Temporal Progress of Yellow Sigatoka and Aerobiology of *Mycosphaerella musicola* Spores

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**Abstract**

An understanding of the progression of a disease is important in the adoption of control strategies as well as the evaluation of their efficacies. Temporal analysis is especially useful because it integrates the evolution of the interaction between the components of the pathosystem, as expressed by the accumulated data on the incidence and severity of disease and depicted by the disease progression curve. Within a given patho-system, the dispersed airborne spores are important components in the progress of plant disease epidemics. Our aims were to evaluate the temporal dynamics of yellow Sigatoka in a banana plantation located in Coronel Pacheco, MG, Brazil, and to assess the aerobiology of *Mycosphaerella musicola* spores throughout the year. During the rainy season, we observed intense disease progression concomitant with high rates of leaf emission, which caused rapid reversal of the severity peaks after the maximum rates were reached. The yellow Sigatoka progress curve showed two peaks of extreme severity. The first, which occurred during the rainy season, was predominantly caused by a high concentration of conidia. The second, which occurred during the dry season, was predominantly caused by a high concentration of ascospores in the air. The ascospore concentrations were correlated with the severity of the disease 29 days later, indicating the average latency period of the disease in that region. The patterns of the severity curves for both peaks fit the monomolecular model, and the progression rates were higher during the rainy season than the dry season. The ascospore concentrations were the same at the two evaluated heights. In all evaluations, it was observed a higher concentration of ascospores than of conidia, with the greatest ascospore concentrations occurring during the early hours of the day and the greatest conidia concentrations occurring later, after the dew has dropped from the leaves.

**Introduction**

The cause of yellow Sigatoka is *Mycosphaerella musicola* (Leach), a polycyclic pathogen that continuously produces its reproductive structures. Because of this reproductive strategy, the disease progression curve in a susceptible host may show exponential growth within a given time interval, provided that the environmental conditions are favourable. These environmental variables also influence the aerobiology of the fungus and the epidemiology of the disease. An understanding of the disease progression, so as to precisely identify the time required for the disease to reach its exponential phase, or maximum intensity, is important to aid in the choice of control strategies and to verify their effects. A better understanding of disease progression would allow for the creation of predictive models and disease risk assessment (Fry 1982; Sutton 1998; Del Ponte et al. 2006). According to Madden et al. (2007), the disease progression curve, described as the proportion of disease over time, is the best way to represent an epidemic.

Temporal analysis integrates the components of the pathosystem, expressed as accumulated data on incidence and severity, and is depicted by the disease progression curve (Vanderplank 1963). Using these representations, it is possible to determine the time of onset of the epidemic, the amount of initial inoculum (Yo), the rate of disease progression (_r_), the area under the progress curve, the maximum amount of disease (Ymax) and the duration of the epidemic in relation to the types of spores and their dispersed concentrations in the air. Thus, the concentration or the amount of spores dispersed in the air can be important components of the progression of plant disease.
epidemics both in the short-term and over longer periods (Campbell and Madden 1990). However, the success of this analysis depends on the knowledge of the pathosystem, the types of propagules and the methods used to quantify them.

Two types of spores are involved in the propagation of yellow Sigatoka, namely, ascospores and conidia (Cordeiro 1997). Conidia (asexual spores) are usually produced continuously in environments of high relative humidity. They are disseminated by the washing of the leaf surface by rain or dew, which explains the severe infections sometimes observed in the tiller under more mature plants. However, ascospores (sexual spores), although produced at the same lesions from which conidia were released previously, appear later and are forcibly ejected from pseudothecia, also owing to high relative humidity, and even in dry climates, but owing to greater leaf wetness periods (Simmonds 1966). Thus, the density of conidia in the air is related to the intensity of yellow Sigatoka, the decrease in the incubation periods and symptom generation always associated with variable temperature and relative humidity (Guyot and Cuille 1958).

Yellow Sigatoka is still the main phytosanitary limitation in the production of bananas in the major banana-producing regions of Brazil, where 520,000 ha of banana is cultivated yielding around 6 million tons per year (IBGE 2009). We aimed to characterize the temporal dynamics of yellow Sigatoka and their relationship to the concentration of ascospores and conidia in the air.

Materials and Methods

This study was conducted between November 2006 and December 2007 in the Sítio do Cruzeiro, in the locality of Ribeirão de Santo Antônio, municipality of Coronel Pacheco in the state of Minas Gerais, Brazil. The geographical coordinates were 21°34'26" south latitude and 43°19'45" west longitude, at an altitude of 750 m above sea level. The total area of the banana plantation is 2.79 ha and is planted with 4 x 3 m single rows of the cultivar Saquarema, which belongs to the Cavendish (AAA) subgroup. The soil type is dark red latosol (Oxisol — Typic Haplustox). The site choice was based on the high severity of yellow Sigatoka symptoms and the lack of any disease control measures in this area, which allowed the study of the natural progression of the epidemic.

To assess disease progression, 25 plants were randomly selected and disease severity in all leaves of each plant was recorded according to the methodology proposed by Stover (1971) and modified by Gaulh (1994). All the 25 selected plants were in the same vegetative developmental stage, of an average of 2.5 m in height, containing seven to eight photosynthetic active leaves and three to five shoot apexes. All the evaluations were carried out in the same plants. Whenever one of the plants flowered, the evaluations were carried out in another randomly selected similar plant in height, vegetative development and amount of leaves. Data on the disease severity, weather conditions and aerial spore density were collected every 15 days. The infection rates for each plant were calculated according to the formula: Infection index = \[ \frac{S \times b}{(N-1) \times T} \]

where \( S \) is the number of leaves at each scale level, \( b \) is the scale degree, \( N \) is the number of degrees used in the scale and \( T \) is the total number of leaves evaluated.

The time of disease development (TDD), the youngest spotted leaf (YSL) and the daily leaf emission rate (DLER) were also calculated. The TDD was determined as the period of leaf in stage B development status, according to the scale of Brun (1963), and the observation of ten or more necrotic and mature lesions in this leaf (Fouré 1982). For these determinations, plants with a leaf in stage B were labelled with a plastic ribbon noting the observation date. Among the constant twenty-five plants evaluated along the experiment, only the ones that presented the stage B leaf at the time of evaluation were labelled, and this task was not mandatory, as the plants followed a natural development, varying according to the time of the year. Those leaves were then analysed every 15 days until 10 or more mature lesions were observed. The YSL refers to the first completely open leaf with ten or more necrotic lesions and a dry centre. The DLER refers to the difference between the amount of leaves in a given plant with a disease score of up to 6 and the amount of leaves in the same plant at a subsequent evaluation.

The disease progression curves were plotted using the infection index values over time. The infection index data were adjusted by nonlinear regression analysis to Exponential, Logistic, Gompertz and Monomolecular models. To choose the best model, were considered the adjusted determination coefficient of the regression analysis \( R^2 \), the mean square deviations (obtained from analysis of variance) and the graph of standard residues \( (Y_{\text{obs}} - Y_{\text{exp}}) \) as a function of the independent variable (Campbell and Madden 1990). The rates of disease progression \( r \) were estimated from the infection index curves by the parameter \( b \) of the regression equation obtained from the best-fit linear model.

Before the start of disease progression data collection, a computerized climatological station (Datalogger- CR510; Campbell Scientific Inc., Logan, UT, USA) was installed at the site. The station collected data on the leaf wetness (h/day), precipitation (mm/day), relative air humidity (%), minimum, average and maximum temperatures (°C), wind speed (m/s) and prevailing wind direction. The station was installed in a metal tower located in the centre of the study area with sensors positioned 1.5 m above ground level. There was also a thermohygrometer apparatus located in a covered shelter near the climatological station to collect data on temperature and relative humidity. All environmental variables were tested to assess the significance of the Pearson correlation with the
infection indices (II) using the SAS statistical software (The SAS System for Windows; SAS Institute Inc. Cary, NC, USA).

The concentration of *M. musicola* conidia and ascospores dispersed in the air within the banana plantation was monitored between March and December 2007. For this purpose, we used a model 20 ‘Rotorod Sampler’ collector equipped with two transparent acrylic collecting bars measuring 1.52 × 1.52 × 22 mm, installed vertically with respect to the circular rotation axis. The bars were coated with petroleum jelly to retain fungal spores. The spore concentration (C) was determined according to the formula \( C = \frac{P}{V} \), where \( P \) is the number of spores measured and \( V \) is the volume of air sampled. The equipment was turned on for 15 min every hour, and 0.00632 m³ of air were sampled. Two collectors were used, positioned at 1.5 and 3.0 m above ground level. All collections occurred at a single location in the centre of the banana plantation. The collections were performed every 15 days, on the same days as the disease severity evaluations, over a 12-h period from 6:00 a.m. until 6:00 p.m., according to Wardlaw (1961). The quantification of the reproductive structures was performed in the laboratory under a light microscope at 40× magnification.

The correlations between spore concentrations at different times of the day and from the two collection heights with the II at several time points were evaluated, using the Pearson correlation test, in the SAS statistical program.

**Results**

For the adjustment of fit of the yellow Sigatoka severity progression curve to a nonlinear model, collection period was divided into two distinct segments, A and B (Fig. 2). The first curve segment (Fig. 2-A) represents the period between 09 November 2006 and 09 March 2007. The second segment (Fig. 2-B) subjected to adjustment represents the period between 09 March 2007 and 21 June 2007. Each period produced a disease peak. The first period showed severity represented by an infection index of 46.09%, an average temperature of 23.7°C, a relative humidity of 82.6% and an average rainfall of 41.1 mm. The second disease peak, with an infection index of 53.6%, occurred during the dry season, between mid-July and late August 2007. This period had an average temperature of 18.4°C, average relative humidity of 76.3% and 0 mm rainfall (Fig. 1).

In this study, it was observed that the drought season was harmful for the host (Fig. 3), as the lowest DLERs occurred during this period and reflected in the reduction in the average position of the YSL. However, with the interruption in leaf emission, infections progressed during the periods of increased favorability for the disease, when enough dew was present every day. This progression was expressed as higher II than those recorded during the first peak. The lack of host growth was the main explanation for the behaviour of the disease progression curve.

A significant elevation of the TDD was observed during the driest season, which coincided with an elevation in the infection index. The two variables showed a positive and statistically significant correlation (67.09% at 5% probability). The correlation was not inverse because there were no favourable conditions for the new lesions to develop, but only coalescence of the old lesions emerged way before this period. Thus, it could be seen that the increase in the severity observed during the dry season must have originated previously, given that the highest TDDs were observed during this period (Fig. 3); that is, the lowest rates of lesion development, with values exceeding 100 days at the point at which the greatest disease severity was observed for the whole year. As such, in spite of the banana plantation having shown the greatest disease accumulation during the dry season, during this period the disease developed slowly. Despite the slow progress of the disease during the dry season, the severity was cumulative, and without production of new leaves, the infection rates were the highest.

The negative correlations observed between climatic variables and the infection index at the beginning of the epidemic were probably due to the long incubation period of the fungus. Furthermore, positive correlations were observed between climatic variables and the infection index recorded after 60 and 90 days.

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![Fig. 1](image-url)  
Fig. 1 Severity progress curve of yellow Sigatoka expressed by infection indices, compared to rainfall (mm). Coronel Pacheco, MG, Brazil
Despite the wind being the main agent for ascospore spread after release from the pseudothecia, no significance was found for its intensity or direction on the II or observed ascospore concentrations, probably due to the low occurrence of strong winds in the experimental area.

(Table 1).
The best adjustments for the periods of epidemic growth, both in summer and fall, were observed for the monomolecular model (Table 3). These adjustments were based on lower residues and greater determination coefficients ($R^2$). Although both phases could be adjusted to the monomolecular model, a greater daily rate of disease progression was observed in the summer ($dy/dt = 0.2806$) than in the fall ($dy/dt = 0.1859$). This difference in rates is likely due to the favourable climate conditions in the summer, when the large volume of rain allowed greater continuous production and dissemination of conidia over the first three months of the year.

For both peaks of severity, after the disease had reached its maximum index, there was no lesion stabilization. This finding can be explained by the fact that the infection index formula takes into consideration the evaluation of all the plant leaves, including the newest ones (leaves 0, 1, 2 and 3), which rarely present disease symptoms. In these cases, the decrease in severity following the peaks occurred because the host developed faster than the pathogen; that is, leaf emission rates were more pronounced than disease progression. This inverse relationship was evidenced by the negative and statistically significant correlation ($-0.4225^*$) between DLER and II. In July, disease progression prevailed over the vegetative growth of the host, resulting in the peak with the highest infection rate. It is also important to note that negative values for DLER were caused by the lack of humidity during the dry period of the year, which actually ceased leaf emission and caused total necrosis in the older leaves affected by the Sigatoka lesions. Under this situation, the host plants were not able to overcome the damage caused by the disease launching new leaves, as they did during the rainy period.

*Mycosphaerella musicola* spores were sampled between March and October of 2007. In the initial evaluations in March, the conidia concentrations were relatively high, around 1 800 conidia/m$^3$ of air, likely due to the summer rains. From mid-April, when the dry season began, the concentrations of ascospores increased significantly. This trend was later followed by an increase in conidia concentrations. The lowest relative humidity rates of the whole year were observed between the months of August and October, leading to a decrease in both spore concentration and infection index. By late October, with the occurrence of the first spring rains, the concentrations of conidia and ascospores increased again (Fig. 4).

**Discussion**

During the first period, the infection of 46.09% was owing to extremely favourable environmental conditions. Significant positive correlations were found between the variables rainfall (RF) and leaf wetness (WET), which are responsible for free water on the leaves, and the infection rates (Table 2). According to Simmonds (1966), conidia are produced continuously throughout the rainy season and disseminated through a film of free water, resulting from either rainwater or dew dripping on the leaves. During the dry season, however, the rates of leaf emissions were lower (negative values for DLER), allowing higher II owing to the increase in lesion number in the absence of full vegetative growth of the host. Thus, it could be observed that the lesions were concentrated on old leaves, and there was no new leaf emission during that season. Furthermore, among all the cultivars traditionally planted in Brazil, cv. Saquarema, which belongs to the Cavendish (AAA) subgroup, has a high degree of susceptibility to yellow Sigatoka (Gasparotto et al. 2006). According to Wardlaw (1961), the highest incidence of small, striped lesions visible to the naked eye on the second, third or fourth leaf depends on the banana variety and the environmental conditions.

According to Meredith (1970), conidial germination is always associated with the presence of free water on leaves and occurs approximately 6 h after deposition as long as the temperature is favourable; the optimum

<table>
<thead>
<tr>
<th>Time of IF evaluation</th>
<th>$T_{\text{max}}$</th>
<th>$T_{\text{aver}}$</th>
<th>$T_{\text{min}}$</th>
<th>RH</th>
<th>RF</th>
<th>WET</th>
<th>From 01/09/07</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same day</td>
<td>0.47**</td>
<td>-0.36**</td>
<td>0.52**</td>
<td>0.21</td>
<td>-0.07</td>
<td>-0.65**</td>
<td></td>
</tr>
<tr>
<td>15 days later</td>
<td>-0.47**</td>
<td>0.05</td>
<td>-0.37**</td>
<td>0.32*</td>
<td>-0.05</td>
<td>-0.65**</td>
<td></td>
</tr>
<tr>
<td>30 days later</td>
<td>-0.36**</td>
<td>0.26</td>
<td>-0.13</td>
<td>0.43**</td>
<td>0.02</td>
<td>-0.57**</td>
<td></td>
</tr>
<tr>
<td>45 days later</td>
<td>-0.19</td>
<td>0.08</td>
<td>0.08</td>
<td>0.45**</td>
<td>0.09</td>
<td>-0.42**</td>
<td></td>
</tr>
<tr>
<td>60 days later</td>
<td>-0.03</td>
<td>0.58**</td>
<td>0.43**</td>
<td>0.48**</td>
<td>0.28*</td>
<td>-0.11</td>
<td></td>
</tr>
<tr>
<td>90 days later</td>
<td>0.47**</td>
<td>0.86**</td>
<td>0.70**</td>
<td>0.35*</td>
<td>0.47**</td>
<td>0.28</td>
<td></td>
</tr>
</tbody>
</table>

**Significant at 1% probability; *significant at 5% probability.**

<table>
<thead>
<tr>
<th>Climatic variables</th>
<th>RF</th>
<th>WET</th>
<th>$T_{\text{max}}$</th>
<th>$T_{\text{aver}}$</th>
<th>$T_{\text{min}}$</th>
<th>RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>IF</td>
<td>53.47*</td>
<td>78.92**</td>
<td>-0.063</td>
<td>-0.016</td>
<td>0.427</td>
<td>0.22</td>
</tr>
</tbody>
</table>

**Significant at 1% probability; *significant at 5% probability.**
temperature is around 25°C. After conidia deposition, an epiphytic phase, lasting four to six days, may occur. During this phase, the growth of the germ tube is halted during the hottest and driest hours of the day and resumes under more favourable conditions, which generally occur at night (Meredith 1970; Stover 1972; Zadoks and Schein 1979). It may be clearly seen in Fig. 4 that from the period of 18 March 2007 until 5 April 2007, the conidia concentration was initially high (around 1800 conidia/m³), whereas the ascospores concentration was asymptotic to the zero level. If we consider that the first peak of Infection Index was registered on 7 January 2007, around 69 days before the measurements of spores concentration initiated, it may be observed that lesions as old as 69 days of age had enough time to reach latency period and discharged initially large amounts of conidia during the rainy season. Thus, we consider that the first peak of infection, which was observed at the beginning of summer, was predominantly a result of conidial infection, given that at this time, constant rainfall provided the maintenance of a film of free water for extended periods at an ideal temperature for infection by the pathogen. In contrast, the second peak of greater intensity (53.66% average infection index) occurred during the first week of winter, when the lowest rainfall levels were noted. In both in Queensland, Australia and Fiji, the climatological factors most commonly associated with yellow Sigatoka were relative humidity and temperature, and the disease generally reached its maximum activity during the periods of lower temperature and maximum relative humidity (Wardlaw 1961). In places where the infection peaks coincided with a reduced leaf emission rate, the plantation became severely affected (Wardlaw 1961). This finding was also observed in the coastal region of Santa Marta, Colombia, which is character-

Table 3
Comparison of the linear models to describe the estimated rates of severity progression (r), initial severity and final severity of banana yellow Sigatoka infection in two distinct periods

<table>
<thead>
<tr>
<th>Models</th>
<th>R</th>
<th>$Y_o$</th>
<th>$y_f$</th>
<th>$R^2$</th>
<th>QMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logistic</td>
<td>0.01</td>
<td>0.29</td>
<td>0.43</td>
<td>0.78</td>
<td>0.06</td>
</tr>
<tr>
<td>Monomolecular</td>
<td>0.003</td>
<td>0.29</td>
<td>0.42</td>
<td>0.80</td>
<td>0.006</td>
</tr>
<tr>
<td>Gompertz</td>
<td>0.006</td>
<td>0.29</td>
<td>0.42</td>
<td>0.78</td>
<td>0.02</td>
</tr>
<tr>
<td>Exponential</td>
<td>0.006</td>
<td>0.29</td>
<td>0.43</td>
<td>0.76</td>
<td>0.03</td>
</tr>
<tr>
<td>Logistic</td>
<td>0.006</td>
<td>0.19</td>
<td>0.52</td>
<td>0.92</td>
<td>0.04</td>
</tr>
<tr>
<td>Monomolecular</td>
<td>0.003</td>
<td>0.08</td>
<td>0.52</td>
<td>0.93</td>
<td>0.006</td>
</tr>
<tr>
<td>Gompertz</td>
<td>0.005</td>
<td>0.17</td>
<td>0.52</td>
<td>0.93</td>
<td>0.0152</td>
</tr>
<tr>
<td>Exponential</td>
<td>0.004</td>
<td>0.22</td>
<td>0.53</td>
<td>0.91</td>
<td>13.25</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Models</th>
<th>R</th>
<th>$Y_o$</th>
<th>$y_f$</th>
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<td>0.93</td>
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</tr>
<tr>
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<td>0.17</td>
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</tr>
<tr>
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<td>0.22</td>
<td>0.53</td>
<td>0.91</td>
<td>13.25</td>
</tr>
</tbody>
</table>


Fig. 4 Yellow Sigatoka severity progress curve as a function of infection indices (II) and conidia and ascospore concentrations, as measured at heights of 1.5 m (Low) and 3.0 m (High), in Coronel Pacheco, MG, Brazil
ized by an arid climate but also has constant occurrences of morning dew associated with long periods of leaf wetness. Yellow Sigatoka was also reported to have two yearly peaks of maximum severity in Suriname, the first peak in February and the second in July. According to Stahel (1937), these peaks should be attributed to the accumulation of infections in the previous four to five weeks.

Given the low rainfall recorded during the second peak of the disease, it is possible to associate the elevation in the sexual spore concentration seen during the period from 15 April 2007 to 15 July 2007 with the second peak of severity, whose maximum concentration was observed 60 days before the maximum severity of the disease (Fig. 4). Stahel (1937) stated that 28 days or more were needed after inoculation for evidence of formation of the first lesions to be visible to the naked eyes. In this study, despite the reduced rainfall, there was sufficient relative humidity to promote conidial production during the same period, albeit at a much lower concentration. However, the symptom patterns observed during the dry season were typical of ascospores (tip spotting), further supporting the proposed relationship.

Despite the importance of the spore concentration on yellow Sigatoka progression, Burt et al. (1997) found that it was similarly important to evaluate the effects of UV radiation on the survival of these propagules, which could limit successful long-distance spread of the pathogen.

In Coronel Pacheco, MG, there was a positive and significant correlation between the relative humidity and the infection index 30–90 days later. However, for all remaining variables, with the exception of leaf wetness, the correlations were only significant for the period 60 and 90 days after the climatic events. These periods are within those reported by Meredith (1970), who indicated that infections usually occur in the three newest leaves, with the first symptoms (striações) initially appearing between 11 and 106 days after germination.

In all assessments, we observed a higher concentration of ascospores than of conidia, in contrast to the results described by Burt et al. (1997). However, a film of free water on the leaves is necessary for the successful dissemination of conidia, as they are dispersed by splattering and dripping, whereas the ascospores need only an atmosphere with high relative humidity for wind dispersal (Stover and Simmonds 1987). Given that the spore traps were located among the plants and not over them, it was observed a higher efficiency for ascospore quantification. Even though conidial concentrations were observed to have similar peaks as ascospore concentrations, one must consider that during the cold season, these propagules usually did not find ideal conditions for germination and penetration.

In all evaluations performed, there was no significant difference between spore concentrations at the two heights evaluated, which was further supported by the significant correlations between the two heights used for the spore trap equipment (Table 4). The same tendencies were observed by Burt et al. (1997) when evaluating the concentrations of Sigatoka conidia and ascospores in Costa Rica at three different heights (3.0, 2.0 and 1.5 m).

In both the rainy and dry seasons, the highest spore concentrations occurred during the first hours of the day, 6 and 7 a.m. There was a considerable decrease in conidia and ascospores between 2:00 and 4:00 p.m., due primarily to the low relative humidity associated with the higher temperatures during the entire day. Ascospore concentrations were reduced by approximately 16% during the dry season as compared with the rainy season, except for the counts at the time of highest spore concentration, that is, 7:00 a.m., which were similar to those observed during the rainy season. These data follow the same trend described by Leach (1941), and referenced by Wardlaw (1961), who reported the release of ascospores at higher relative humidity without the need for a film of water on the leaves. It was found that the higher concentrations of conidia were not observed at dawn but rather a little later, increasing at 7 a.m. and reaching a peak at 8 a.m. According to Wardlaw (1961), the conidiophores are likely covered by a film of water for several hours until the spore can be transported by spatter. In fact, during the first collection hours, we observed retention of morning dew in the abaxial and adaxial surfaces of leaves and with the first rays of sun, the large dripping of water released from the leaf blades created the false impression of rain. During the dry season, when no dew formation was observed on the leaves, the concentrations of conidia were almost negligible compared with those of ascospores. These data show that the average relative humidity of 73% seen during the month of August was sufficient to trigger the release of ascospores.

The analysis of the distribution of the concentrations of conidia and ascospores at different times of the day, over 29 days, demonstrated that only the ascospores showed significant positive correlations with the *M. musicola* infection index (Table 5). This finding is justified by the average duration of the disease incubation period, which, according to Stahel (1937), is a minimum of 28 days from inoculation to the emergence of the first lesions visible to the naked eye.

**Table 4**

| Correlation between total ascospore and conidia concentrations of *Mycosphaerella musicola* throughout the day at the different heights analyzed (1.5 and 3.0 m) |
|-----------------------|-----------------------|
| **Ascospores low** | **Ascospores high** | **Conidia low** |
| **Conidia high** | **Conidia high** | **Conidia high** |
| **Ascospores low** | – | 0.85** |
| **Ascospores high** | 0.85** | – |
| **Conidia low** | – | 0.72** |
| **Conidia high** | 0.57* | – |

**Significant at 1% probability; *significant at 5% probability.**
The climate was a determinant for the oscillation in conidia and ascospore production, which, in turn, resulted in the peaks of disease severity. To this effect, Calpouzos et al. (1962, 1964) in Puerto Rico reported that rain is very important in predicting the disease and recommended that spraying be performed when a rainfall equal or greater to 76 mm was recorded over the preceding 3 weeks. Likewise, Mass (1967) found a strong correlation between the frequency of light rain and stain emergence in the striae stage within about three weeks.

Leach (1941) reported that the rate of ascospore production per leaf injury is considerably lower than that for conidia. However, the discharge of ascospores can happen owing to increased relative humidity, in a manner independent of a water film over the leaf. Ascospores can be released even from the lowest leaves of the plant, which are not affected by dew, but this is not true for conidia. The author also mentioned that the ideal temperature range for this release is between 21.1 and 28.9°C but gave no details regarding the duration of the incubation period or latency.

These results show the average duration of the disease cycle. They may assist in establishing a schedule for spraying and removal of inoculum sources in affected areas that have similar weather conditions as those in this study.

**Conclusions**

The progression curve of yellow Sigatoka in Coronel Pacheco, MG, shows two periods of greatest severity, the first during the rainy season and the second during the driest season of the year. The high severities observed during the rainy season were predominantly caused by conidia, while in the dry season they were caused mainly by ascospores.

The climatic variables that had the most effect on disease progression were rainfall, relative humidity and leaf wetness. In the rainy season, disease progression is associated with host vegetative growth, with shorter periods being observed for the development of new lesions. In the dry season, the lesions intensify the severity of disease owing to the lower vegetative growth of the host. The disease progression best fits the monomolecular model in both the rainy and dry seasons.

The determination of spore concentration in a given area can be obtained from collections at heights of either 1.5 m or 3.0 m. It is possible to correlate ascospore concentration with the severity of the disease 29 days after counts are performed. Ascospore release occurs predominantly in the early morning, while the release of conidia only occurs after the drainage of the dew present on the leaves.

**References**


Temporal Progress of Yellow Sigatoka and M. musicola Spores


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