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Sigatoka Disease Severity Reduced by Agro Forestry and Production of Plantains under Those Conditions

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ABSTRACT

Plantain is an important cash crop of countries like Colombia. A traditional way of producing plantain is intermingled with trees in places close to farmhouses called "conucos". Personal observations suggested such association had several advantages. So, a project of plantain production as a secondary crop under forests was evaluated. The first and most outstanding observation was a reduction of black Sigatoka severity. Tissue damaged for Sigatoka kept around 1 to 10% throughout the year while sunlight exposed plants had damages of 30 to 40%. Youngest leaf spotted remained around 6 to 13 while plants exposed to sunlight had YLS around 3. Changes on micro climate were responsible for the good answer. A lacking of dew condensation on leaves makes infection and incubation processes not to happen. Almost all trees behaved well in association with plantains. Nevertheless, three forest arrangements were considered better for plantains. First, fast growing trees planted simultaneously with crop; second, association with secondary forest thinned out to 50% of canopy to allow plantain crop to grow well with incident sunlight; and third, association with old forests which require trimming. Advantages of intermingling plantains with forest were evident at harvest. Plantain plants had good canopies, taller and thicker pseudostem and heavier and healthier bunches. Forest offers to plantains a good level of nutrients, better hydraulic conductivity which improves nutrition and reduction of fertilizer requirements. Main antagonist effect was competency for light, physical damages and longer vegetative cycles of plantain plants. Association offers until 45% of reduced cost of production and a novel methodology for farmers.

Keywords: adaptability to forest, agroforestry, black sigatoka, cash crop alternative, plantains production

INTRODUCTION

Plantain production during the last century was the main cash crop for many farmers at the bottom of the mountains of the Eastern Colombian plains. *Musa* species are well cultivated on alluvial soils of many streams coming down from the eastern mountain of the Andes. All basins of rivers which go west in the eastern Colombian plains, have pretty nice alluvial soils for plantain production. Starting with the northern river Arauca in the border with Venezuela until the southern Guaviare River at the entrance of Amazonia all have *Musa* species in their basins. Approximately 50.000 hectares and almost 18.000 families used to produced and lived of plantains. In 1995, Black Sigatoka disease (*Mycosphaerella fijiensis*, Morelet) the main foliar disease of *Musa* species appeared in this region. By 1999, only 18.000 ha remained on plantain depleted by Black Sigatoka Disease. To top of it, the region is a tropical humid climate very convenient for Sigatoka incidence. Farmers were small-scale producers without enough income for spending on chemical control or technical improvement of crops. So, they got trapped in a poorness process due to reduce income, lesser harvesting and quality of plantains which finally affected their life standards. They left their farms unattended, some changed to illegal crops like coca and others decided to put them on rent to agribusiness farmers. Whatever the case a trouble of settlement of these farmers is taking place now and a social responsibility has to be solved by returning them a profitable business with any crop or agriculture alternative.

Sigatoka disease appeared in Colombia by the end of 1981, possibly by aerial dissemination from Panama. The pathogen colonized the main bananas region of Colombia, the Urabá region closed to Panama border, and latter spread throughout the country reaching new areas cropped by Musa within the country and away from it. Ecuador, Venezuela and the Amazonian north region of Brazil were colonized by the pathogen. According with registered data of Colombia by 1983 there were around 450.000 ha planted with plantains. By the end of 1990, only a total of 250.000 ha were registered as cultivated with plantains. In the Orinoquia region (name which the eastern plains are designnated), before the appearance of Black Sigatoka, 95% of plantain farmers were small producers or cash crop producers (Martinez and Becerra 1998). In contrast, for 2001 plantain crops are back in agricultural activity but in hands of agribusiness farmers. 55% of entrepreneurial farmers are now the plantain producers. They applied very well a technological package developed by ICA and Corpoica (Research Institutions) for this crop and went into business by controlling the merchandise process, offering very good quality plantains. Small farmers have no money for investments and do poor agricultural practices, so they are pulled out of the good market and force to sell their yield for local consumption. Low prices are finally got for their plantains. If they want to participate of the bigger market they must improve their crops.

A local customary of farmers and cattle farms that have an area of agriculture only for consumption, is to crop plantains in a stratified agro forestry arrangement called "conuco". It is an area close to the farmhouse, planted with perennial species of trees which produce fruits, firewood or wood for farm use or timber. Other type of plants are also intermixed with these trees and herbaceous plants, like shrubby leguminous, decumbent leguminous, Araceae plants, hot pepper shrubs, cassava plants and plantains and bananas trees (*Musa* AAB and *Musa* AAA, Simmonds). Plantain trees have also been used as a cash crop intermixed

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with coffee and cocoa trees in Colombia. A common practice is to establish a shadow crop for these crops using plantain trees as a transitory shadowing while the main shadow trees grow. So, it has been observed that many plantain plants remain under the shadow trees long after the crops have been established. Those plantain trees are usually free of Yellow Sigatoka and black Sigatoka.

In 1995, when black Sigatoka disease appeared at the eastern plains region, Corpoica was involved in a project of technology implementation for improving the plantain crop as an alternative against Sigatoka depletion. Field observation corroborated once more those farmers where right using "conucos" as a way of getting plants free of Sigatoka. Measurements confirmed that shadowed plantain trees had lower disease severity than those planted without any layer of crops above them. An agro forestry system was then established to cultivate plantains in "Puente de Tabla," a village of Tame municipality, Arauca state (1996). Since then, an arrangement of agro forestry has being improved by research with use of local species of trees, planting arrangements, spacing and so on. It has been possible with collaboration of intergovernmental institutions like Agriculture secretaries of the states of the region.

The pathogen

1. Origin and distribution

Black Sigatoka was first observed as a pathogen of *Musa* species in Fiji islands. There were several registrations of observed symptoms very much alike Black Sigatoka by the beginning of the 20th century. The pathogen was identified and registered as a Musa disease in 1964 and found later on in the pacific islands and east tropical Asia. It appeared in Gabón, Africa in 1979 (Rhodes 1979) and some other countries afterwards (Robinson 1996). In America, the disease was found in Honduras in 1972 (Stover 1972). During the 1970's the pathogen was spread through the Central American countries (Stover 1980). In Colombia appeared in the bananas region closed to Panama in 1981 (Mayorga 1990) and actually is present in all Colombian regions where bananas and plantains are cropped.

2. Biology of the disease

The causal agent of disease is an ascomycete called *Mycosphaerella fijiensis* Morelet, which forms ascospores. During its anamorphic phase the fungus produces conidia of the genus *Paracercospora fijiensis* (Ponds 1987). Except in the Philippines and Colombia, Sigatoka disease has been replaced by black leaf streak disease. Sigatoka disease or Yellow Sigatoka is better adapted to cooler areas and dominates at altitudes above 1500 meters above sea level. Severity of the pathogen causes a full lost of foliage and losses in weight and quality of bunches.

Dispersal of ascospores and conidia within, above and outside bananas plantation has allowed estimating the potential viability of spores dispersing through the atmosphere. Spores are airborne and can be found kilometers away of its place of release. Temperature, rainfall and behavior of the wind influence dispersal. Leaf wetness, relative humidity and temperature are responsible for processes of infection and incubation on and within a leaf (Mayorga 1991). Quality of inoculum in terms of viability, genetic diversity of pathogen population, susceptibility of host, and technological package of crop, are the main factors influencing life cycle of disease (Merchan 1996).

Genetic improvement for resistance appears as the most appropriate tool for controlling the pathogen. As a high level of diversity is kept in pathogen populations, the best way of getting resistance cultivars of plantains or bananas is working with partial resistance. It seems to be most durable, instead of total resistance (Roux *et al*. 2002). Molecular and cellular biology tools are providing new knowledge on host-pathogen interactions (Novak 1989). So, a holistic integrated disease management framework is look for as the right approach for deploying resistance against Black Sigatoka (Roux *et al*. 2004).

MATERIALS AND METHODS

A project of research was started many years ago looking for forest species which grow well and could be intermixed with plantains. Based on those results, in 1995 in cooperation with a program called Pronatta (National Program of technology transfer in agriculture by its name in Spanish), several tree species where initially evaluated considering canopy configuration. The purpose was to identify and evaluate good interactions that allow both crops to grow well and had a synergetic effect on final yielding. Good adaptability under mixed conditions of cropping was also an evaluated characteristic.

The general objective of the program was to involve the plantain crop as part of an agro forestry system of production where the plantain tree grows in a lower layer of canopy or multi strata arrangement. As part of this objective, other parameters were registered, like a) Behavior of plantains under their natural ecosystem condition and severity of Sigatoka diseases. b) Depleting of production costs by adaptation of plantains to ecologically favorable arrangements. c) Develop of a system of cropping for small farmers at the foot of the mountains as part of the productive chain. Any pest or disease appeared during the time of the survey has also been registered and evaluated.

Other specific objectives were: 2) Evaluate forest local species or foreign ones which have good configuration of canopy and allow enough sun light to reach down for plantain trees. 3) Evaluate synergetic or antagonist effect between forest trees and plantains trees and possible changes on soil characteristics. 4) Shadow effect of forest trees on vegetative and productive cycles of plantain tree, and quality of the fruit.

Experiment 1

An area located in Puente de Tabla, Tame municipality (Arauca state), initially planted with cocoa under shadowing of bucaré (*Erythrina fusca*) and samán (*Samanea saman*) trees was chopped down of cocoa. Shadow trees arranged at distances of 12 to 15 m were trimmed in order to get a 50% of shadowing. Beneath the forest plantain plants were planted at 3 m × 2 m for a total of 1660 plants/ha. All observation made in the shadow plot were compared with similar observations carried out in a plot of plantains without shadowing and planted next to the first one. Management of both plots was identical.

A weekly evaluation of Sigatoka was carried out for a period of six years using Stover and Dickson scale of evaluation. None of the plots had during the time of evaluation any type of disease control.

Experiment 2

At Villanueva (Casanare state) a forest of eucalyptus (*Eucalyptus pellita*) planted at 4 m × 2 m was intermixed with plantain trees of Boroukou variety. Eucalyptus trees were established 4 months before the planting of plantains. Eucalyptus trees were fertilized with slaked lime and Calfos (an enriched solution of lime and 10% of phosphorus). A dose of 500 kg/ha was applied before sowing. One month after planting, each tree received a dose of fertilizer consisting of 60 g of diamonium phosphate, 60 g of Sulpomag (Sulphate of magnesium and potassium) and 10 g of Borum. One and two years after planting, same fertilizers were applied to each tree but double dose. Twice a year the tree crop was hoisted by removing the lower branches. During the time of experiment the size and high of trees was measured and registered.

A plantain crop was placed in the middle of the rows of eucalyptus at a similar plowing distance, which allowed of having an amount of 1300 plantain plants/ha. *Desmodium ovalifolium* was used as coverage of soil. Management of plantains was made following a technological package of Corpoica (Martínez 2001), including fertilization, defoliation, weed control, and all practices required for a good cash crop. Sigatoka disease was measured using Stover and Dickson scale of evaluation in a weekly basis.

Experiment 3

Another location at Casanare state planted with *Pinus caribea*, was also planted in association with a plantain crop. Pine trees were a forest of 9 years of age planted at 4×3 m, which was thinned out to leave better trees for future sawing and timber. After thinning out the pine forest the amount of incident sunlight was around 50%, so it was possible to sow an agricultural crop like plantains and get yielding while the forest allow it. Sowing distances of the plantain crop was 3×2 m, where possible. During the time of experiment, black Sigatoka severity was measured following Stover and Dickson scale and only with research purposes.

Experiment 4

In collaboration with Agricultural Secretary of Casanare, an experiment was established in three different locations of the state, Yopal, Paz de Ariporo and Pore. Forests of different type were used for establishing the plantain crop.

First plot was done at Yopal. A secondary forest having mainly palm mil pesos (*Jessenia policarpa*), balso (*Ochroma lagopus*), yopo (*Anadenanthera peregrina*) and samán (*Samanea saman*) was thinned out or trimmed for having enough incident sunlight for cultivating plantains under them. 50% of sunlight reaching the ground was a level considered enough for plantain trees. Because of the secondary development of forest and further thinned out, it was not possible to say an average distance of trees. Some of them with big configuration canopies remained at 10 or 15 m while smaller ones were settled as close as 4 m. In order to have a forest rich in timber trees new ones were planted in open areas. The selected species for replanting were aceite (*Calophillium mariae*), red acacia (*Delonix regia*), bucaré (*Erythrina fusca*), nauno (*Pseudosamanea guachapele*), guásimo (*Guazuma ulmifolia*) and caracaro (*Enterolobium cyclocarpum*). A crop of plantains was established under the forest at planting distances of 4 m × 2 m which gives an average of 1300 plants/ha. Plantain crop was managed according with Corpoica advises following a strict program of manual working.

Second trial was conducted at Paz de Ariporo location. A forest was planted at planting distance of 4 m × 2 m with trees of the species bucaré (*Erythrina fusca*), guásimo (*Guazuma ulmifolia*), nauno (*Pseudosamanea guachapele*), leucaena (*Leucaena leucocephala*), algarrobo (*Hymenaea courbaril*) and pink cedar (*Cedrela odorata*). A plantain crop was simultaneously established in the same area at distances of 4 m × 2 m but locating the rows of plantains in the middle of the rows of trees. 1250 plants/ha was the plowing density of plantains. Corpoica technological package for plantains was the recommendation of management of the crop.

Finally, the third trial was located at Pore following the same method of establishment used in Paz de Ariporo. This trial was a replica of previous ones, but forest was established using a mixture of tree varieties of pink cedar (*Cedrela odorata*), guayacán (*Tabebuia chrysantha*), guava (*Psidium guajaba*), caracaro (*Enterolobium cyclocarpum*), nauno (*Pseudosamanea guachapele*), bucaré (*Erythrina fusca*) and lemon (*Citrus medica*). Black Sigatoka collection data was made by means of Stover and Dickson scale.

Experiment 5

A rubber plantation of 3.5 years of age planted at CI La Libertad of Corpoica in Villavicencio, Meta; was an agro forestry arrangement evaluated in association with plantains. The rubber was planted in a double crop rows with distances among them of 13 m and plowing distances among double rows of 3 m × 2.5 m. In the middle of double rows, three rows of plantain were planted at distances of 3 m × 2 m allowing a density of just 900 plants/ha. The plantain rows were planted in such a way that did not interfere with a normal development of rubber neither rubber had an interference with normal growing of plantain and had at least a 50% of sunlight reaching the area where they were planted. None chemical control of Black Sigatoka was made on the plantains. A full package of management of plantain was settled and a leaf stripper made some removing from time to time.

Statistical analysis of data

Black Sigatoka evaluations were expressed as youngest leaf infected (YLI), youngest leaf spotted (YLS) and severity of disease (S). For each term, a weekly mean was calculated from at least 30 observations corresponding to 3 parcels per treatment. Data were subjected to multifactor analysis of variance (ANOVA) per each experiment. In relation with plantain production the parameters of plant growing where gathered at specific times of crop growing and means were calculated from field data and subjected to multifactor analysis of variance. Plant yielding was measured at time of harvesting, weight and size of bunches were the main compared factors using again multifactor analysis of variance.

On the other hand behavior of forest trees, rate of development, synergetic or antagonic effects on plantain crop and quality of shadowing, was obtained by measuring of a sample of 50 trees by experiment. Also, general observation on the whole planted area was done every other week in order to see changes of plants that affected plantain crop. Results of tree behavior where also compared by multifactor analysis of variance.

In order to determine which soil was influenced by the forest and which one changed its physical or chemical characteristics, the resulting data of laboratory analysis were compared using a multiple range test comparison (Duncan's). As samples were taken at different depths comparisons were made accordingly.

RESULTS

Agro forestry system of production of plantains as part of multi strata layers

1. Experiment 1

Plantains plants established in the area under the trees had a mild attack of Black Sigatoka. Severity disease through the year was 10.2% and is an indication of infected tissue of the total available. Disease severity on plants growing at sunlight exposure was 47.2% during the same period of time. The youngest leaf spotted (YLS) on shadowed plants was number six and they showed a low level of tissue damaged. Older leaves had also a low level of severity of Sigatoka which increases slowly, being leaf number 14 the one with 25% of tissue damaged. In the plot without shadowing Black Sigatoka spots were already ob-served on leaf 3. Leaf 4 showed 20% of damage tissue while 5 got even more damage with a 40% of attack. Leaves 6 to 9 were absolutely destroyed by Black Sigatoka (**Fig. 1**).

The plants in the shadow plots had a higher number of leaves. As a result of a better yielding capacity due to a larger amount of canopy and better photosynthetic foliage, bunches of the shadow plots had an average weight of 17 kg. While plots expose to sunlight produced bunches of only 9 kg. The plants of the shadow areas also had 1.12 m higher than the ones expose to sunlight and showed a thicker pseudostem of 0.06 m. This response is probably an answer to lower levels of light which induces taller plants looking for sunlight. Plants under shadowing showed a longer vegetative cycle than the exposed to sunlight with 62 days more on the field, possibly another response to reduced incident sunlight. These parameters were measured at flowering time.

A picture of the crop planted under shadowing conditions was taken in 2002 (**Fig. 2**), six years after the establishment of trial. Please, take a look of the size of Bucaré and Saman trees after the evaluation which offered a good layer of canopy over the plantain crop. The very good sanitary levels of plantain foliage can also be observed. A comparison of two young plants of plantains was made in these plots. **Fig. 3** showed a sunlight expose plant of plantains with leaves 8 and 9 absolutely destroyed by Black Sigatoka, while the plant on the right side of the picture is a shadowed plant growing under protection of Bucaré tree. It was possible to find 14 leaves of plantain absolutely healthy and free of Black Sigatoka. A bunch of plantains is also observed in the picture giving us an indication of good size and quality.

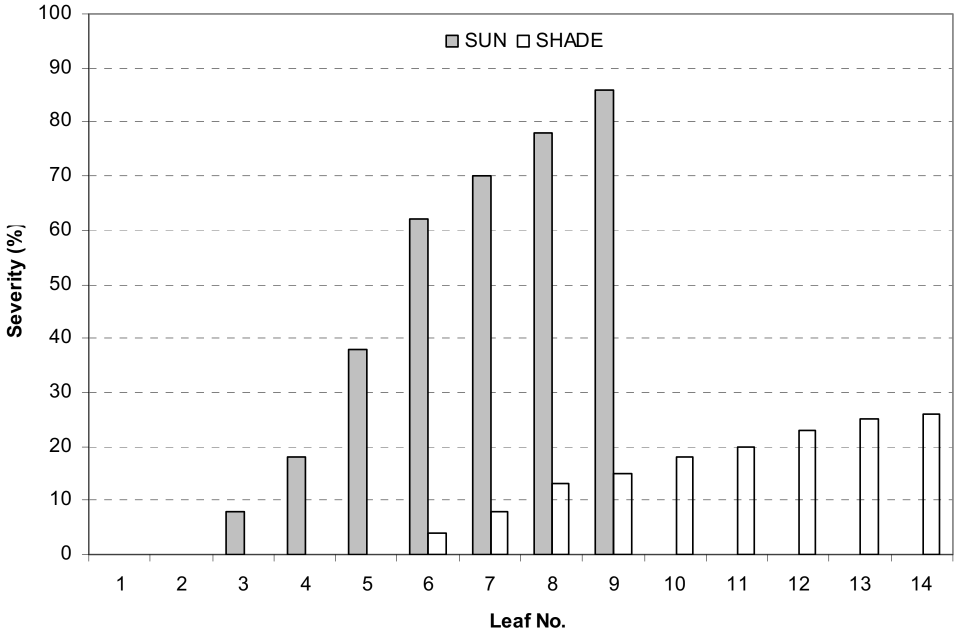

Fig. 1 Level of severity of Sigatoka on plants of plantain under a shadow plot of agroforestry and on a traditional sunlight plot. Puente de Tabla. Arauca. 1996-2003.

Fig. 2 Plantain crop under an agro forestry system with Bucaré and Samán trees. Planted on 1996 after cacao crop. Puente de Tabla, Tame; Arauca, 2003.

Fig. 3 Shadowing effect on Black Sigatoka disease severity observed on plants of plantain. Left picture is a plot with 50% of shadow of Bucaré and Saman trees.

2. Experiment 2

Black Sigatoka disease appeared early in the plants of plantain at Villanueva and was controlled only with occasionally defoliation of old infected leaves.

The level of severity observed in the crop during the time of evaluation was 11%. The older leaf had the higher foliage damage. YLS remained around leaf number six and caused a high level of damage in older leaves (**Fig. 4**). It was not possible to have a test plot in this experiment which gave an indication of behavior of the disease under expose conditions to sunlight. Nevertheless, compared with the results observed in Puente de Tabla experiment (previous), we could add that behavior of Sigatoka to total sunlight exposure can be worse. Due to a quick development of Eucalyptus trees the plantain crop had only two cycles of production. After the second one the amount of light going through the eucalyptus canopy layer did not allow any development of plantains and the crop simply disappear. In **Fig. 5**, it is possible to see the size of eucalyptus trees two months after planting of plantains. A fast growing crop like plantains is incapable of competing properly with this tree, after two years.

Eucalyptus trees in the agro forestry system grew higher than those planted without plantains. A 17% more of development indicated that there was a competency by sunlight in this type of association. Probably they grow well in association at other planting distances, but due to a lacking of information in this sense, it is necessary to consider further observations about density of both crops. Eucalyptus is a fast growing tree in the tropics (grow more than 4 m/year), so it is also possible to consider that the species is fitted for association only during first years.

3. Experiment 3

After a year of cropping plantains associated with pine trees, the amount of Sigatoka disease present in the plantain crop was summarized and plotted (**Fig. 6**). There is a low level of Black Sigatoka disease in plants of plantain established under pine forest (**Fig. 7**). Severity level was only 0.73%, which means that all leaves of plants were almost healthy and capable of synthesized properly for a good plantains yielding (**Fig. 6**). YLS remained around leaf 13 which is absolutely marvelous for production. It is possible to conclude that because of covering of pine layer, the natural

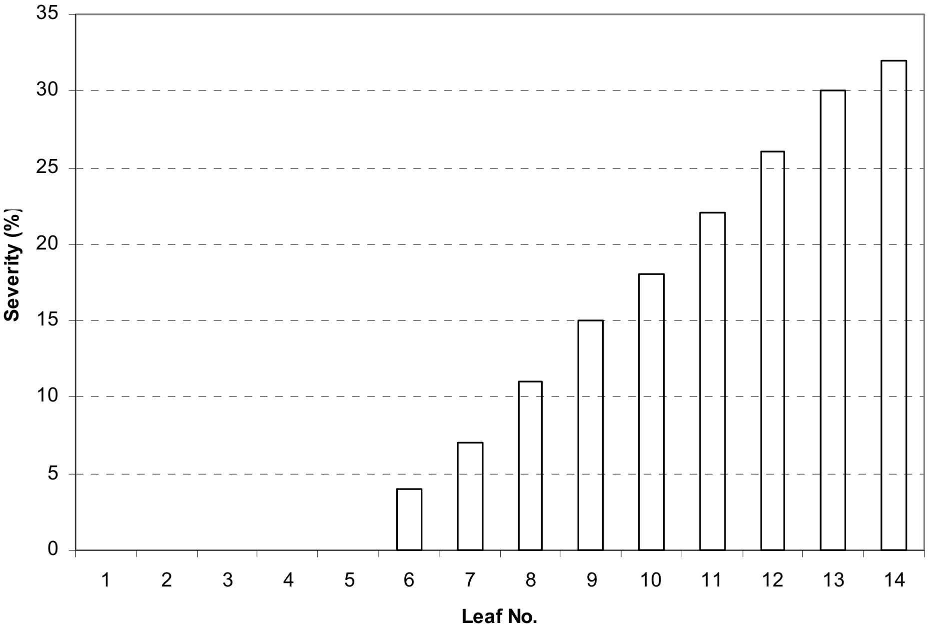

Fig. 4 Assessment of Black Sigatoka in a plantain crop in an agro forestry arrangement with *Eucalyptus pellita*. Villanueva. Casanare.

Fig. 5 *Eucalyptus pellita* trees in association with plantain Kborokou variety. A very good Desmodium ovalifolium soil covering was reached in this crop.

Fig. 7 Plantain crop arranged within a thinned out pine crop of 9 years of age. Villanueva, Casanare.

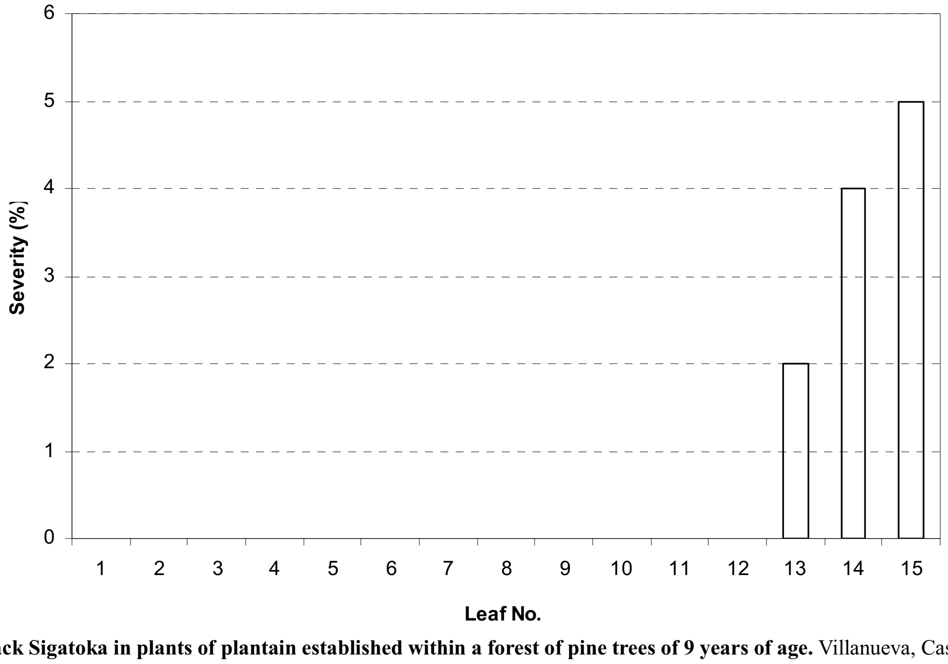

Fig. 6 Severity of Black Sigatoka in plants of plantain established within a forest of pine trees of 9 years of age. Villanueva, Casanare.

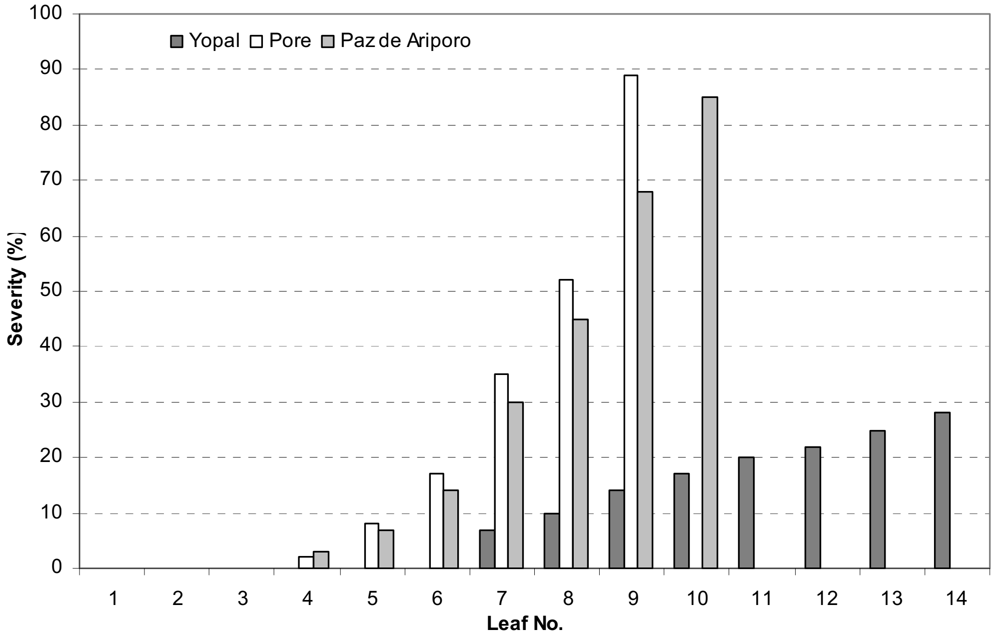

Fig. 8 Black Sigatoka severity on leaves of plantain plants cultivated in agro forestry arrangements at three locations of Casanare.

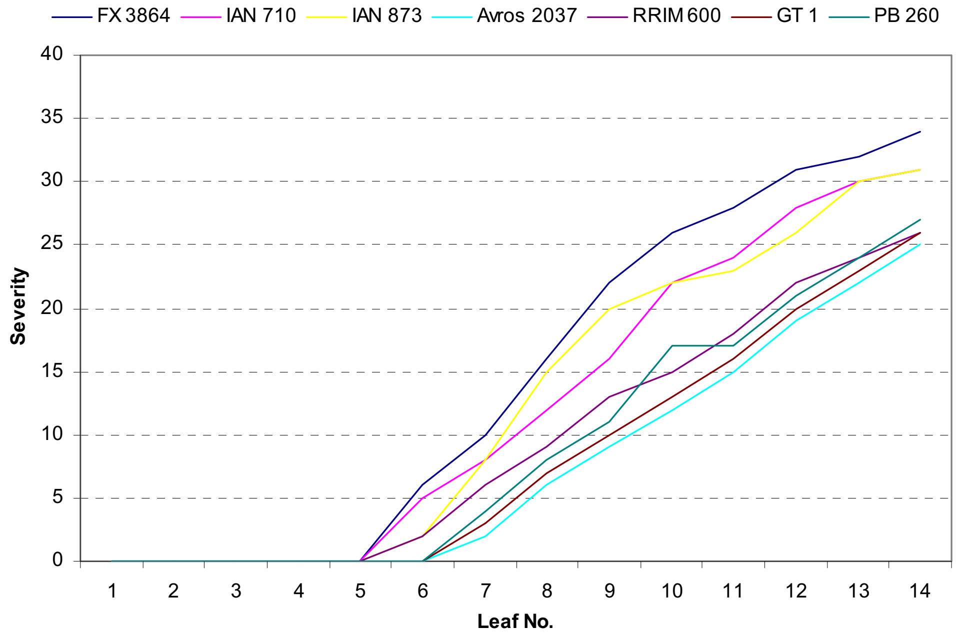

Fig. 9 Severity of Black Sigatoka on plantain associated with rubber. Rubber plants were 7 clons of 3.5 years of age.

conditions for development of Sigatoka are not suitable enough. Despite none of the climatic factors favorable for Sigatoka attack were measured, main reason for lacking of Sigatoka infection is the absence of dew on leaves of plantain. Dew is form on surface of leaves as a result of condensation when temperature differences between leaves and air are enough to condensate. It is called dew point and the pine layer of canopy above the plantain tree makes the differences between air temperature and plantain canopy temperature not appropriate for reaching dew point. Without water spores of the fungus are not capable of germinate, penetrate or even survive on leave surface. Some other factor like wave length of sunlight reaching plantain leaves can be a limiting reason for spores to germinate. However, it was not measured in the present experiment and of course it is not possible to conclude something in this sense.

4. Experiment 4

All three locations of Casanare having similar climate had a very similar behavior of plantain. Plants developed as expected, grew well and had a normal life cycle, but a great difference was observed on level of Sigatoka. It is assumed that those differences were due to system of planting among trials. In Yopal for example, where plantain was sowed beneath a forest, plantain trees showed a higher number of green leaves during the productive cycle. The youngest leaf spotted was number 7 and plants had a total amount of 14 leaves. Severity of black Sigatoka reached an average of 9.57% of infected tissue during the time of observation. The trial at Pore which was started at the same time with the forest grew as a crop exposed to sunlight. Level of disease behaved as it does in a crop without control reaching severities of 23%, YLS was number 4 and leaf 9 was completely destroyed by Black Sigatoka. Paz de Ariporo Trial showed an equal behavior, which also was a crop totally exposed to sunlight. Youngest leaf spotted was number 4 and plants had just 10 leaves, being the last one destroyed by the disease. Severity was also measured at 23.6% (**Fig. 8**).

There is not a synergetic effect of association when forest and crop are started at the same time. At least during the first cycle of plantains, not a benevolent effect can be

Fig. 10 Agro forestry association of rubber and plantains. The rubber crop was first associated with other annual crops and latter soil was protected with *Desmodium ovalifolium*. CI La Libertad; Villavicencio, Meta. **Fig. 11** Plantain intermingled with Ceiba tolúa (*Pochota quinata*), Arauquita, Arauca. Trees completely defoliated during dry season. **Fig. 12** Forest fast-growing species associated with plantains. Melina (*Gmelina arborea*) and Ceiba Tolúa (*Pochota quinata*). Village la Calceta, Yopal, Casanare. **Fig. 13** Melina (*Gmelina arborea*) a fast growing tree intermingled with plantain. Village la Calceta, Yopal, Casanare. **Fig. 14** *Acacia magnium* and plantain in an agro forest system of production. Village la Calceta, Yopal, Casanare. **Fig. 15** Plantain established under shadowing of caracolí. Farm Santa Helena of Fedecacao. Arauquita, Arauca. **Fig. 16** Crop of plantain under a secondary growing forest thinned out to establish the crop. Barranca village, Paz de Ariporo, Casanare. **Fig. 17** Plantains under existing shadowed areas of Bucaré (*Erythrina fusca*). Previously a cocoa plantation. Arauquita, Arauca. **Fig. 18** Brazilian nut tree (*Bertolletia excelsa*), on left, and Copoazú (*Teobroma* sp.), on right, associated with plantain. Embrapa field station Manaos-Boa Vista. Plantain tree is free of Black Sigatoka despite it causes full losses in the region.

observed and measured. A clear indication of it is bunches average weight. Plantain plants at Yopal formed bunches of 15.2 kg. Plants of other two trials have not been gathered yet, but they looked thinner and bunches smaller. A 50% reduction in bunch weight was the expected loss.

5. Experiment 5

A similar behavior of Sigatoka as those seen in previous experiments, was measured on different plots intermixed with varieties of rubber (**Fig. 9**). Nevertheless, slight differences were observed when the Asiatic varieties were compared with Brazilian ones. Sigatoka incidence was lower on plants associated with Asiatic varieties (RRIM 600, AVROS 2037, GT 1 y PB260) which had a higher foliar area index (FAI). Brazilian varieties (IAN 710, IAN 873 and FX 3864) with a lower FAI and a lower insertion angle of branches to the stem allowed more Sigatoka. Black Sigatoka severity was around 12.86% on plants with Brazilian varieties while it was just 8.21% in Asiatic ones. That 4% of lower infection of plants grown with Asiatic varieties indicates a better response of plantain probably because Sigatoka was less favored by shadowing of those materials (**Fig. 10**). The youngest leaf spotted in the plantain plants associated with Asiatic varieties was number 7, slightly lower than their similar planted with Brazilian species which usually showed leaf 6 as YLS.

Observations done on these trials have shown differences of behavior of Sigatoka in each plantain crop according with forest involved. The main effect was age of the forest which is related with tallness of trees. Under pine, severity of black Sigatoka was less than 1%; while in association with rubber of 4 years of age, the Sigatoka severity reached level of 8-12%. Beneath other trees, disease severity also remained around 10%. And the highest level of black Sigatoka severity was observed on plants of plantain which grew at the same time with the forest and behaved like crops without any favorable association or synergetic help. These differences of behavior support the observations that canopy of involved trees change the climatic conditions of the air around the plantain plants. Dew point is not suitable on plantains for dew appearance and of course without such free water the liberation process of spores of the fungus is reduced. Same happen with processes like germination, penetration and incubation, water is required for happening. As stated before, a reduced amount of light reaching the plantain plants might affect the photosynthetic process, but also can cause a negative effect on infective process of spores of Sigatoka which receive a different wave length than required for growing.

Table 1 Chemical analysis of soil of trials with plantains cultivated under agro forestry arrangements (average of 3 replicates). Samples were taken from shadow and sun light sites. Tame, Arauca.

Samples	Depth (cm)	pH	M.O (%)	P (ppm)	AC	Ca	Mg	K	Na	Fe	B	Cu	Mn	Zn
					(meq/100 g)					(ppm)				
Shadow	0- 5	6.3	5.9	216	-	8.0	3.50	0.36	0.16	18	0.40	0.9	61.0	27.7
	5-10	6.2	3.4	218	-	6.1	2.68	0.26	0.17	45	0.32	2.0	27.3	16.0
	10-20	5.6	2.3	143	0.4	4.4	2.40	0.18	0.16	103	0.30	4.1	16.3	4.7
	20-30	5.7	2.1	127	0.4	4.9	2.43	0.20	0.18	92	0.30	3.5	22.0	6.0
Mean		5.9	3.4	176	0.2	5.8	2.75	0.25	0.17	64	0.33	2.6	31.6	13.6
Sun light	0- 5	6.3	5.5	175	-	6.6	3.07	0.28	0.16	25	0.49	2.3	63.3	35.3
	5-10	5.8	2.3	230	0.1	4.1	2.32	0.28	0.15	73	0.28	2.4	25.7	7.3
	10-20	5.5	2.2	171	0.9	4.2	2.45	0.24	0.17	101	0.30	5.9	34.7	7.2
	20-30	5.3	1.7	77	1.9	4.6	2.47	0.23	0.17	108	0.28	6.9	32.7	9.6
Mean		5.7	2.9	163	0.7	4.9	2.58	0.38	0.16	77	0.34	4.4	39.1	14.8

Evaluation of forest species by their good canopy, quick growing and enough sunlight reaching down for plantain trees

Three different types of agro forestry arrangements were observed during the time of trials and have been selected as good association for plantain yielding and adaptability of forest species.

a) Agro forestry system of association between plantain and trees which are planted simultaneously, require fast growing tree species. They create a special shadowing that favors Sigatoka disease reduction and avoid other type of disease control. *Acacia mangium*, *Eucalyptus pellita*, and yopo (*Piptadenia sp.*) are fast growing species that grow more than 4 m per year. Tambor or frijolillo (*Schizolobium parahibum*) grows more than 6 m per year. Balso (*Ocrhoma pyramidale*) which also grows 6 m per year was observed in a farm of a plantain producer with good behavior. Other species like *Erythrinas* (bucaré, cámbulo), *Pseudosamanea guachapele* (nauno, iguá), *Inga* (guamo), *Samanea saman* (samán), *Gliricida sepium* (matarratón), *Acacia*, *Leucaena*, *Anacardium excelsum* (caracolí) and *Tectona grandis* (teca), are middle growing species. They grow from 3 to 4 m/year and have a better response to Sigatoka control on plantains when they are planted 6 months before the crop (**Figs. 11-16**).

b) When the association is started in a forest of secondary growing or shrubby areas, it is suggested to thin out the forest to increase the amount of light reaching the ground. 50% of incident sunlight going through the forest canopy is considered appropriate for plantains. Forest trees of poor quality or palms of no value should be replaced by trees of valuable wood like pink cedar, caobo, walnut, moncoró, etc. (**Fig. 16**).

c) When an agro forestry system has been established for growing some other shadowed species like cocoa and this crop has disappeared, it is required to thin out the forest to get 50% of sunlight passing through the canopy in order to cultivate plantains. A lower amount of light going through means stunting of plants and risk of dying. So 50% of incident sunlight must be kept by pruning the forest every 4-6 months (**Fig. 17**).

d) Last but not least important, is the association including annual crops and forest trees starting at the same time. Plantain as a crop can be included and intermixed with other species, taking in consideration the associated plants and light requirements of each crop involved (**Fig. 18**).

Evaluation of synergetic or antagonist effect between forest trees and plantains trees and possible changes on soil characteristics

There is some ancestral knowledge about synergism and antagonisms among plantain tree and forest species. Such advantages and disadvantages have been observed by farmers and an attempt to classify them has been done by Corpoica technicians.

Table 2 Density of soil at 30 cm of depth, planted with plantains beneath a forest and without it. (Soil humidity: 42%). TAME, Arauca.

Depth (cm)	Shadow	Sunlight
0-10	1.03	1.07
10-20	1.08	1.11
20-30	1.07	1.13

Advantages of such association can be observed by better nutritional levels of plantain, better yielding, similar life cycles and lower level of diseases.

A chemical analysis to the soil where experiment one was done, was conducted in order to determine any differences about availability of nutrients to plantains (**Table 1**). Few variations were measured about levels of some nutrients. Only the amount of Organic material was significantly different and was lower in the soil where sunlight exposure crop was planted. A higher level of potassium was found in ground of shadowed plantains, reaching level of proper requirements for *Musa* species. The level of potassium close to surface of ground where decomposition is taken place was quite high. Potassium is responsible of many synthesis processes within plants and also helps improving resistance capacities to infection of fungus. Plantain plant has a root system close to surface where 75% of active roots are present. So it suggests that higher levels of potassium helped the plantain crop beneath trees for having a better response to attacks of black Sigatoka. A good amount of forest debris is present permanently on areas with trees. In the trials, trees were trimmed out to allow a proper amount of sunlight reaching the plantain foliage. This practice increased the amount of debris decomposed and of course favored the availability of nutrients which explain the high levels of potassium available for the second layer crop.

A test of soil samples was conducted for measuring density of soils cultivated with plantains in Tame, Arauca. Results were pretty similar at depths among 0 to 30 cm suggesting there are not variations because of the type of arrangement with or without shadowing (**Table 2**).

Another sample was taken from an agro forestry system at parish La Calceta in Yopal. The arrangement had plantains beneath a forest of ceiba tolúa (*Pochota quinatta*) and melina (*Gmelina arborea*). The lab test showed physical changes in the soil of the agro forestry system compared with soil with plantains only and even worse compared with soil on cattle farm exploitations. Samples were taken from adjacent areas within the same farm and results are showed in **Table 3**. Hydraulic conductivity was far better on soils of agro forestry than in those of just plantain crops and farther better than soils with pastures for cattle farming. Hydraulic conductivity brings advantages to the soil because improves the ability of holding water-air and improves cationic interchange capacity (CIC). So any crop on soils with these better conditions will have improved development and productivity.

Table 3 Hydraulic conductivity of soils of 3 systems of soil management in a farm of the eastern plains. Village La Calceta, Yopal, Casanare.

Depth	Agro forestry + plantain		Plantain as monoculture		Pastures	
	Hydraulic conductivity cm/h		Hydraulic conductivity cm/h		Hydraulic conductivity cm/h	
	Values	Classified as	Values	Classified as	Values	Classified as
0-5 cm	11.11	Moderate to quick	2.67	Moderate	*	Damaged
5-10 cm	2.89	Moderate	2.00	Mod to slow	0.74	Mod to slow
10-15 cm	18.89	Quick	3.33	Moderate	4.68	Moderate
15-20 cm	12.89	Quick	1.97	Mod to slow	0.49	Slow
20-25 cm	15.55	Quick	0.74	Mod to slow	0.00	Zero
25-30 cm	6.22	Moderate	3.45	Moderate	0.49	Slow

*Spoiled in process

Table 4 Percentage of elements measured on samples of foliar tissue of plantains. Samples from two systems of production agro forestry and exposed to sun light. Tame, Arauca.

Treatment	N	P	K	Ca	Mg	Mn	Zn	Cu	Fe	B
			%					ppm		
Shadowed	1.8	0.30	3.70	0.23	0.25	265	16	7	95	18
Total sunlight	1.8	0.45	2.84	0.55	0.24	270	14	5	88	12

Cattle originate compactation of soils by its process of wandering around while they feed themselves on pastures. The first soil layer (5 cm) where they feed is affected seriously. When rains animals stand over on wet soil causing degradation of structure. A better hydraulic conductivity was observed in soils of agro forestry which had a classification of moderate to fast (11.25 cm/h average), compared with soils cultivated with plantains as single crop that showed a moderate conductivity (2.39 cm/h average).

A foliar analysis of plants of plantain grown beneath a forest and totally exposed to sun light was carried out to determine levels of nutrients absorbed by plants and depending of the agricultural system where they were grown. Samples of leaf surfaces were taken from midrib of leaf number 3 of adult plants at the moment of flowering. Percentage of elements present on leaves was determined by atomic absorbance. Results of evaluations are registered in **Table 4**.

Foliar analysis results indicated similar levels of nutrients on leaves and soil. Exception made of Calcium because this element is associated with respiration process and it is transported within the plant by xylem when it synthesized. Plants growing under shadowed conditions have a lower respiration rate and it is expected of having lower levels of calcium. The amount of calcium in leaves of sunlight exposed plants was higher than shadowed plants. The level of elements in soil of shadowed forest areas was better than the cropping at sun light exposure. Shadowed plants also had a good amount of potassium in correlation with higher levels of this element in soil of forested areas.

Pruning and trimming of trees increased the amount of forest debris adding elements to soil. A simple calculation of the amount of green material removed from the forest contributed with approximately 21.3 tons of organic debris per year. So, it is possible to estimate that from that organic material some 420 kg of N, 74 kg of P, 572 kg of K, 54 kg of Ca and 42 kg of Mg, could be added to soil. Such contribution is enough for a good physiological development of any crop. It is also possible to say that no fertilizer applications would be necessary for balancing a nutrient program for plantains.

Some negative effects of the association between forest and plantains were also observed and defined in three groups. First antagonism was stunting of plantains, second was competition by nutrients and third was physical damages by losing part of the tree structure.

First one is an association with trees which have a dense canopy and ball like shape. They form dense shadowing and causes stunting of plantain plants. *Samanea saman* is a clear example of this type of trees that can be replaced by similar ones like *Pseudosamanea guachapele* with canopy in layers and a lower retention of sunlight. Besides, wood from *Pseudomanaea* is far better than the one from *Samanea* and growing rate is quite similar.

Second group of trees occurred when there is an evident antagonism between the forest tree and the plantain plant. Antagonism might occur because tree reduces availability of nutrients to plantain or even availability of water. Dinde mora (*Chlorophora tinctoria*) and black or white pardillo (*Cordia alliodora y Cordia gerscantum*) compete for water with plantains. So, it is not recommended to associate such a tree with plantains.

Third group is related with trees which loss part of their structure and might cause damages to plantain trees. Softest ones are those having defoliation during the dry season like cieba tolúa, pink cedar and rubber after its fifth year. Absence of canopy during the dry season is disadvantageous because causes not hydraulic regulation of water in the soil. However, it could be consider a light trouble in areas with not many troubles of availability of water. Trees like *Erythrina* release remains of flowers during blossom time. On such remains a fungus called fumagina (*Meliola chagres*) grows on and so it does over any other material where the remains are deposited. When a plantain crop exists under an *Erytrina* forest, fumagina grows on surface of leaves. Fumagina fungus causes not problem on crop otherwise than a probable reduction of photosynthesis due to its presence on surface. A harder effect of losing part of their structures is the case of palms when old leaves come to the ground and are capable of destroying a plantain plant. Caracolí tree also releases branches in a natural way and they destroy whatever is down.

Shadow effect on productive cycles of plantain and quality of fruit

In **Table 5** are registered some observations of productive cycle of plantains and weight of bunches on trials conducted at several locations. There are different types of productive systems registered in the table. The most contrasting ones are of course the opposites. Single crop plantains had a good weight of bunches between 12 and 18 kg. But for reaching those weights the plantation demanded a good control of Sigatoka and fertilization programs. In contrast, agro forestry systems produced bunches of 14 to 17 kg and did not demand black Sigatoka control. They did not require fertilization programs either, because the association with forest offered plantains a remarkable level of nutrients. Agro-forestry systems also behaved very well on poorer soils like the high terraces (Villanueva and Villavicencio), where bunches weight 12.7 to 15.7 kg. Unfortunately there were no registered data of bunches produced on single crops on high terraces, but local observation indicated they hardly reach 10 kg.

It seems also that type of tree associated with plantains can influence positively bunches weight as data of trials suggest. Samán and Bucaré trees produced better bunch size than other trees.

Table 5 Average bunch weight and vegetative cycle of plantains at several locations of eastern plains. Agro-forest system of production compared with single crop system.

Locations	System	Accompanying trees	Bunch weight (kg)	Vegetative cycle (days)
Fuente de Oro (Meta)	Single crop, one cycle per year* 9 sprayings against Black Sigatoka 1st cycle planted in September. Alluvial soils (C1)		16.2	340
Paratebueno (Cundinamarca)	Single crop, one cycle per year 13 sprayings for black Sigatoka Irrigation system for drought Alluvial soils (C2)		15.3	350
Tame (Arauca)	Single crop, perennial* 10 sprayings for black Sigatoka Alluvial soils (C1)		18.0 (1st cycle) 15.5 (2nd cycle) 13.2 (3d cycle) 12.0 (4th cycle)	332 (1st cycle)
El Castillo (Meta)	Single crop, perennial* Without sprayings against BS Alluvial soils (C1)		11.0 (1st cycle) 9.2 (2nd cycle) 7.5 (3d cycle)	350 (1st cycle)
Saravena (Arauca)	Single crop, perennial Without sprayings against BS Alluvial soils (C1)		9.8 (1st cycle) 7.6 (2nd cycle) 6.5 (3d cycle)	355 (1st cycle)
Tame (Arauca)	Agro-forestry system, perennial Without sprayings against BS No fertilizers used Alluvial soils (C1)	Samán and bucaré thinned out till 50% of shadowing beneath them	17.3 (1st cycle) 16.8 (2nd cycle) 16.2 (3d cycle) 15.7 (4th cycle) 15.3 (5th cycle)	410 (1st cycle)
Saravena (Arauca)	Agro-forestry system, perennial Without sprayings against BS No fertilizers used Alluvial soils (C1)	Bucaré thinned out till 50% of shadowing beneath them	15.5 (1st cycle) 15.0 (2nd cycle) 14.3 (3d cycle) 14.1 (4th cycle) 14.0 (5th cycle)	407 (1st cycle)
Villanueva (Casanare)	Agro-forestry system, perennial Without sprayings against BS High terrace soils (C4)	*Eucalyptus pellita* planted at 4 m × 2 m and same plantains	14.2 (1st cycle) 12.7 (2nd cycle)	370 (1st cycle)
Villavicencio (CI la Libertad, Meta)	Agro-forestry system, perennial Without sprayings against BS High terrace soils (C4)	7 rubber clones plantain planted at 3d year of rubber	15.7(1st cycle)	395 days for Brazilian rubber and 415 for Asiatic ones
Yopal (Casanare)	Agro-forestry system, perennial Without sprayings against BS Alluvial soils (C2)	Secondary forest thinned out for planning plantains	15.2(1st cycle)	402 (1st cycle)

*One cycle per year is a crop planted for collecting once, while perennial is a year round production.

Two traditional localities where plantains are produced by poor farmers, where evaluated in these trials (El Castillo and Saravena). Plantain over there is usually cultivated as a single cash crop, perennial, without black Sigatoka control and scarce fertilization. So, bunches are usually small, low weight and poor quality (weighted between 6.5 and 11 kg in trial, **Table 5**). They are sold for local consumption mainly reaching prices of just US$ 0.09/kg. In a market like Bogotá, a good plantain gets values of US$ 1/kg. This bad quality of plantains has discouraged farmers of keeping on in business.

Agro forestry system established in Saravena showed that plantains form better bunches of better weight and keep producing same quality, cycle after cycle. It was far better than single crop system used in the region for decades. Only life cycle duration has been affected slightly by the forest. In farms where association with trees was established, plantain plants elapsed 50 days more than those planted as single crop in sunlight exposure.

An economical comparison of costs of production of plantains under these two types of agriculture systems is a must in order to give best advising about plantain production. A single crop production system cost US$2.300/ha/year (indirect costs only). It does not matter whether you place your crop beneath a forest or exposed to sun light, costs will be the same. But according with results when you establish the crop under a forest, there is not need of controlling black Sigatoka. There is not a competency with weeds and because of the supply of nutrients by forest debris; the need of applying fertilizer is solved.

In economical terms it is possible saving money in activities not done. Black Sigatoka control may cost US$450/year (between 7-10 sprayings), weed control cost US$200/year (4 cycles), and fertilization program values US$390 (3-4 cycles). Summarizing such items there is a reduction of US$1.040 or 44% of lower cost. A survey done during some field activities with plantain farmers in the city of Arauca, confirmed that implementing agro-forestry system with plantains as a secondary accompanying crop may reduce production costs to levels of 60%.

A final observation of the agro forestry system is the capability of having higher yields. Usually, plantain crop in agro forestry arrangements have yield 10 tons more of plantains than single crops sun light exposed.

CONCLUSIONS

After five years of research and having good supporting evidence is possible to conclude:

- The agro forestry arrangement for plantain production reduces strongly black Sigatoka severity. There are some climatic factors altered under this association which causes such changes. Sun light is responsible for temperature rising. Less sun lighting above plantain leaves make them get warmer slowly and sometimes lesser rise temperature than exposed to sun light plants. When sunset starts and leaves get colder, those protected by forest canopy loss less temperature than exposed ones. A more stable temperature of leaves makes dew point difficult to reach on surfaces affecting presence of free water which influences spore germination, fungus infection and further tissue colonization.
- Black Sigatoka fungus produces a phytotoxin called Cercosporin. Such metabolite is synthesized under

some wave length conditions. When plantain is cropped in agro-forestry system conditions of light within the forest, it seems to be unfit for developing such metabolite. So, apparently these are part of factors affecting Sigatoka metabolism in a forest that were responsible for lower levels of disease.

- Agro forestry arrangements offer a good alternative for producing plantains and timber. Nevertheless, it is necessary to take in consideration type of tree, arrangement of planting and age of forest, because all of them affect the association. Synergetic effects were observed with almost all trees and antagonism were also evidenced due to limiting factors. It is suggested to take these results as a guide for planting agro-forest systems, but local evaluations and local trees must be considered before a suggestion is made.
- A longer productive cycle of plantains has been registered under forestry systems. Initially, it could be consider a problem, but a healthier crop with good production and good quality of fruit makes this longer cycle a minor factor. Besides, increases on life cycle were only 10% of total cycle, while increases on production were of 50% and reduction costs were of 44%. So there is no problem with plants lasting a bit longer in field.
- Agro-forestry system makes a better management of soils and improves nutrition to both trees and plantains. Permanent addition of green material coming from all plants causes an improving of physical and chemical conditions of soil. Plantain production was possible beneath a forest without supplementation of fertilizers because of adding of nutrients from debris.
- Agro forestry system has proved to be good for controlling other production limiting factors. A CATIE trial in Costa Rica showed that forests reduce damage by nematodes as a result of a depleted population. Same happened in Arauca where populations of root borers were reduced and get incapable of causing losses.
- Agro forestry is an arrangement very well fitted to be implemented for small farmers who have not enough money for producing under sunlight conditions. It is an alternative for areas of agriculture at the foot of the mountains in the eastern plains and favors all type of farmers from small to industrialize. It is also good for the planet because place us in an alternative agriculture more amicable with environment.
- Best result of agro forestry was reduction costs of plantain production and improved quantity and quality of plantain fruit. These favorable results are a synergetic effect of production which takes advantage of the best offer of each crop and best natural behavior on agriculture.
- As agriculture beneath a forest does not require chemical protection or supplementation of nutrients by pesticides or fertilizer, the yielding of such crops can be considered natural product and offered as organic production.
- Agro-forestry is not new in Colombia; association of plantains with other trees is a common practice in many parts of the country. It is possible to find plantains growing in middle of rows of citric, fruits and nuts. However, it is suggested to evaluate their advantages and disadvantages before any association is made. Some fruit trees must be evaluated in trials.

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