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Surveillance and forecast preliminary study for black sigatoka (*Mycosphaerella fijiensis* Morelet) disease in *Musa* AAB cv Hartón plantain crop in "Macagua-Jurimiquire", Yaracuy state

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Abstract

To establish a survey and forecast program for black sigatoka disease in *Musa* AAB cv Harton plantain established on growing in small production system. The severity average index (SAI), youngest spotted leaf position (YSLP), foliar emission (FE), daily precipitation (PP), relative humidity (RH), evaporation (EVA), maximum and minimum temperature (Tmax and Tmin), cloudiness (CL), insulation and radiation were determined every 2 weeks. The averages per month for some of these climatic variables were: PP 143.5 mm; Tmax 29°C; Tmin 21°C and RH 78.5%. The SAI was correlated to the climatic variables during 8-consecutive weeks, previous to evaluate the disease severity. The variable with the best correlated coefficients were analyzed by using multiple regression method. The higher values of SAI were observed in January 1.31; May 1.14; September 1.32; October 1.20 and December 1.21 during this study. The YSLP average was 5.38 with a maximum of 6.88 and minimum of 4.40; while SAI average was 1.13 with a minimum of 0.64 and a maximum of 1.32. A negative correlation were observed between SAI and YSLP (r = - 0.7132), and between SAI and FE (r = - 0.2556). The disease behavior is 33.32% explained by the following equation: SAI = 3.7241** - 0.0047**CL – 0.0015**Tmin +

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2.019**RH – 0.0051**EVA, according to accumulated values during 6-consecutive weeks previous to the last week of SAI observation.
Key words: epidemiology, disease incidence, pest integrate management, climate, black sigatoka disease, *Musa* AAB, Venezuela.

Introduction

Plantain (*Musa* AAB) is very important in the diet of the Venezuelan, though for lots of years the crop has been handled traditionally and with few reorientation opportunities of the productive system (17).

In 1998 the national surface of this crop was of 73.606 ha (2). For 1999, in Yaracuy were reported 1.735 ha and a yield of 9.8 t/ha; municipalities of higher importance for this season were Veroes with 732 ha and San Felipe with 513 ha, followed by Nirgua, Bolívar, La Trinidad, Cocorote, Sucre, José Antonio Páez and Bruzual municipalities (10).

Black Sigatoka is an illness that affects severely the plantain crop if it is not handled in the right moment. The causal agent of the illness is fungus *Mycosphaerella fijiensis* Morelet, which imperfect shape corresponds to *Paracercospora fijiensis* (Zimm) Deighton (21). The banana industry is seriously threatened when the illness is on the plantations, due to the huge quantity of spores (ascosporas) that the fungus produces; the control difficulty and the high cost since the highest sporulation happens in the **envés** of leaves and the infection pattern is toward the central vein (19).

Black Sigatoka is the illness that causes more damages in the production of the banana and in plantain, general lost have been estimated in approximately from 50 to 100% (23, 31). It affects drastically the foliar system and causes important lost in the crop, in banana, lost are from 10 to 30%, also lost in quality of the fruit by premature ripening (27). In plantain lost mainly happen in small plantations when it is not controlled chemically (5).

In Venezuela the illness was firstly detected in 1991, in Zulia state. In 1992 started to extend to Mérida, Trujillo and Barinas states, and from 1994 to 1997 disseminated in Portuguesa, Yaracuy, Carabobo, Aragua, Miranda, Sucre, Bolívar and Delta Amacuro (11). After being in the Independencia municipality, Yaracuy state (1994) started tracking activities of the illness in plantations of the state, including neighbors areas to Lara and Carabobo. Consequence of this tracking, sigatoka negra was found in all producers municipalities of banana and plantain of Yaracuy and Carabobo states (11).

The fungus agent of the illness develops in leaves in different position of the plant, in rainy or drought periods, though it turns more severe when the relative humidity is higher and with high precipitations. The evolution velocity of the illness depends on the behavior of the air temperature and of the duration of leaves with sprinkling and rain. There is a highly significant relation between the illness and the number of weekly leaves with relative humidity superior at 95% in six and eight weeks previous to the observation of the illness (20).

Researches mention the relation between weather, incidence and the development of the illness (3, 5, 30). In Venezuela was observed the influence of weather in areas, where the black sigatoka caused damages in the production, which are characterized by having a higher precipitation of 1.520 mm/year, in variable concentration of six to ten months, relative humidity of 80 to 82% and average temperature between 25 and 28ºC (16).

The illness has been controlled in different countries using fungicides and mixing them with products, with a scheduled application frequency independently of the environmental conditions and the severity of the illness, even doing 19 application per year in some cases (6). Fungicides, specially the systemic ones, still have an effective control against black sigatoka; however, the resistance development of the pathogen against these agro-chemical had been observed, besides, the effects in the environment are worrying (8).

The environmental registers allowed to use information to detect and to control the illness (7). Due to the elevated number of applications of chemical products, black sigatoka has been handled in some areas of the world using warning systems of biological and physiological type (14, 26). For example, an alternative proposed in Costa Rica was to predict the latent period of black sigatoka using the procedure "Step by step regression", where with information collected in two localities selected, two models that explained 78% of the variation observed in the latent period of the illness (24).

The objectives of this investigation were: 1) To evaluate the progress of black sigatoka in plantain crop at Macagua-Jurimiquire, Veroes municipality, Yaracuy state. 2) To correlate the progress of the illness with environmental of the area under study. 3) To determine an equation to guard and to detect black sigatoka, as a strategy of integral handling of the illness in small production systems of plantain.

Materials and methods

Description and location of the production unit:

A plantation of 10-year-old plantain *Musa* AAB cv Hartón was selected with continuous exploitation and with a surface of 4 ha, located at Macagua-Jurimiquire, Veroes municipality, Yaracuy state, bordering Yaracuy river and located approximately at 20 Km of San Felipe city, at 10º 21’ 45” of latitude and 68º 39’ 00” of longitude, and a height of 107 msnm (4). The area corresponds to the classification of Tropical Dry

Forest (12), with sandy loamy texture, low in phosphorus, potassium, organic matter, electrical conductivity and very high in calcium.

During the evaluation period (1998-2000), the area presented a maximum temperature of 29ºC, and a minimum temperature of 21ºC, and an average temperature of 25ºC; with relative humidity of 78.5% and a precipitation of 143.5 mm (4).

From the total surface of the smallholding (4 ha), 1 ha was selected where 25 sampling units were established, each one constituted by one plant in a complete vegetative development and with an average of seven photosynthetically active leaves (2 months old). In each plant were evaluated relative variables in the crop and relative variables in the incidence and severity of the illness, until the emission on inflorescence. Once the plant emitted inflorescence, a new plant was selected near the one eliminated for sampling, and with the same characteristics previously described.

Evaluations started in June, 1998, and finished in December, 2000 with a fifteen-day frequency between evaluations.

Variables evaluated in the research:

1) Variables related to the incidence and severity of the illness: the damage proportion of the illness in each leaf was established according to the modified Stover scale (6, 28, 29); the position of the youngest leaf spotted with black sigatoka (PHJM), numbering leaves through the short blade and down (13). With this information, the average infection was determined (PPI), where PPI= $\sum$ [(spotted leaf by degree x corresponding degree of severity)]/total of evaluated leaves by plant which result is expressed as an index that expresses the severity of the illness.

2) Variable related to the crop: foliar emission (EF), which represents the number of leaves emitted by the plant, it is expressed in «hojas candela» (1) and number of photosynthetically active leaves by plant (NHP).

3) Variables related to the weather: according the weather registered given by the meteorological station of Danac-Polar foundation and the Environmental and Natural Resources Department (4), located at San Javier-Guarataro road, approximately at 10 Km from the area under study, during the research period were daily measured: maximum temperature (TMáx) and minimum temperature (TMín) in ºC, precipitation (PP) in mm, relative humidity (HR) in percentage, evaporation (EVA) in mm, cloudiness (Nub) in octavos, sunstroke (Ins) and radiation (Rad) in cal/cm^2/min.

Statistical analysis of results:

The information compiled in the field was registered in a calculus paper, where PPI, PHJM and the EF average were determined. For the analysis of the information the normal distribution of variables was considered with the WILK-Shapiro test, to those cases where data did not have a normal distribution, the transformation of these was done.

Variables where was not possible their normalization were handled according to their nature with the non parametric via. Data was processed using the Statistix software. Version 7.0.

In order to select the best equation that would estimate the behavior of black sigatoka, the phytopatological variables (PPI and PJM) and the climatic (HR, Tmax, Tmin, Eva and Nub) were evaluated. A correlation analysis between variables and subsequently a multiple regression analysis were done, where the dependent variables were those related to the severity of the illness and those independent to the weather. Finally, to evaluate the behavior of black sigatoka in function of climatic variables, data was processed by two methods. The first related PPI to the accumulated values and successions of the climatic variables of one, two, three, four, five, six, seven and eight weeks prior the evaluation date of the severity of black sigatoka in the plantation. In the second method were analyzed the accumulated information from one to eight weeks previous to the evaluation of the illness, but considering the accumulated values of one week only. In both cases, the week where each variable had the highest correlation coefficient was analyzed by multiple regression in function of PPI (22).

Results and discussion

Behavior of the position of the youngest spotted leaf, of the infection average and foliar emission:

The annual average value of PHJM was 5.38; with a minimum value of 4.40 and a maximum value of 6.88 spotted leaves with black sigatoka. While the average of PPI was 1.13; with a minimum value of 0.64 and a maximum of 1.32 during the evaluation period. The average of EF was 1.42 leaves with a minimum value of 0.70 and maximum of 3.0 emitted leaves fortnightly (figure 1, table 1). The number of leaves per plant was considered to determine PPI.

The behavior of the illness was subjected to a dynamic that depended on the environmental conditions during 1998-2000, which showed different development phases, which indicates that the illness is cyclic showing variable fluctuations during the year and during the years of the evaluation, with an abrupt exponential growth between june-july, august-september, november-january and april-may (figure 1). Then a deceleration phase of the growth appears in september-november and January-april. The time where appeared symptoms of the illness with higher severity was in January, may and September, after this time it can be said that a self-destruction phase of the fungus was defined in February, march, april and October; since it was observed a recovery period of the plant, corroborating it to the increment of values of PHJM (figure 1).

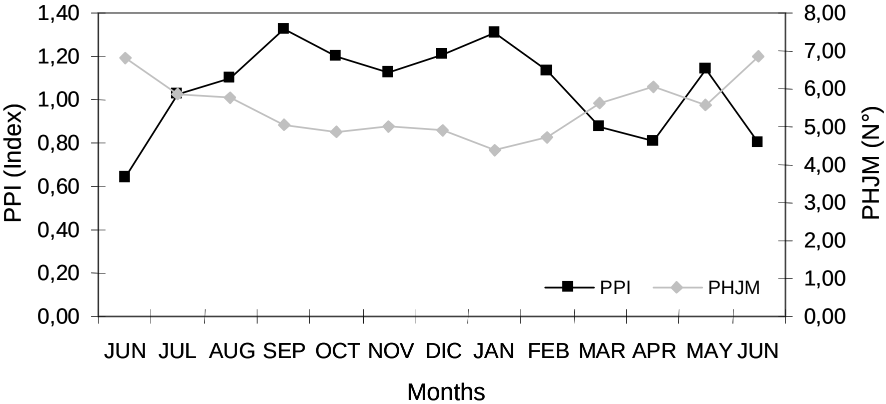

Figure 1. Average of infection (PPI) and position of the youngest spotted leaf (PHJM) with black sigatoka in plantain. Macagua-Jurimiquire, Yaracuy. June 1998 to december 2000.

The progress curve of black sigatoka by year of study showed that the highest incidence and severity of the illness occurred in september and october, 1998; in january, may, august and october, 1999; and in january, september, october and december, 2000 (figures 2 and 3). Once known the dynamic of the illness, an integral handle program of black sigatoka was established (6, 22, 15), according to the obtained results, practices of phytosanitary control in Macagua-Jurimiquire and in the areas with similar environmental conditions, in months of growth or exponential

Table 1. Descriptive statisstics[1] for an average of infection (PPI), the youngest spotted leaf (PHJM) with black sigatoka and foliar emission (EF) in plantain. Macagua-Jurimiquire. June 1998 – december 2000.

Statistics	PPI (Index)	PHJM (No.)	EF (Leaves. blossom)
Average	1.13	5.38	1.42
SD	0.25	0.81	0.45
Variance	0.07	0.65	0.20
CV	22.5	14.90	1.73
Minimum value	0.64	4.40	0.70
Maximum value	1.32	6.88	3.08
Kurtosis	0.26	2.22	0.35
Wilk-Shapiro	0.96	0.91	0.93

[1] For the estimation of statistics a population N= 92 was considered.

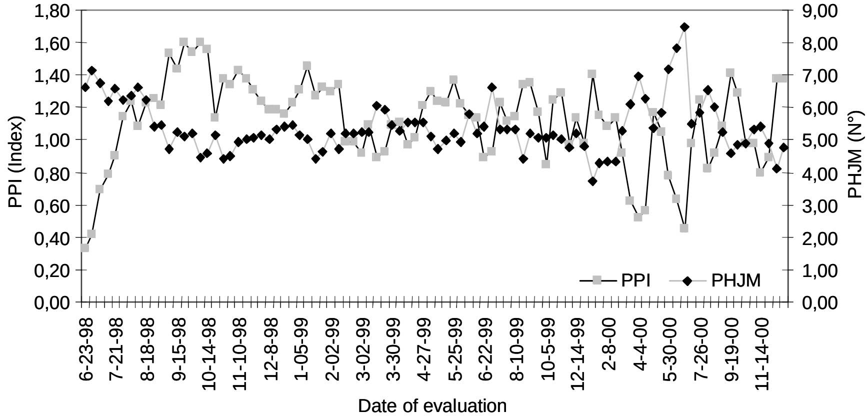

Figure 2. Distribution of the average of infection (PPI) and position of the youngest spotted leaf (PJM) with black sigatoka in plantain. Macagua – Jurimiquire, Yaracuy. June 1998 to december 2000.

phase of the illness. In this area, it is adequate to do a preventive control in march-april, june-july and November.

In México, during 1985-1987 a study determined that black sigatoka had annual epidemical cycles where an exponential phase was seen from the beginning of the rainy season (june-august) and an end phase induced by the change of the rain and a reduction of the temperature that affect the pathogen in september-octuber, and finished in april and may of the following year (22).

In the correlation analysis, a highly significant inverse relation was observed ($\alpha \leq 0.05$) between PPI and

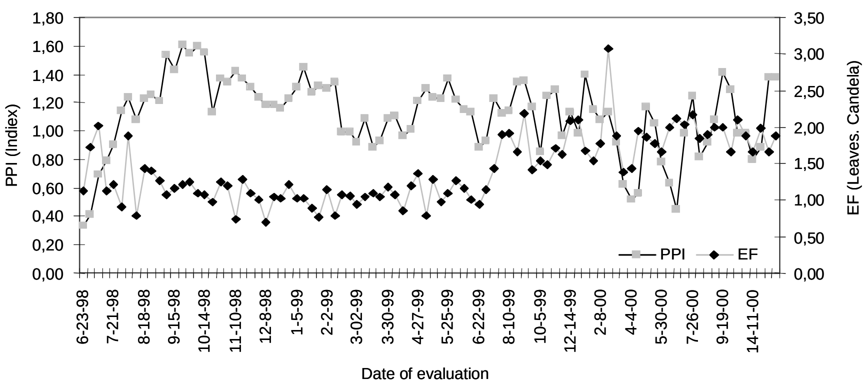

Figure 3. Distribution of the average of infection (PPI) of black sigatoka and the foliar emission (EF). Macagua-Jurimiquire, Yaracuy. June 1998 to december 2000.

PHJM with black sigatoka (r = -0.7132**); this indicates that when the degree of severity increases, the position of the youngest spotted leaf reduces, due to leaves near the short blade (candela) show the first symptoms of black sigatoka. This relation has been observed in other investigations, in Honduras for example, was observed an inverse correlation between PHJM and the intensity of the illness (28); and this same behavior was mentioned by Gauhl in Costa Rica (5).

The relation between PPI and EF was inverse and significant, with a correlation coefficient same at r = -0.2556*; when the severity of the illness increases, the production of leaves in the plant reduces (figure 3). Physiologically, it is proved that a plantain plant must produce an average of seven leaves to emit a well formed bunch (18).

None correlation was observed between PJM and EF (r = 0.1067^{ns}), which indicates that the plant emits leaves in presence or absence of black sigatoka; this might be observed in the progress curve of the illness for these two variables (figure 4), though when the illness is severe with a high index of PPI, EF is slower. Also, it has been mentioned that there is not any relation between the vegetative cycle of the plant and the number of leaves at flowering (18).

Relation between climatic variables and the average of infection:

The evaluated methods allowed to establish regression equations that related different levels, the behavior of the illness in function of the climatic conditions (table 2 and 3). The most adequate method to determine the regression equation that explains the behavior of the illness resulted to be the one where the consecutive

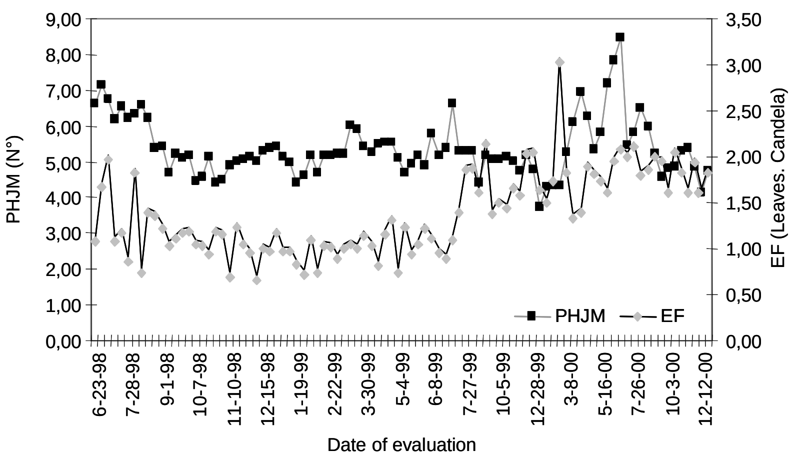

Figure 4. Position distribution of the youngest spotted leaf (PHJM) with black sigatoka and the foliar emission (EF) in plantain. Macagua-Jurimiquire, Yaracuy. June 1998 to december 2000.

Table 2. Regression variables for the dependent variable for the average of infection of black sigatoka in function of accumulated variables consecutive by week of variables precipitation, relative humidity, maximum and minimum temperature, evaporation and cloudiness. Macagua-Jurimiquire, Yaracuy. Junio 1998 – december 2000.

Sem	Variables and coefficients with their probabilities for each equation and= $a + bX_1 + cX_2 + dX_3 + eX_4 + fX_5 + gX_6$	R^2
1	PPI = 2.1039** - 0.0131(Nub)* - 0.0027(Tmin)*	0.1002
2	PPI = 1.0659** + 0.0040(Tmax)** - 0.0055(Tmin)**	0.1260
3	PPI = 2.8247** - 0.0086(Nub)** - 0.0016(Tmin)**	0.1760
4	PPI = 2.9776** - 0.0071(Nub)** - 0.0014(Tmin)**	0.1861
5	PPI = 3.6497** - 0.0063Nub** - 0.0017Tmin** + 1.4268HR** - 0.0042Eva**	0.2861
6	PPI = 3.7241** - 0.0047Nub** - 0.0015Tmin** + 2.0190HR** - 0.0051Eva**	0.3332
7	PPI = 1.6336** - 0.0029Tmin** + 0.0018Tmax** + 2.6145HR** - 0.005Eva**	0.3042
8	PPI = 1.5814 – 0.0026Tmin** + 0.0016Tmax** + 2.7783HR** - 0.0045Eva**	0.2992

PPI: average of infection, PP: precipitation, HR: relative humidity, and Tmax: maximum temperature, Tmin: minimum temperature, Eva: evaporation and Nub: Cloudiness. Sem: week.

Table 3. Regression model for the dependent variable of average of infection of black sigatoka, considering accumulations from one to eight weeks of variables precipitation, relative humidity, maximum and minimum temperature, evaporation and cloudiness prior to the evaluation of PPI. Macagua-Jurimiquire, Yaracuy. June 1998 – december 2000.

Sem	Equation and probability of coefficients and their variables and= $a + bX_1 + cX_2 + dX_3$	R^2
1	PPI = 2.0776** - 0.0117Nub* - 0.0028Tmin*	0.1002
2	PPI = 1.0239** + 0.0048Tmax* + 0.0061Tmin**	0.0752
3	PPI = 2.1019** - 0.0119(Nub)* - 0.0109(Eva)**	0.1143
4	PPI = 1.9882** - 0.0109(Nub)* - 0.0091(Eva)**	0.0890
5	PPI = 1.1405**	0.0000
6	PPI = 1.1432**	0.0000
7	PPI = 1.1368** - 0.0130Nub** + 0.0008HR* + 0.0012PP**	0.1424
8	PPI = 1.6084** – 0.0111Nub*	0.0594

PPI: average of infection, PP: precipitation, HR: relative humidity, and Tmax: maximum temperature, Tmin: minimum temperature, Eva: evaporation and Nub: cloudiness. Sem: week.

accumulated values for some weeks were considered of variables precipitation, relative humidity, maximum and minimum temperature, evaporation and cloudiness (table 2).

The equation that explained the PPI of the black sigatoka in the area under study was the one that considered the accumulated values of the climatic variables of six consecutive weeks and prior to the last week of the evaluation of PPI, with a low determination coefficient that might be considered acceptable (R^2 = 0.3332) with a high statistical significance for a £ 0.05 in each of the equation coefficients, this was obtained from the first analyzed method (table 2). This indicates that 33.32% of the illness behavior is explained by the accumulated values for six consecutive weeks of variables cloudiness, minimum temperature, relative humidity and evaporation, prior to the evaluation of the illness in the field, expressed by the equation:

PPI = 3.7241** - 0.0047** Nub – 0.0015** Tmin + 2.019** HR – 0.0051** Eva.

The fact of taking as reference the weather information registered by a meteorological station located at 10 Km of the area under study might had influenced in the obtained percentage of 33.32%. Though it can be affirmed that the rest 66.68% might be attributed to other factors that were not studied in this investigation. In other study, significant results were found when the climatic information was registered inside the plantation; a multiple regression analysis was done between PPI and the climatic factors (Stepwise) a 76.95% of the severity explanation was found for the 14 climatic variables, where T of the afternoon air, HR day and night and events without PP, 20 days before (25) were emphasized.

On the other hand, the severity variation depends on the interaction pathogen, host, weather and space, as has been said in other investigations (15, 22), therefore it must be considered the use of agronomical practices of the crop in this investigations, as for example, to strip in the right moment and in a controlled way, weeds control (as alternant hosts), as well as the fertilizer use, which was not considered in this investigation.

The highest, most significant and highly significant association for a £ 0.05, between PPI and the climatic variables in Macagua-Jurimiquire, was found with PP accumulated for two weeks (14 days) (r = 0.2816*), HR accumulated for six weeks (49 days) (r = 0.4749**), Nub accumulated for three weeks (21 days) (r = -0.3928**) and sunstroke accumulated for eight weeks (56 days) (r = 0.4713**). An investigation done at the South of Maracaibo's Lake showed a correlation between severity of the attack of the illness and precipitation, air temperature and relative humidity accumulated for 25 days prior to the evaluation of black sigatoka (7).

It could also be determined a dependence relation between PPI with Tmin and Nub, accumulated for one, three and four weeks, but with a low determination coefficient. Meanwhile, consecutive accumulations of Tmaz, Tmin, HR and Eva were related with the PPI of seven and eight weeks accumulated consecutively and prior to the calculus of PPI with values of approximately $R^2 = 0.30$ (table 2).

Studying the multiple regression for the second analyzed method between PPI and accumulated climatic variables of even eight weeks (table 3), none observation was observed between PPI and climatic variables; the determination coefficients (R^2) were very low. The highest R^2 was of 0.1424 for seven weeks, this means that 14.24% of PPI is attributed to variables Nub, HR and PP accumulated for one week, but seven weeks prior to the illness evaluation in the field.

This investigation was done in the plantain crop, and it was observed that precipitation was not presented as a determinant factor in the incidence of black sigatoka. Though in banana has been determined that the most influent behavior of this illness is PP, by its frequency or intensity (19).

Conclusions and recommendations

This investigation constitutes a surveillance and forecast preliminary study done in the country, which determined and quantified the existent relation between incidence and severity of black sigatoka and meteorological conditions (cloudiness, temperature, relative humidity and evaporation) in plantain crop, using the statistical procedures in an area of small producers as is AC Macagua-Jurimiquire, Veroes municipality, Yaracuy state.

The mathematical model that was obtained, explains in 33.32% the severity of black sigatoka through PPI, attributed to cloudiness, minimum temperature, relative humidity and evaporation, accumulated for six consecutive weeks and prior to the evaluation of the illness. It is recommended to continue investigating the behavior of the illness considering the install of a climatic station in the experimental plantation.

This investigation represents a contribution to the information of this illness, therefore the validation of the obtained model is recommended, also to continue doing investigations that would integrate variables as cultural practices of the crop as well as doses of the fungicide against black sigatoka.

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