at harvest (PR). For grade control, once a week (every Tuesday), 20 bunches bearing the colour of the strap to be graded, in relation to the flower count, were identified in each experimental plot. After identifying the second hand of the bunch, the sizer was placed horizontally on one of the three middle fingers and the grade was noted. A grading strap was then attached to the stem above the second sap puller indicating that this bunch was graded. The harvesting team (consisting of a cutter and two porters) then cut the stem with a machete, ensuring that the porter was in the correct position to receive the bunches. The harvested bunches were weighed as they left the plot using an electronic scale and the weight was recorded.

2.3. Analysis of the Data

Two types of statistical analysis were used in this study. These were analysis of variance (ANOVA) and principal component analysis (PCA). The statistical analyses of the data were carried out with STATISTICA 7.1 software. The one-way ANOVA was used to evaluate the effect of the two mechanical control methods for NTM. The analysis of variance with two classification criteria was used to study the combined effects of planting density and banana cultivars. The Newman Keuls test in case of significant difference was used to compare the mean values of the parameters evaluated at the 5% risk in order to classify the treatments. Principal component analysis (PCA) was used to characterise the planting densities and banana cultivars with the best agrophysiological performance.

3. Results

3.1. Effect of Density and Cultivar on YLS during the 1st Production Cycle

The effects of density on the rank of the youngest leaf affected by the disease during the first production cycle were variable (Figure 4A and B). Planting density influenced the rank of YLS in both cultivars. Variations were observed throughout the first production cycle. The highest mean values of YLS rank were obtained at densities of 1550; 1600; 1650 and 1700 plants/ha, with 7.0; 7.1; 7.0; 7.2 for the cultivar Grand Nain and 7.2; 7.0; 7.1; 7.1 for the cultivar Williams, respectively (Figure 4A and B). The differences noted were highly significant (P = 0.00010) at the 5% threshold for the effect of planting density. However, for the effect of cultivar, these differences were not significant (P = 0.9108) at the 5% level (Table 2).

3.2. Effect of Density and Cultivar on YLS in the 2nd Production Cycle

The highest average YLS was recorded in the plots with densities of 1700, 1650, 1600 and 1550 plants/ha, regardless of cultivar (Figure 5A and B). For these four densities, the YLS rank values varied on average from 4.5 to 8.5. With the densities of 1900, 1850, 1800 and 1750 plant/ha, the values ranged from 4 to 7 (Figure 5A and B).

These evaluations showed variations in the YLS parameter in relation to planting density, with highly significant differences (P = 0.000001) at the 5% threshold. There was no effect of cultivar on YLS rank (P = 0.703827) at the 5% threshold (Table 2).

3.3. Effect of Density and Cultivar on YLN during the First Production Cycle

The YLN rank varied between 9 and 14 in the cultivar Grande Nain and between 8 and 13 in the cultivar Williams (Figure 6A and B). The YLN values showed low black sigatoka inoculum pressure on the plots for the different treatments. The observed differences in density were not statistically significant (P=0.448201) at the 5% level. Also the type of cultivar did not have a significant influence (P=0.287743) on the YLN (Table 2).

3.4. Effect of Density and Cultivar on YLN during the 2^{nd} Production Cycle

A general observation was that the responses of the plants to the YLN rank were similar regardless of planting density and cultivar (Figures 7). YLN values ranged from 10 to 14 in both dessert banana cultivars (Figures 7A and B). The effects of cultivar and density did not significantly influence YLN (P= 0.36) at the 5% threshold (Table 2).

3.5. Effect of Planting Density and Cultivar on Pseudotruncular Height and Girth at Flowering during the First Production Cycle

The height of banana plants at flowering varied from 216.9 to 227.1 cm in the cultivar Grand Nain. The variation in height recorded in the Williams cultivar was between 228.6 and 237.0 cm. During the first production cycle, the height of the banana plants was not influenced by planting density and cultivar. The differences observed were not significant (P = 0.088316) at the 5% threshold (Table 3). On the other hand, for the pseudotruncular circumference, for both banana cultivars and the eight densities, a significant difference was observed (P=0.012787). The values for this parameter ranged from 67.5 to 71.5 cm in the Grand Nain cultivar and from 70.6 to 75.5 cm in the Williams cultivar. The highest average circumference values were observed at densities of 1900 and 1800 plants/ha (Table 3). As for height, in both banana cultivars there was a significant difference between the banana plants in terms of girth. For this parameter the values ranged from 58.2 to 62.0 cm for the cultivar Grand Nain and from 60.0 to 63.7 cm for the cultivar Williams. The highest averages of pseudotruncular circumference were observed with densities of 1900 plants/ha.

3.6. Effect of Planting Density and Cultivar on the Number of Leaves at Flowering and the Number of Leaves at Harvest during the 1st Production Cycle

During the first production cycle, the number of leaves erected at flowering (NFF) on banana plants ranged from 10.4 to 11.9 in Grand Nain and from 10.3 to 12.4 in Williams. NFF was significantly influenced by density and cultivar (Table 3). The highest NFF values were obtained with the cultivar Williams at the density of 1600 plants/ha. At harvest, the number of leaves (NFR) varied very little. The banana plants had a number of living leaves that varied between 5.6 and 6.5. There were no significant differences between treatments (P = 0.959696) at the 5% threshold. However, the highest NFR values were noted in the Grand Nain at the density of 1550 plants/ha.

3.7. Effect of Planting Density and Cultivar on Pseudotruncular Height and Girth at Flowering in the 2nd Production Cycle

Banana plants at flowering varied in height from 241.6 to 274.8 cm in the cultivar Grand Nain with a predominance for the density of 1550 plants/ha (Table 3). In the cultivar Williams, the measured plants had heights between 270.2 and 291.4 cm. During the second cultivation cycle, it was found that cultivar and density had a significant effect (P = 0.000765) on pseudotruncular height. With regard to pseudotruncular circumference, the values recorded in Grand Naine ranged from 53.4 to 60.6 cm. The largest circumference was observed at a density of 1550 plants/ha (60.6 cm). In the Williams cultivar the variation was from 52.8 to 60.2 cm with the largest value obtained at the density 1650 plants/ha (Table 3). Significant differences (P = 0.000187) were observed in pseudotruncular circumference.

3.8. Effect of Planting Density and Cultivar on Number of Leaves at Flowering and Number of Leaves at Harvest during the Second Production Cycle

During the second production cycle, banana plants had an average of 13.3 live leaves at flowering in Grand Nain (Table 3). The average NFF value in Williams was 12.4. As in the first growing cycle, significant differences (P = 0.002729) were observed at cultivar and density level. For the NFR, the values recorded for the cultivar Grand Nain changed from 7.3 to 9.0 leaves. In the williams cultivar, a variation from 6.8 to 8.3 leaves was observed. The variations between the different densities within the same cultivar were not statistically significant (P = 0.280110) at the 5% level. However, a significant difference (P = 0.000514) in NFR was observed between cultivars (Table 3).

3.9. Impact of Planting Density and Cultivar on Banana Production Parameters

3.9.1. Effect of Planting density and Cultivar on Number of Hands (NM), Grade (GR), Bunch Weight (PR) During the First Production Cycle

The mean value of the number of hands (NM) was 7.30 for the cultivar Grand Nain (Table 4). The highest value was recorded with 1900 plants/ha. In the cultivar Williams, the average observed was 7.02 hands per diet, and the highest value was observed with the density of 1900 plants/ha. The NM was not influenced by density within the same cultivar. However, a significant difference (P=0.013622) was observed between cultivars indicating a better average number of hands obtained in Grand Nain. The 2nd hand sizing data showed that the best grade averages were obtained at 1600 plants/ha in the Grand Nain cultivar (36.4 mm) and at 1650 plants/ha in the Williams (37.0 mm). There was a significant difference between the densities and also the density-cultivar interaction was highly significant (P = 0.000001) at the 5% threshold. At harvest, the best mean bunches weights were expressed at the density of 1900 plants/ha in the cultivar Grand Nain. The value recorded was 22.6 kg and for the cultivar Williams, the density of 1550 plants/ha gave the best average bunches weight (23.09 kg). A significant difference (P = 0.011728) at the 5% level was observed indicating that planting density and banana cultivar influenced the average bunch weight parameter.

3.9.2. Effect of Planting Density and Cultivar on Number of Hands (NM), Grade (GR), Diet Weight (DW) in the Second Production Cycle

During the second crop cycle, the number of hands (NM) varied and was influenced (P=0.0) by the treatments (Table 4). In Grand Nain, values ranged from 7.37 to 8.0 hands per diet, while in Williams, this variation ranged from 7.40 to 8.0 hands per diet. The highest Nm values were found at a density of 1550 plants/ha in Williams. In the case of the Grand Nain, the highest values of the number of hands per bunch were also observed at the low densities (1500, 1650 and 1700 plants/ha). In terms of 2nd hand size, the grade values ranged from 36.0 to 37.0 mm in Grand Nain. The highest grade averages were noted at the density of 1550 plants/ha. For the cultivar Williams, the graded banana fingers gave values between 34.7 and 37.0 mm. The density of 1650 plants/ha gave the maximum grade values. The observed variations were significantly influenced (P = 0.025006) at the 5% threshold by the interaction of density and cultivar. The average weight of the bunches at harvest varied from 24.7 to 29.6 kg in the Grand Nain cultivar, while in the Williams cultivar the average weight of the bunches varied from 25.2 to 30.6 kg. The best bunch weights were observed in plots with densities of 1700 plants/ha for the Grand Nain and 1750 plants/ha for the Williams cultivar. The effect of density on bunch weight was significant (P = 0.003261) at the 5% level.

3.10. Selection of Successful Densities and Cultivars

Principal component analysis (PCA) was used to screen densities and cultivars on the basis of phytopathological, growth and production parameters. During the first production cycle, axes 1 and 2 were sufficient to characterise the parameters assessed. These axes contributed 63.11% of the observed variation. The parameters diet weight, finger grade, number of leaves at flowering, number of leaves at harvest, youngest leaf reached, and pseudotruncular circumference were negatively correlated to axis 1 (Figure 9A). This axis allowed the pair (cultivar, density) to be divided into three groups (Figure 9B). The (α) group is constituted by GN-1550; GN-1600; W-1550; W-1650; W-1600 characterised by better agronomic performance and productivity. Then follows the group (β) formed by average performances: GN-1650; GN-1700; GN-1750; GN-1800; GN-1900; W-1700; W-1750; W-1800. Finally the group (ɣ) constituted by low performances in which, we meet the GN-1850; W-1850; W-1900. In the second cycle, the evaluated parameters were positively correlated with axis 1, which allowed us to divide the treatments into 3 groups (α, β, γ) in relation to agronomic performance (Figure 10A and B). This time, the α group is composed of low performances, these are: GN-1900; W-1750; W-1800; W-1850; W-1900. Next comes the β-group with medium performance with GN-1600; GN-1650; GN-1700; GN-1750; GN-1800; GN-1850; W-1550. W-1600; W-1650; W-1700. The group (γ) was constituted by the best performances in which the GN-1550 is found.

4. Discussion

4.1. Effect of Density and Cultivar on Phytopathological Parameters of NDR

The recorded results showed that there was an effect of planting density on the severity of black streak disease regardless of cultivar. The youngest leaf Spotted (YLS) was significantly elevated at low densities during the 1st and 2nd cycle. Indeed, in the densities of 1550; 1600; 1650 plants/ha, the first symptoms were observed on leaves with rows higher than 7 in contrast to the other densities where the rows of affected leaves varied between 5 and 6. This would imply that the development of the disease is less intense with plantations having a reduced number of banana trees per hectare. The reduction in the severity of the black stripe disease could be attributed to the overall environmental changes within the plantations, mainly relative humidity and temperature. Indeed, when there is a high plantation density, the leaf biomass becomes also important and leads to an increase in relative humidity. The amount of residual water present on the leaves also becomes important, which favours the germination of the fungus propagules. Similar results were obtained in Cuba by Pérez [13] with plantains where disease development was more severe using 2000 banana trees/ha compared to 1850 banana trees/ha of plantation. Also, in Côte d'Ivoire, the work of Kobénan, *et al.* [14]. On 3 planting densities of the Orishélé cultivar (1667; 2500 and 3333 plants/ha) showed that the incidence of black sigatoka increased with planting density. Another explanation could be that at low densities (when there are fewer banana plants), sanitary leaf removal becomes less restrictive and the worker takes the time to remove all infested leaves, his yield is less affected. With regard to YLN, there is no variation between planting densities and dessert banana cultivars in the Tiassalé production area. Mechanical management by removal of necrotic leaves or leaves showing stages 4 and 5 of black stripe disease was well practised by a weekly pass on the same plot. These results corroborate those of N'guessan, *et al.* [15] on the removal of areas with immature lesions from infested leaves, which should take into account not only the necrosis to be removed, but also stages 4 and 5 of MRN in order to ensure rows of younger necrotic leaves between 10 and 12.

4.2. Effect of Density and Cultivar on Banana Growth Parameters

The height of the banana plants at flowering was not influenced by the planting densities during the first crop cycle in both cultivars. An average of 221 and 234 cm was recorded in the Grand Nain and Williams cultivars respectively. The homogeneity of height observed in the first production cycle is disturbed in the second cycle, with significant differences between densities. From one production cycle to the next, an increase in height (of more than 40 cm) was observed. Variation in height was also observed by Oliveira, *et al.* [16] on the cultivar Grand Nain. They explained this variation by the climatic and edaphic factors of the growing area, and our results seem to confirm theirs. Lichtemberg, *et al.* [17], in Brazil used planting densities of 1667, 2000 and 2500 plants/ha of plantain and found that the average plant height at flowering was higher with increasing planting density. This was in the context of intraspecific competition for light use. However, this was not observed in this work, and could be due to the fertility of the soil favouring the growth of banana plants. Indeed, the supply of fertilising elements and especially organic matter (in the form of cocoa parchment) to each banana plant increased the organic matter content of the soil, favouring the development and maintenance of the root systems [18]. Pseudotruncular girth varied significantly with planting density and cultivar over the two production cycles. This could be explained by the fact that the soils in the Tiassalé area have a sandy-silt and clayey-silt texture, and induration at shallow depths which contributes to the formation of hydromorphy and a high level of coarse elements. This limits the sustainable exploitation of a plantation, and yield decreases are generally observed after the harvest of the 2nd cycle fruits [12]. The number of leaves at flowering (NFF), was influenced by density in both cycles. The results obtained in our work were superior to those of Oliveira, *et al.* [19], who conducted a similar study on the effect of planting density on the development of yellow cercosporiose (*Mycosphaerella musicola*) in the cultivar Grand Nain and in the cultivar William. In Grand Nain, 11.5 leaves were obtained in the first cycle and 10.6 live leaves at flowering in the second crop cycle. The number of leaves at harvest (NFR) was not influenced by planting densities in the first production cycle in Tiassalé for both cultivars. Clearly, the average NFR (6-8 leaves) shows that the remaining leaf biomass is important, indicating that alternating applications of different fungicide chemical groups and removal of infested leaves from the early stages was effective in controlling the disease. In a study conducted on Grande Nain, Brazil, where yellow cercosporiose was prevalent, the amount of leaves at harvest obtained was 2.8 leaves in the 1st production cycle and 4.3 active leaves in the 2nd production cycle [19].

4.3. Impact of Density and Cultivar on Banana Production Parameters

The number of hands (NM) in the 1st production cycle was not influenced by the different planting densities, but this parameter was influenced by the type of cultivar, characterised by a superiority of the number of hands (7.30) for the cultivar Grand Nain. In the second production cycle, heterogeneity was observed between planting densities and the type of banana cultivar, but still with a superiority of the Grande Nain cultivar, which had an average of 7.84 hands per bunch, compared to 7.76 for the William cultivar. The average number of hands increased from the 1st to the 2nd production cycle. Our results were identical to those of Muñoz [20], who found that the hand counts were not significantly different. These authors worked with 1100, 1458, 1750, 2916 and 3300 plantain plants per hectare, monitored during two production cycles. Regarding the grade of the 2nd hand, in Tiassalé over the two growing cycles, the average grade was not influenced by the planting densities of the Grande Nain. On the other hand, for the cultivar William, planting densities had an impact on the grade in both production cycles. From an agronomic point of view, it can be seen that, as for the number of hands, the best grade averages for the second hand are observed in the Grande Nain cultivar. The sizing of the fingers of the second hand showed that the grade increased from the first to the second production cycle. In fact, from the second production cycle onwards, a disturbance in the spacing between banana plants is observed after the harvesting of the fruits of the 1st production cycle. This slight increase in spacing allows for better light penetration, which is used by the successor shoots (2nd cycle banana plants) to carry out various metabolisms such as photosynthesis. This study shows that in the first production cycle, the cultivar Grande Nain records the best diet weights compared to the cultivar Williams from a statistical point of view in particular and over the whole of the 2 cycles from an agronomic point of view. This corroborates our observations, which indicate that the bunches from the Grande Nain cultivar have higher average weights than those from the Williams cultivar. In general, within the same cultivar and production cycle, this study shows that bunch weight is not affected by increasing planting density. This was also observed by Cuellar and Morales [21]. According to this author who followed 3 production cycles of cv. Williams, bunch weight only increased from one generation to the next. These results confirm those of this study on banana dessert cultivars. On the other hand, they are contrary to those of [22-24], which showed that the lowest densities of plantain had the highest diet weights. These authors based their assertion on the fact that when the number of banana plants grown per hectare is low, they are able to make better use of light and suffer less from competition for water and nutrients, which favours plant development and therefore fruit production. In our case and in general in industrial plantations, the technical itinerary of fertilisation and watering of banana plants in the form of irrigation is calculated on the basis of plants/ha regardless of the planting density. All banana plants are supposed to receive the same amount of fertiliser and the same amount of water. Under these conditions, intra-plant competition becomes weak, all plants potentially developing at the same rate. To this must be added the activities of drainage, amendment, etc., which are defined in the establishment and operation of a banana plantation, allowing for better fruit production. The comparison of growth parameters such as pseudotruncular circumference, banana tree height and production parameters such as bunch weight, grade of the second hand and number of hands per bunch within the same cultivar and from one cycle to another reveals a proportional relationship. This relationship shows that the weight of the bunch increases as the height and girth increase.

5. Conclusion

This study showed that the removal of immature lesion-bearing areas combined with planting density had varying effects on the black stripe disease status, growth and productivity of banana plants of the cultivars Grand Nain and Williams in the test locality. However, several planting densities were selected for their good performance in terms of growth, productivity and phytopathological parameters. The results show that the low planting densities of all banana cultivars were favourable. These densities are 1550, 1600, 1650 plants/ha, but with a slight performance advantage for the Grande Nain cultivar over the 2 production cycles. However, the physical and chemical properties of the soils in the different localities must be taken into account in order to adapt the appropriate cultivation practices to maintain sustainable fertility. Strong correlations were observed between the circumference of the trunk, the height of the banana trees at flowering and the weight of the bunch at harvest, as well as the grade of the second hand. These correlations showed that good growing conditions of the banana plant are necessary for the production of higher weight bunches.

Acknowledgements

The authors are very grateful to SCB for their technical support. They also thank all the staff for their technical assistance.

Ethical Approval

All the experiments in the study were approved by the ethics committee of the Biosciences UFR of the University Félix HOUPHOUET-BOIGNY in Côte d'Ivoire.

Conflicts of Interest

The authors declare no conflict of interest.

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Figure-1. Map of the study area

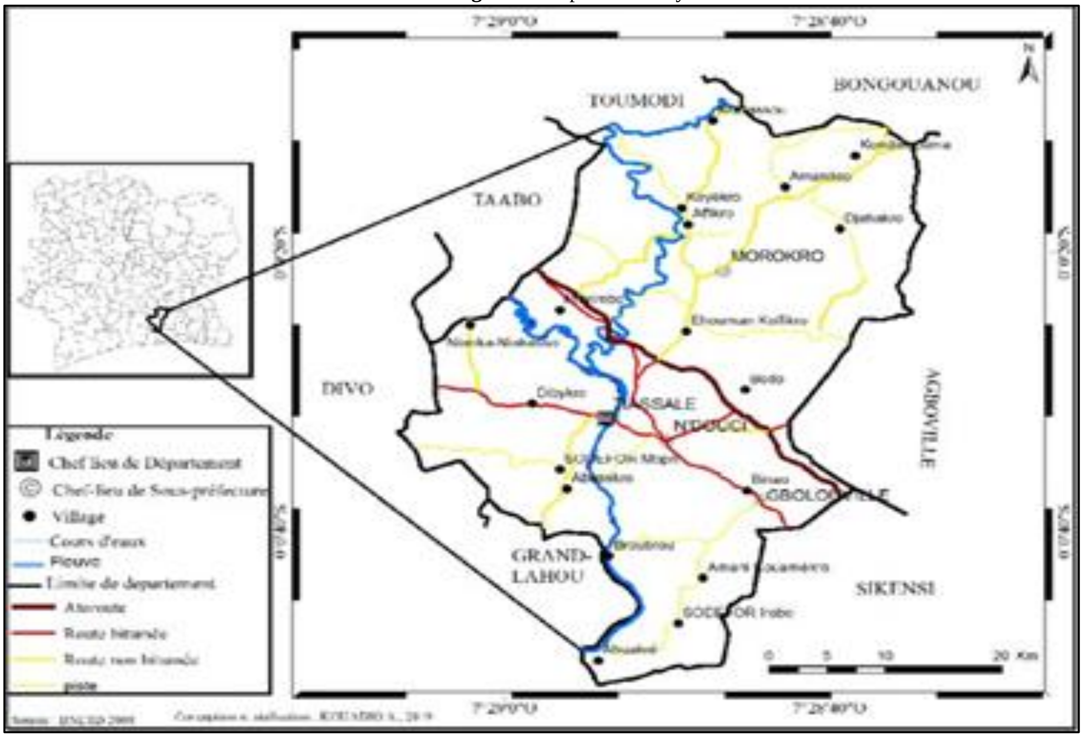


Table-1. Evaluated planting density

	Number of plants	
Density (plants/ha)	**Grand Nain**	**Williams**
D1 : 1550	93	95
D2 : 1600	95	95
D3 : 1650	95	98
D4 : 1700	117	117
D5 : 1750	97	100
D6 : 1800	100	100
D7 : 1850	122	120

D8 : 1900	122	123

Figure-2. Completely randomised block design)

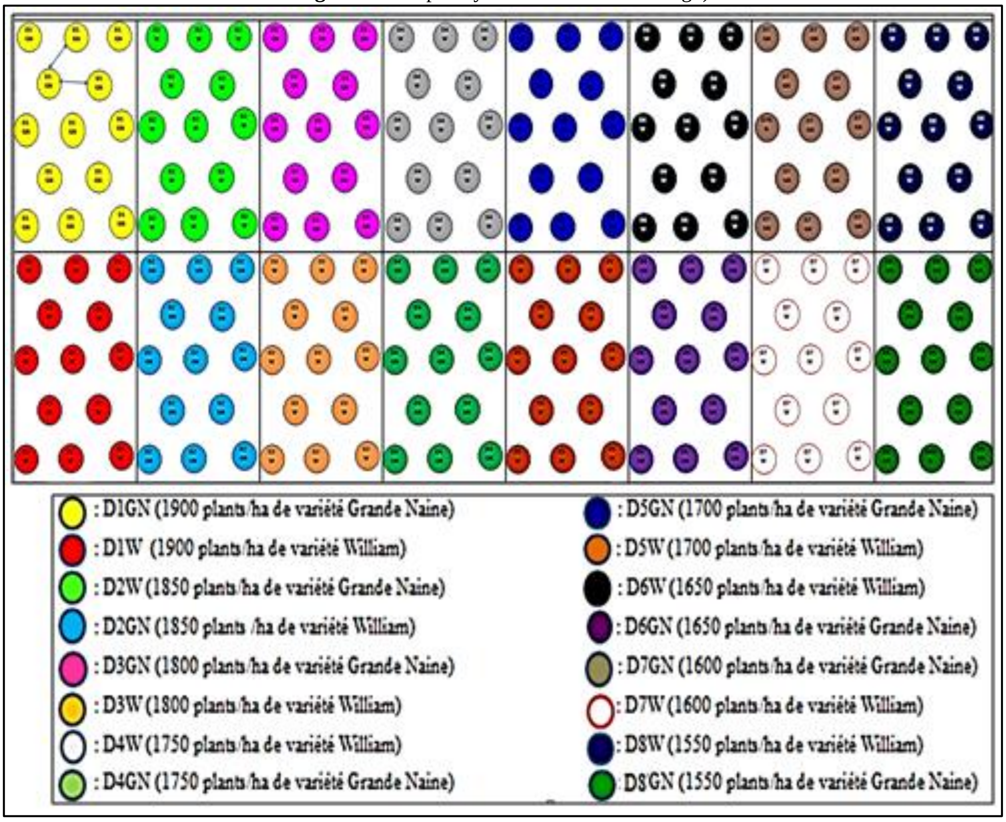


Figure-3. Staggered planting pattern of banana plants

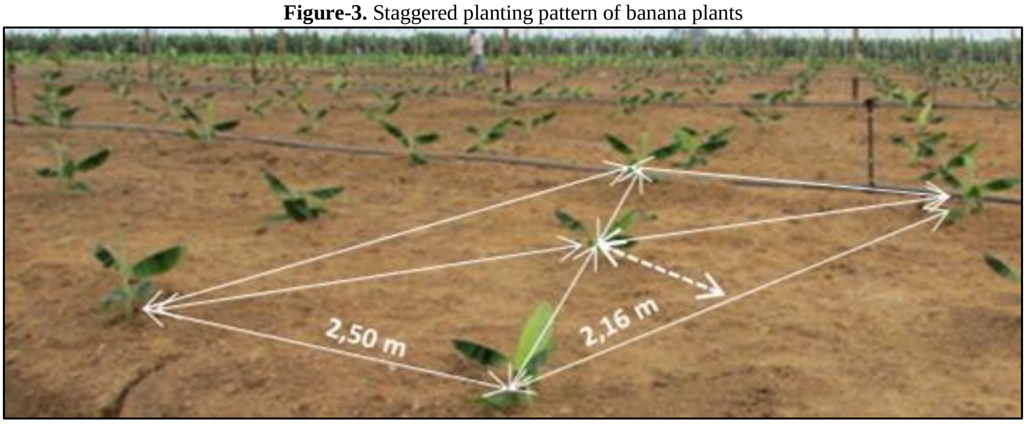
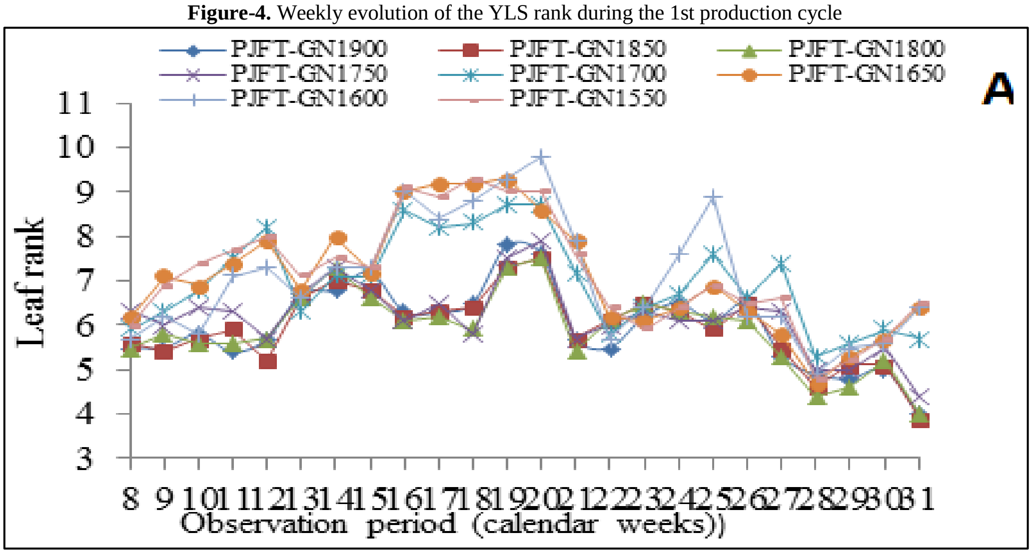
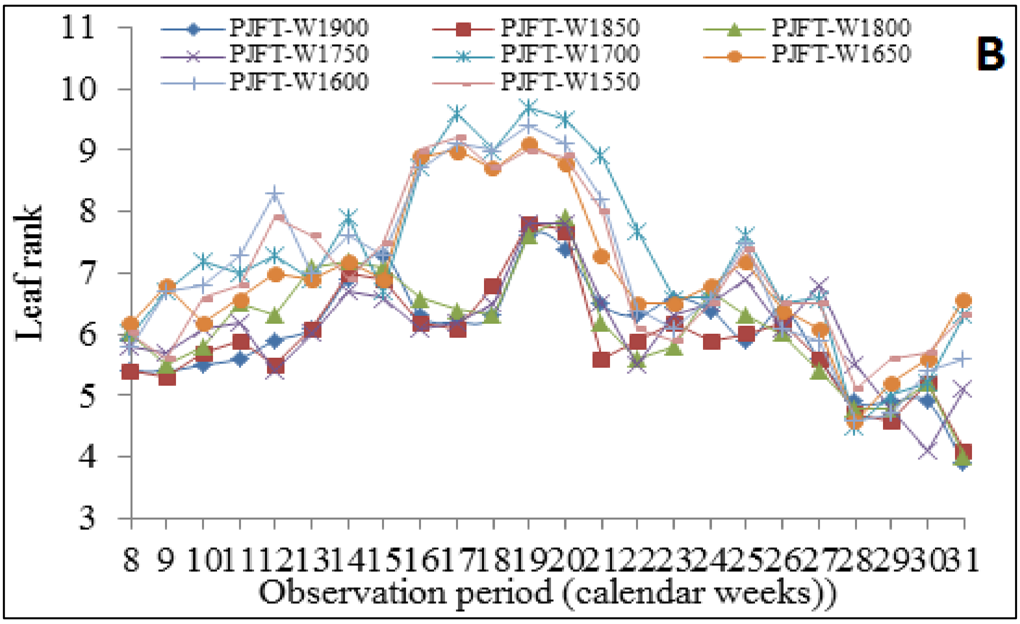


Figure-4. Weekly evolution of the YLS rank during the 1st production cycle



A: in the dessert banana cultivar Grand Nain



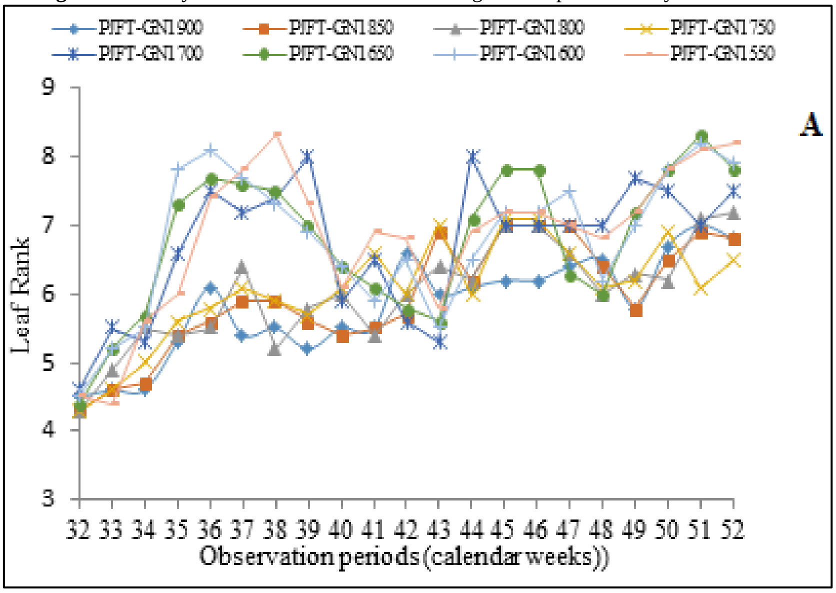
B: in the dessert banana cultivar Williams

Table-2. Ranks of youngest affected leaf, youngest necrotic leaf under 8 planting densities and 2 dessert banana cultivars during the two production cycles

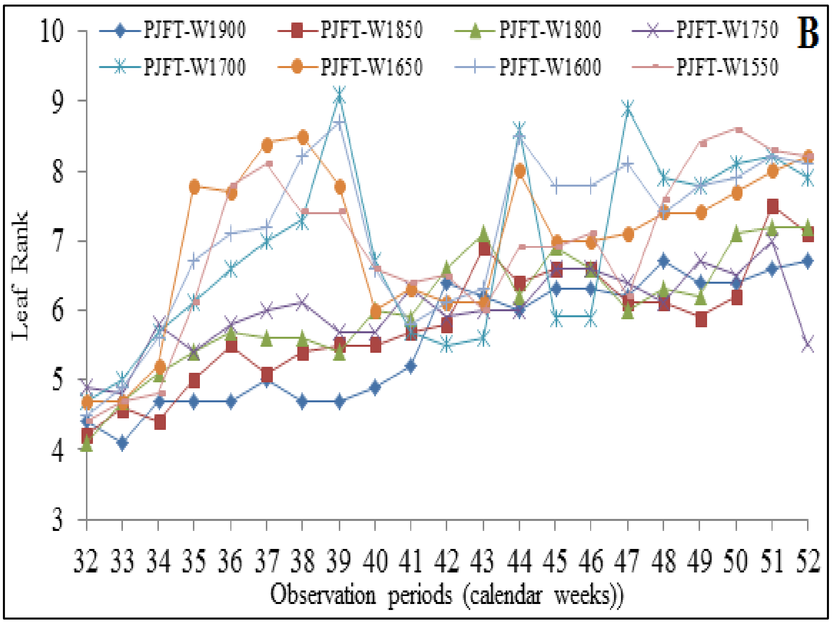
		Youngest Leaf Spotted		Youngest Leaf Necrosed	
Cultivars	**Densities (plants/ha)**	**1er cycle**	**2e cycle**	**1er cycle**	**2e cycle**
Grand Nain	**1 900**	5,91 b	5,83 de	11,42 a	11,48 a
	1 850	5,96 b	5,96 bcde	11,27 a	11,57 a
	1 800	5,96 b	6,02 bcde	11,25 a	11,20 a
	1 750	6,12 b	6,06 be	11,36 a	11,20 a
	1 700	6,87 a	6,72 cd	11,21 a	11,55 a
	1 650	6,95 a	6,78 c	11,33 a	11,72 a
	1 600	6,93 a	6,80 bc	11,29 a	11,44 a
	1 550	7,02 a	6,82 bc	11,33 a	11,64 a
	Average	6,47	6,37	11,70	11,66
Williams	**1 900**	5,81 b	5,59 e	11,36 a	11,51 a
	1 850	5,88 b	5,81 de	11,21 a	11,54 a
	1 800	6,06 b	6,04 bcde	11,50 a	11,52 a
	1 750	6,08 b	6,04 bcde	11,43 a	11,62 a
	1 700	6,94 a	6,87 abc	10,95 a	11,82 a
	1 650	6,98 a	7,00 a	11,12 a	11,79 a
	1 600	7,06 a	7,11 a	11,28 a	11,59 a
	1 550	7,08 a	6,88 a	11,22 a	11,70 a
	Average	**6,49**	**6,42**	**11,37**	**11,44**

For each banana cultivar and plantation density, in the same value followed by the same letter are not significantly different at the α = 5% threshold according to the Newman-Keuls test

Figure-5. Weekly evolution of the YLS rank during the 2nd production cycle in Tiassalé

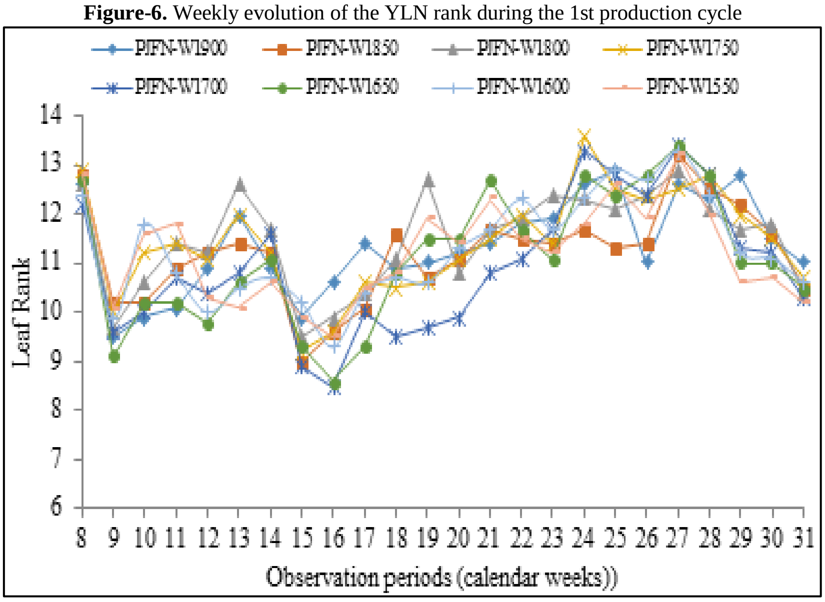


A: in the dessert banana cultivar Grande Naine

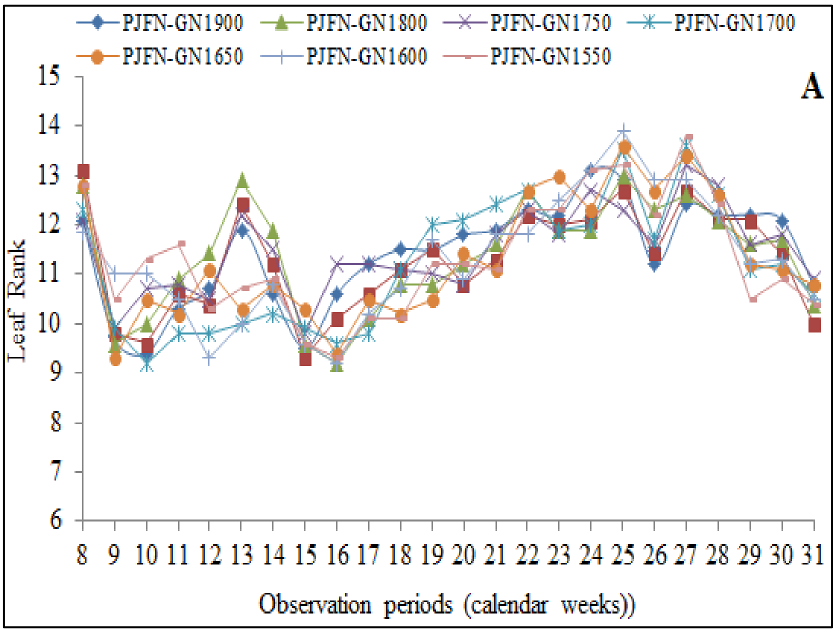


B: in the dessert banana cultivar Williams

Figure-6. Weekly evolution of the YLN rank during the 1st production cycle

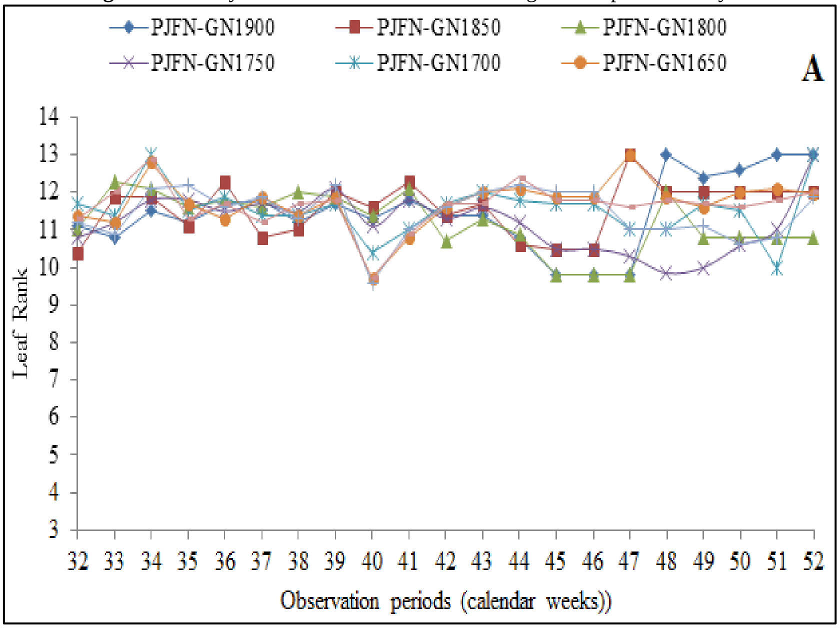


A: in the dessert banana cultivar Grande Naine

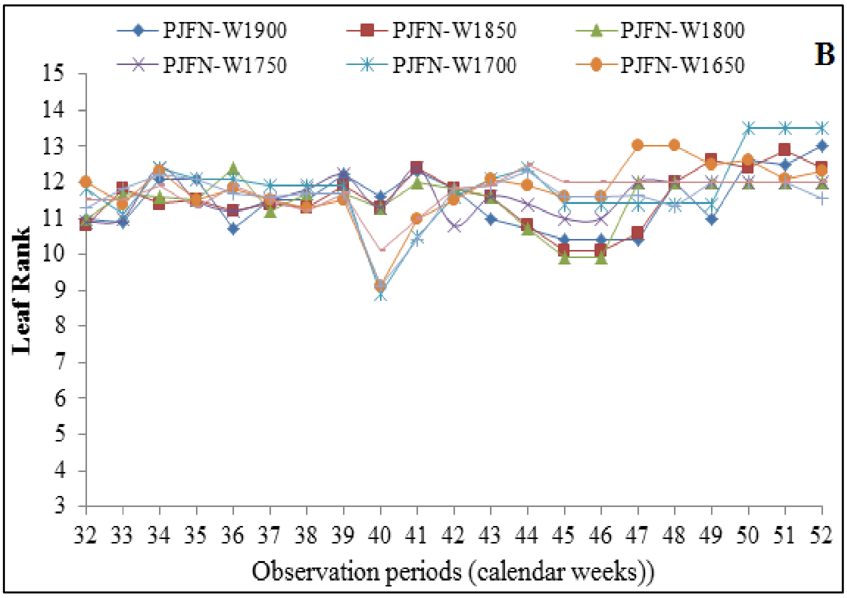


B: in the dessert banana cultivar Williams

Figure-7. Weekly evolution of the PJFN rank during the 2nd production cycle



A: in the dessert banana cultivar Grande Naine



B: in the dessert banana cultivar Williams

Table-3. Agromorphological parameters under 8 planting densities and 2 dessert banana cultivars during the two production cycles

		Height (cm)		Circumference (cm)		Number of leaves at flowering		Number of leaves at harvest	
Cultivars	**Densités**	**1er cycle**	**2e cycle**	**1er cycle**	**2e cycle**	**1er cycle**	**2e cycle**	**1er cycle**	**2e cycle**
Grand Naine	1 900	225,0 abc	261,7 bcd	71,1 bcde	58,2 abc	10,4 de	12,3 bcde	6,2 a	7,3 bc
	1 850	221,4 bc	241,6 d	70,1 de	53,4 bc	10,7 cde	14,0 a	5,9 a	9,0 a
	1 800	227,1 abc	271,0 abc	71,5 bcd	59,9 ab	11,0 bcde	12,7 abcde	6,2 a	7,7 abc
	1 750	218,7 c	259,9 bcd	67,5 e	58,3 abc	11,4 abcde	13,3 abcde	6,1 a	8,2 abc
	1 700	218,7 c	263,2 bcd	69,6 de	60,6 a	10,7 cde	13,5 abcd	5,9 a	8,6 ab
	1 650	216,9 c	262,8 bcd	69,1 de	58,1 abc	10,8 e	13,4 abcd	6,1 a	8,5 abc
	1 600	222,3 bc	250,8 cd	71,0 bcde	60,1 b	11,6 abcde	13,5 abcd	6,2 a	8,4 abc
	1 550	220,0 c	274,8 abc	70,6 cde	60,6 a	11,9 abc	13,8 ab	6,5 a	9,0 a
	Average	**221,2**	**260,7**	**70,0**	**58,6**	**11,0**	**13,3**	**6,1**	**8,3**
Williams	1 900	236,9 a	270,2 abc	74,8 ab	53,2 c	11,7 abcd	12,2 bcde	5,8 a	7,5 abc
	1 850	234,6 a	288,6 a	73,1 abcd	59,3 abc	11,7 abcd	12,0 de	5,6 a	6,8 c
	1 800	228,6 abc	273,8 abc	70,6 cde	55,8 abc	11,1 abcde	12,9 abcde	6,4 a	8,1 abc
	1 750	237,0 a	291,4 a	72,9 abcd	57,2 abc	10,9 bcde	12,1 cde	6,1 a	7,0 bc
	1 700	231,7 ab	270,7 abc	72,2 abcd	52,8 c	12,0 abc	12,4 bcde	6,1 a	7,0 bc
	1 650	234,5 a	288,0 a	75,5 a	60,2 ab	10,3 cde	12,4 bcde	6,1 a	7,5 abc
	1 600	235,5 a	283,0 ab	72,6 abcd	56,8 abc	12,4 a	13,7 abc	6,2 a	8,3 abc
	1 550	235,9 a	289,5 a	74,3 abc	60,1 a	12,2 abc	11,8 e	6,2 a	7,0 bc
	Average	**234,2**	**281,9**	**73,2**	**56,9**	**11,6**	**12,4**	**6,1**	**7,4**

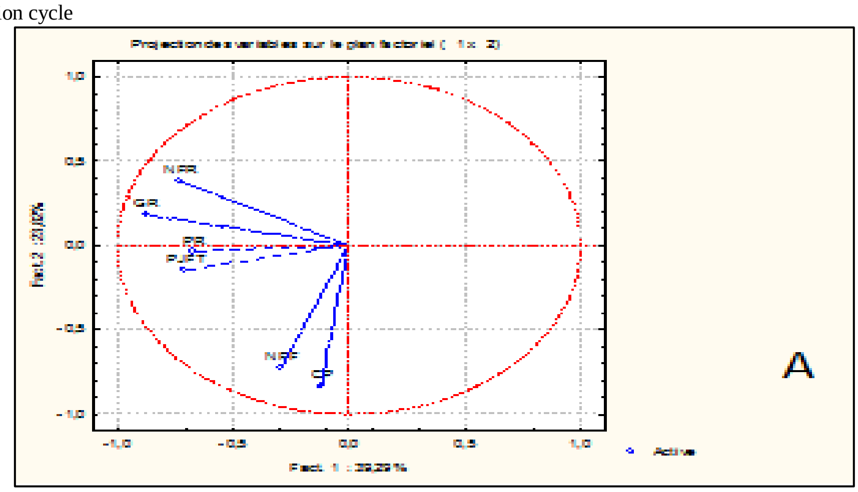
For each banana cultivar and plantation density, in the same column the values followed by the same letter are not significantly different at the α= 5% threshold according to the Newman-Keuls tes

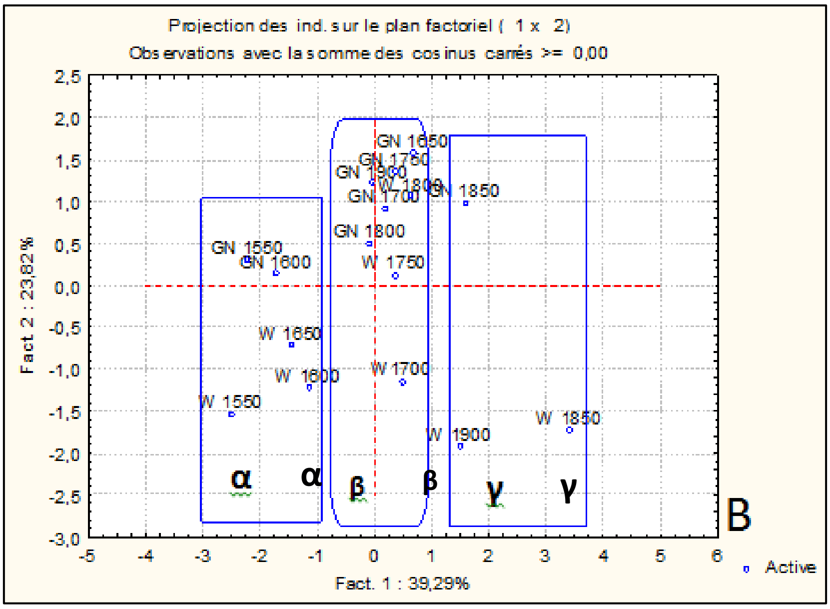
Table-4. Number of hands, grade, and bunch weight under 8 planting densities and 2 dessert banana cultivars during two production cycles

		Number of hands		**Grade (mm)**		**weight (Kg)**	
Cultivars	**Densities**	**1er cycle**	**2e cycle**	**1er cycle**	**2e cycle**	**1er cycle**	**2e cycle**
Grand Naine	**1 900**	7,63 a	7,90 b	35,38 abc	36,45ab	22,60 ab	28,13 abcd
	1 850	7,21 ab	7,37 c	35,29 abc	36,37 ab	19,59 bc	24,73 d
	1 800	7,60 ab	7,78 abc	35,20 abc	36,00 ab	22,49 ab	28,54 abcd
	1 750	7,25 ab	8,00 b	35,58 abc	36,33 ab	21,03 abc	29,60 ab
	1 700	7,25 ab	8,00 b	35,19 abc	36,60 ab	21,35 abc	27,98 abcd
	1 650	7,25 ab	8,00 b	34,50 bcd	36,50 ab	20,22 abc	28,02 abcd
	1 600	7,11 ab	7,75 abc	36,39 abc	36,35 ab	22,01 abc	25,93 bcd
	1 550	7,12 ab	8,00 b	35,82 abc	36,95 a	22,11 abc	28,94 abc
	Average	**7,28**	**7,85**	**35,41**	**36,46**	**21,41**	**27,71**
Williams	**1 900**	7,50 ab	7,53 abc	34,00 cd	34,68 c	21,59 abc	25,80 bcd
	1 850	6,55 b	7,63 abc	32,64 d	36,26 ab	19,31 c	26,49 bcd
	1 800	7,00 ab	7,91 b	34,83 abc	35,32 bc	19,17 c	28,48 abcd
	1 750	7,17 ab	7,85 ab	35,17 abc	36,15 ab	21,04 abc	27,41 abcd
	1 700	7,13 ab	7,95 b	34,13 cd	36,74 ab	19,84 bc	30,62 a
	1 650	6,75 ab	7,40 ac	37,00 a	36,95 a	21,46 abc	25,20 cd
	1 600	7,06 ab	7,85 b	35,69 abc	36,75 ab	20,51 abc	27,80 abcd
	1 550	7,07 ab	8,00 b	36,57 ab	36,94 a	23,09 a	28,26 abcd
	Average	**6,95**	**7,76**	**35,38**	**36,21**	**20,75**	**27,49**

In each locality, for each banana cultivar and plantation density, in the same column, the values followed by the same letter are not significantly different at the threshold α = 5 % according to the Newman-Keuls test

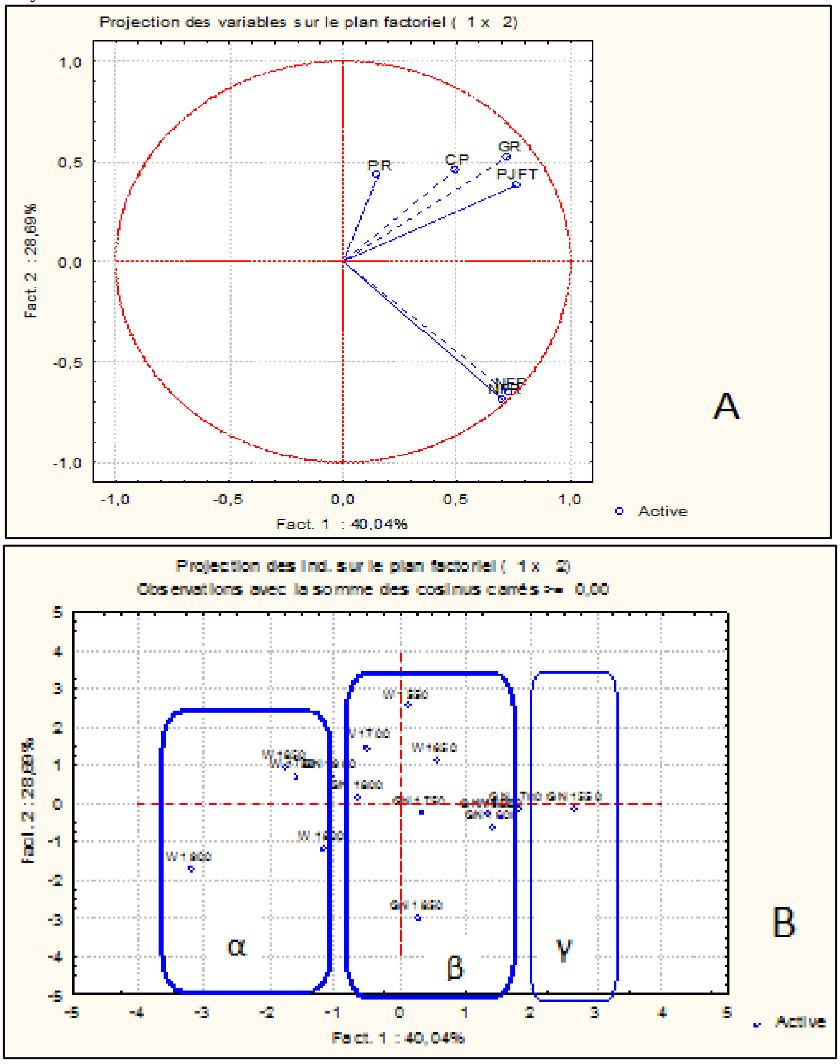
Figure-9. Correlation circle (A) and dispersion of densities and cultivars (B) obtained after PCA of agrophysiological data of banana plants during the 1st production cycle





NFF: Number of leaves at flowering ; PR: Bunch weight, ; GR: Finger grade, ; NFR: Number of leaves at harvest, ; PJFT: Youngest leaf Spotted, ; CP: Pseudotruncular circumference ; GN: Grand Nain W: Williams

Figure-10. Correlation circle (A) and dispersion of densities and cultivars (B) obtained after PCA of agrophysiological data of banana plants during the 2nd production cycle in Tiassalé



NFF: Number of leaves at flowering ; PR: Diet weight, ; GR: Finger grade, ; NFR: Number of leaves at harvest, ; PJFT: Youngest leaf reached, ; CP: Pseudotruncular circumference ; GN: Large Dwarf
W: Williams.