A biological forecasting system to control Sigatoka disease of bananas and plantains

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Abstract — **Introduction**. This protocol aims at monitoring the development of Sigatoka disease (*Mycosphaerella musicola / Pseudocercospora musae*) of banana plants in order to control this disease with a minimum of fungicide applications. A good timing of fungicide application will result in lower cost of control, lower risk of fungicide resistance and lower negative environmental impact. The principle, key advantages, starting plant material and expected results are presented. **Materials and methods**. Details of the seven steps of the protocol allowing banana plot preparation, data collection, stage of evolution of the disease (SED) calculation, and timing of fungicide applications are described. Possible troubleshooting is mentioned. **Results**. Weekly observation of selected banana plants allows filling in a data sheet used for the calculation of the SED. A graphic representation of the weekly evolution of this SED can then be used for timing of fungicide spraying decisions.

France (Guadeloupe) / *Musa* sp. / methods / disease control / *Mycosphaerella musicola* / agricultural warning services

Un système d'avertissement biologique pour le contrôle de la maladie de Sigatoka chez les bananiers et plantains.

Résumé — **Introduction**. Ce protocole permet de quantifier le développement de la maladie de Sigatoka (*Mycosphaerella musicola*) du bananier pour raisonner la lutte chimique de cette maladie avec un minimum de traitements fongicides. Une bonne programmation de l'application des fongicides permettra de diminuer le coût du contrôle, le risque de voir apparaître des souches de *M. musicola* résistantes aux fongicides, et l'impact négatif des traitements sur l'environnement. Le principe, les principaux avantages, le matériel végétal de départ, et les résultats attendus de la méthode sont présentés. **Matériel et méthodes**. Le détail des sept étapes de réalisation du protocole permettant la préparation de parcelles en bananeraie, la collecte de données, le calcul de l'état d'évolution de la maladie (EE) et la programmation de l'application des fongicides est décrit. De possibles problèmes sont évoqués. **Résultats**. L'observation hebdomadaire des bananiers choisis permet de remplir une fiche de données utilisée pour le calcul de l'EE. Une représentation graphique de l'évolution hebdomadaire de cet EE peut être alors utilisée pour programmer l'application des fongicides.

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1. Introduction

Application

This protocol aims at monitoring the development of Sigatoka disease (*Mycosphaerella musicola / Pseudocercospora musae*) [1] in order to control this disease with a minimum of fungicide applications. A good timing of fungicide application will result in:

– lower cost of control,

– lower risk of fungicide resistance,

– lower negative environmental impact.

Principle

The biological forecasting system is based on the early detection of new attacks through the calculation of the Stage of Evolution of the Disease (SED). This SED represents the speed of evolution of the disease, which reflects the climatic conditions and the intensity of the infection [2, 3]. Because of fungal antagonism on old leaves, infection only occurs on the cigar or leaf No. 1. Thus, new attacks are only detected on young leaves. If the climatic conditions are very favourable to the development of the disease, the first symptom will appear on leaf No. 2, twelve days after infection of the cigar, considering that the Foliar Emission Rate (FER) is one leaf per week. If the climatic conditions are less favourable, the first symptom will be observed either on leaf No. 3, or on older leaves. In adverse conditions, no symptom might develop following leaf infection. Consequently, there is a gradient of evolution of the disease from the top to the bottom of the banana tree. Lastly, in order to maintain the sources of field inoculum as low as possible, it is essential to stop the disease before necrotic formation occurs: sporulation starts in necrotic stages of the disease. This is why this method focuses on early detection of new attacks of the disease.

A forecasting system to control Black Leaf Streak Disease (BLSD) has been developed [4] from the initial method to control Sigatoka disease described here. However, SED calculation is different for Sigatoka disease and for Black Leaf streak disease. Thus, in order to avoid any confusion on the complex determination of SED, we described the forecasting method of the two diseases in two separate protocols.

Key advantages

The incubation period, as well as the transition period of the disease, are very variable according to climatic variations, since they can last for 100 d. This highlights the interest in the forecasting systems, especially where climatic conditions are not optimum for disease development. In this way, this forecasting system has been operating successfully since 1972 in the French West Indies, where an average of six fungicide applications are carried out every year, and where in certain areas only one or two fungicide applications are necessary [5]. Using the forecasting method, Sigatoka disease is correctly controlled and does not affect the quality of exported fruit. The cost of control is limited and represents less than 3% of the production cost. The number of treatments and the quantity of pesticides discharged in the environment have been reduced eight- to tenfold using this forecasting system.

As wind-transported ascospores can disseminate the disease over long distances, control of the disease should be maintained by all growers of the area, using the same technical guidelines. Failure of control in one area can affect neighbouring areas. In the French West Indies, the forecasting system is carried out by the same technical team that decides the fungicide applications for the whole banana plantations.

Starting material

The estimation of the stage of evolution of the disease (SED) requires a banana plot of ten young banana trees.

Time estimation

For evaluation of the disease (10 plants), the time required is 15 min, but transportation to the field is not included. For calculation of the SED and graphic representation: 15–30 min manually, but 5 min if a computer is used.

Expected results

The results of the SED calculation allow making a decision for the necessity of a new fungicide application.

2. Materials and methods

2.1. Protocols

Banana plot preparation

• Step 1
Choice of the plants and first observation:

– Two months after the plantation of the plot, select 10 banana plants.

– The day of the first observation, examine for each plant the total number of leaves and score this number on the first unfurled leaf. Identify and number these 10 plants in order to observe them every week.

Note: the evaluation of symptoms has to be done on unflowered plants, so it is advised to maintain the 10 young banana trees by replanting 20 new banana trees (suckers, bulbs or vitroplants) every 3–4 months. In this way, at the flowering of the initial 10 banana trees observed for SED evaluation, it is possible to move all the observation to young plantings. For a good continuity and reliability of information, the banana plot must be localised in the same geographic place all the time. The information of this plot will account for disease development for an area of 20–200 ha according to the uniformity of the area.

Data collection

• Step 2
Organisation of the data sheet prior to field examination for the SED:

– Prepare a data sheet (*table I*).

– Copy numbers of banana trees into the column BTN (*table I*).

– Copy the number of leaves of each banana plant into the column OLN (*table I*).

– For each plant, note the stage of cigar development according to the five stages of Brun's scale [6] (*figure 1*). According to this scale, the following values are attributed to each stage: stage 0 corresponds to 0 leaf; stage 2, to 0.2 leaf; stage 4, to 0.4 leaf; stage 6, to 0.6 leaf; stage 8, to 0.8 leaf. Copy the cigar stage of each of the 10 banana plants into the column OCS (*table I*).

Note: for the first observation of the banana plot, copy these data in the field; for further observations, copy these data from the former data sheet.

• Step 3
Observation of the disease on the banana leaves, the day of field examination:

– Observe the youngest leaves of the banana trees (leaves Nos. 1 to 5) every week, and score the most advanced stage of the disease according to Brun's scale [6]:

1. Stage 1: a spot is just visible to the naked eye as a minute yellowish-green speck inferior to 1 mm.

2. Stage 2: the streak increases in size, notably in length, and remains yellowish-green. Its size is superior to 1–2 mm.

3. Stage 3: the streak begins to broaden slightly as well as increase in length and it begins to turn rusty red.

4. Stage 4: this is the first spot stage. The streak turns dark brown, is sunken and has reached its final size. A water-soaked yellow halo forms around the spot. Conidia are formed at this stage.

5. Stage 5: this is the final stage of the lesion. The central area of the spot turns grey and the margins of the spot are black. Some minute black points are visible, to the naked eye or with a magnifying glass, in the central area. They correspond to perithecia and spermogonia where ascospores and spermatia are produced.

– Report the most advanced stages of the disease observed for each banana tree and for each leaf, by a "×" in the corresponding column of the data sheet (*table I*).

• Step 4
Weekly observation of the banana plants:

– For each plant, observe the number of the last unfurled leaf and copy the number of leaves into the column (NLN) of the data sheet (*table I*).

– For each plant, note the stage of cigar development according to the five stages of Brun's scale [6] (*figure 1*) and copy the new cigar stage number into the column (NCS) of the data sheet (*table I*).

Table I.
Example of data sheet for field assessment of the Stage of Evolution of Sigatoka Disease (in red, data of the past week).

Data for Foliar Emission Rate (FER) assessment						Data for disease assessment																		
Banana Tree Number (BTN)	Old Leaf Number (OLN)	Old Cigar Stage (OCS)	New Leaf Number (NLN)	New Cigar Stage (NCS)	(FER)	Leaf 1		Leaf 2			Leaf 3				Leaf 4					Leaf 5				
						1	2	1	2	3	1	2	3	4	1	2	3	4	5	1	2	3	4	5
1	14	2	15	0	0.8							×					×					×		
2	13	6	14	4	0.8						×						×						×	
3	14	0	15	0	1						×					×								×
4	13	6	14	4	0.8								×				×							×
5	15	8	16	6	0.8								×					×					×	
6	15	2	16	2	1											×							×	
7	14	0	14	8	0.8			×				×						×						×
8	15	4	16	4	1							×						×						×
9	14	2	15	0	0.8						×						×						×	
10	13	6	14	2	0.6						×						×							×
Sum at each stage for the 10 trees (Sum)						–	–	1	–	–	4	3	2	–	–	2	5	3	–	–	–	1	4	5
Coefficient value (Coef) (see *table II*)						100	120	80	100	120	60	80	100	120	40	60	80	100	120	20	40	60	80	100
(Coef) × (Sum)						–	–	80	–	–	240	240	200	–	–	120	400	300	–	–	–	60	320	500

Sum_{FER}	8.4
$Number_{days}$	7
FER_{10d}	1.2
$FER_{past\ week}$	1.3
$FER_{new\ week}$	1.25
Sum_{coef}	2460

Stage of Evolution of the Disease

$SED = Sum_{coef} \times FER_{new\ week} = 3075$

Calculation of the Stage of evolution of the disease (SED)

Determine the SED as a successive calculation of several intermediates:

• Step 5
Calculate the foliar emission rate of the new week ($FER_{new\ week}$) as follows:

Into the column (FER) (*table I*), for the banana trees 1 to 10, calculate the values of (FER) as: FER = {(NLN) + [0.1 × (NCS)} – {(OLN) + [0.1 × (OCS)]}.

Caution: at each new observation, the values of column (NLN) and (NCS) become the values reported in (OLN) and (OCS).

• Step 6
– Sum all values of the column (FER) to obtain the sum of foliar emission rates of the 10 plants observed and copy this value into the box (Sum_{FER}) (*table I*).

– Note the number of days between the old and the new observation (ordinarily 7) in the box ($number_{days}$) (*table I*).

– Calculate the foliar emission rate for 10 days (FER_{10d}) as: (FER_{10d}) = (Sum_{FER} × 10) / ($Number_{bananas}$ × ($number_{days}$), where ($Number_{bananas}$) is the number of banana trees observed (ordinarily 10). Copy the result into the box (FER_{10d}) (*table I*).

– Calculate the foliar emission rate of the new week ($FER_{new\ week}$) as: ($FER_{new\ week}$) = [($FER_{past\ week}$) + (FER_{10d})] / 2, ($FER_{past\ week}$) is the foliar emission rate of the past week. Copy the result into the box ($FER_{new\ week}$) (*table I*).

• Step 7
A coefficient is attributed to each different [(leaf number)/(stage of the disease)] association. This coefficient is characteristic of the speed of evolution of the disease (*table II*). *Note:* for the same leaf, the faster the development of the disease, the higher the value of the stage of the disease. Therefore, the value of the coefficient increases with the value of the stage of the disease. For the same stage of the disease, the faster the development of the disease, the lower the leaf number. So, the value of the coefficient decreases with the leaf number.

Calculate the sum (Sum_{coef}) of all the coefficients for all more advanced stages of the disease observed on the five first leaves of the ten plants. Using the previously described data sheet, proceed as follows (*table I*):
– for each banana tree (1 to 10), sum the number of "×" for each [leaf number/stage of the disease] association and score the value obtained in the box (Sum),
– for each column, multiply the value of this (Sum) by the coefficient value (Coef). Score the result in the row (Sum × Coef),
– sum all the values in the column (Sum × Coef) and then score this value in the box (Sum_{coef}).

• Step 8
Make the correction by the foliar emission rate in order to express the stage of evolution of the disease (SED) as a speed value and to take into account that the more vigorous the growth of the banana trees, the faster the disease evolution [6]. This correction is done as following : SED = Sum_{coef} × $FER_{new\ week}$ (*table I*).

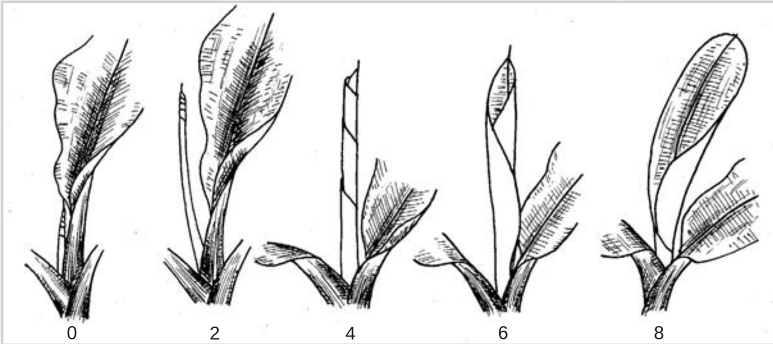

Figure 1.
Brun's scale of cigar development in banana development [6].

Table II.
Coefficients attributed to the different [banana tree leaf number / stage of the Sigatoka disease] associations.

Stage of the disease	Leaf number				
	I	II	III	IV	V
1	100	80	60	40	20
2	120	100	80	60	40
3	–	120	100	80	60
4	–	–	120	100	80
5	–	–	–	120	100

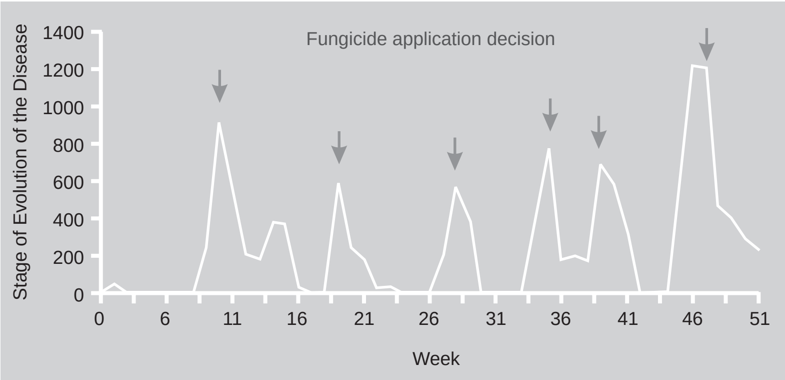

Figure 2.
Weekly variations in the stage of evolution of Sigatoka disease in a banana plot and time proposed for fungicide application.

Timing of fungicide applications

• Step 9

Make a graphic representation of the weekly evolution of the (SED), and use this graphic representation for timing of spraying decisions.

Note: It is considered that the (SED) value should not exceed 2500 to maintain fungicide efficiency. The decision for a new fungicide application will be decided according to the trend of the SED curve (*figure 2*). After a fungicide treatment, the curve decreases and no fungicide application will be decided until a significant rise in the curve is observed.

2.2. Troubleshooting

Frequent replanting of the observation plot is necessary for reliable information determination. However, several factors can affect the efficiency of the control based on this forecasting method. This troubleshooting will be detected by the following evolution of the curve after a fungicide application:

– no decrease in the curve is observed,

– the time between two rises of the curve is very short.

The success of this control strategy relies on several aspects such as timing of applications, fungicide treatments used and global organisation of the control [7].

Timing of applications

The time between the decision for and execution of one application should not exceed 7 d and the whole spraying area should be sprayed on the same day. Treatments are carried out by aeroplane, allowing a fast operation. However, care must be taken with the climatic conditions of aerial spraying: only a small window, early in the morning and late in the afternoon, is suitable; otherwise, thermal inversion and air turbulence do not allow correct spray deposition. Aerial application is not possible on rainy and windy days. Logistics available for aerial sprayings are therefore essential to optimise spraying during this small window.

Treatment efficiency

The efficiency of treatments is dependent on the quality of the foliar application. A good coverage is also indispensable. Bad weather conditions on the day of application, an irregular topography of the zone or the presence of obstacles might alter the uniformity of the treatment. The use of mineral oils as a carrier considerably improves the quality of coverage through aerial spraying with low volumes (12–15 $L \cdot ha^{-1}$). A strong synergy between the aerial spraying companies and the banana growers is also important to ensure the quality of the aerial applications.

The efficiency of treatments relies on a strong curative effect. Thus, systemic fungicides (antimitotics, sterol inhibitors of group 1 and 2, strobilurines) are preferred to contact fungicides. The use of these fungicides in pure oil strengthens their curative effect, because mineral oils are fungistatic. Attention should be paid to the formulation of the fungicide used. Only formulations compatible with pure oil should be used. The phytotoxic effect of the oil has to be preliminarily determined. Fungicide concentration must also be determined according to preliminary field experiments.

Special attention should be paid to managing the possible fungicide resistance that might develop following the repetitive use of unisite fungicides. Alternation between different groups of fungicides, or mixtures with contact fungicides, is essential to delay the emergence of such resistance.

Keeping the sources of inoculum at a very low level is also important to ensure good efficiency of treatments. Where extensive spotting is present, new infections will develop quickly because chemical sprays do not eliminate the disease from spotted leaves and the only solution is to remove them mechanically from the banana tree.

Organisation of control

Since ascospores are transported by wind over long distances, the control strategy should be the same in all banana plantations to prevent any disruption. The organisation of the treatments is more efficient when a centralisation of the decision is performed by a unique technical service operating according to rational guidelines rather than if each grower implements his own strategy. Centralisation of decisions and operations is essential and the banana growers should be grouped in an association that would perform the control strategy.

3. Typical results obtained

Weekly observation of the ten banana plants selected in a plot allows filling in the data sheet used for the calculation of the Stage of Evolution of the Disease (SED) (*table I*). A graphic representation of the weekly evolution of this SED is then used for timing of spraying decisions (*figure 2*).

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