Forecasting Spore Episodes of *Botrytis squamosa* in Commercial Onion Fields in New York

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ABSTRACT

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Previously published models for forecasting sporulation by *Botrytis squamosa* often failed to forecast major spore episodes of this pathogen when weather and Hirst spore trap data collected in a commercial onion field in Orange County, NY were used to evaluate the models. The sporulation index model for *B. squamosa* forecasted only 51.2% of the minor spore episodes (daily mean, 1–9.9 spores per m^3 of air) and 58.7% of the major spore episodes (mean $\geq$ 10 spores per m^3) in a 7-yr data set. The DINOV submodel of the BOTCAST predictive system for *B. squamosa* forecasted 81.8% of the minor spore episodes but only 56.5% of the major spore episodes in a 2-yr data set in which all appropriate weather data were available. An alternative model was developed by deriving a set of decision rules (modifications from BOTCAST) and regression equations that identified conditions associated with the occurrence or nonoccurrence of significant spore episodes. Temperature, relative humidity, and calendar date were used as variables in the model, which was designed to issue a daily forecast—the inoculum production index (*IPI*)—for the presence or absence of significant sporulation. The *IPI* model correctly forecasted 66.7% of the minor spore episodes and 94.2% of the major spore episodes in the 7-yr data set used to develop the model. Similar results were obtained with a 4-yr data set not used in model development (76.2 and 88.6% of minor and major spore episodes, respectively), indicating the suitability of the model for use in independent growing seasons. By incorporating crop age rather than calendar date into the model (IPI_2), further improvement was made in forecasting significant spore episodes. The IPI_2 model should be useful in a predictive system for timing fungicide applications to control Botrytis leaf blight of onion in New York.

Botrytis leaf blight of onion (*Allium cepa* L.), caused by *Botrytis squamosa* Walker (anamorph of *Botryotinia squamosa* Viennot-Bourgin), is controlled with protectant fungicides applied on a regular basis (11,15). Although control of the disease is necessary to achieve good yields, fungicide sprays are unnecessary during periods of the growing season in which environmental conditions are unfavorable for disease development. Postponing the initiation of a regular fungicide spray program until an action threshold of one lesion per leaf is reached can help to optimize fungicide use (16,20). Nevertheless, a predictive system is needed that will allow growers to schedule subsequent fungicide applications on the basis of the potential for disease development rather than according to a fixed schedule.

The production and dispersal of inoculum are key elements of infection periods and should be accounted for in a predictive system for a polycyclic pathogen. Conidia of *B. squamosa* serve as inoculum in epidemics of Botrytis leaf blight in the field (5,8,19). Knowledge of the conditions that precede production and dispersal of conidia of *B. squamosa* is of importance in timing fungicide applications to precede infection periods. This was recognized by Lacy and Pontius, who developed a model that issues a daily sporulation forecast for *B. squamosa* based on temperature and vapor pressure deficit (8). The "daily inoculum value" (DINOV) submodel of another predictive system for *B. squamosa*, called BOTCAST (18), could also be used to forecast sporulation. As part of an effort to develop a predictive system for *B. squamosa* for New York conditions, these models were evaluated, and an alternative model for forecasting spore episodes of *B. squamosa* was developed and evaluated. This paper reports the results of those investigations.

MATERIALS AND METHODS

Monitoring of weather and spore populations. The selected data used in the development and evaluation of the models were taken from data collected yearly in a continuing research program on Botrytis leaf blight in commercial onion fields in Orange County, NY. Eleven years of data (1969, '70, '72, '76, '77, '78, '79, '80, '81, '85, and '86), selected on the basis of completeness and accuracy of data, were collated for subsequent analyses. Bihourly observations of temperature and relative humidity were provided by using a Bendix hygrothermograph (model 594, Science Associates, Princeton, NJ) calibrated weekly with a sling psychrometer and located 122 cm above the soil surface within a standard weather instrument shelter (model 176, Science Associates). Rainfall was monitored with a recording rain gauge (model 551, Science Associates), and leaf wetness was monitored with a Datapod 223 Micrologger (Omnidata International, Logan, UT). The leaf wetness sensor was an unpainted circuit board (Wong Laboratories, Cincinnati, OH), which was found to estimate the onset and cessation of leaf wetness episodes to within 30 min.

Data on densities of airborne spores were collected with a Hirst volumetric spore trap (6) sampling 10 L of air per min, with the trap orifice set at a height of 80 cm above the soil surface. Spores were trapped on slides that were graduated into 2-hr (4 mm) segments and coated with a thin deposit of petrolatum. Spores typical of *B. squamosa* were counted in at least two passes under a compound microscope (440 X), and the number counted in each 2-hr period was recorded. Counts were converted to number of spores per cubic meter of air sampled by multiplying counts by appropriate conversion factors for volume of air sampled and for proportion of the spore trap deposit examined. Counts were not corrected for variation in trapping efficiency associated with changing wind speed (6).

Spore densities associated with yield loss. As a preliminary step to evaluating models for predicting spore episodes of *B. squamosa*, it was necessary to identify spore densities that were associated with significant development of Botrytis leaf blight. This was determined by examining the relationship between two variables: the number of days during the growing season with spore episodes of selected densities, and the yield-loss potential for *B. squamosa*. Yield-loss potential for each season was used as an estimate of disease severity because data on actual disease severities near the weather station were sometimes lacking.

Yield-loss potential for *B. squamosa* was determined for 10 of the 11 yr in this study (1986 excluded) by using the formula (1):

Yield-loss potential (%) = 100([SPRAYED-UNTREATED]/SPRAYED).

In this formula, SPRAYED = mean bulb yield in experimental plots sprayed weekly with a protectant fungicide, and UNTREATED = mean bulb yield from plots not treated with fungicide. For each growing season, yield-loss potential for *B. squamosa* was calculated for each of 2–3 fungicide trials and then averaged. In an effort to standardize comparisons among growing seasons, yields were used for plots treated with one of two standard onion fungicides. For 1969 and 1970, the fungicide used in this analysis was mancozeb at 1.3–2.7 kg/ha, which was the most effective fungicide in New York until the failure of the dithiocarbamate fungicides to control Botrytis leaf blight in 1971 (12). For 1972–'85, chlorothalonil at 1.2–2.6 kg/ha was used in the analysis. The year 1986 could not be included in this analysis because experimental plots treated with chlorothalonil alone were not tested in 1986. It was necessary to use a range of rates of the above fungicides in this analysis because the fungicides were often tested at different rates in different experiments. However, in experiments in which more than one rate was tested, the yield data used were taken from the rate closest to 2.7 kg/ha for mancozeb and 2.6 kg/ha for chlorothalonil because these rates were common to more experiments than other rates tested.

Inoculum levels during each of the 10 yr examined in this analysis were summarized by determining the number of days during 1 July–15 August with daily mean spore densities of <1, 1–9, 10–99, and ≥ 100 spores per m^3 of air. Mean spore density was assumed to be <1 spore per m^3 for days in which spore trap data were unavailable. Yield-loss potential for each season and the number of days during the season with specified spore densities were tabulated to determine minimum spore densities associated with yield loss caused by *B. squamosa*. The models for forecasting sporulation were then evaluated by determining their accuracy in forecasting such significant spore episodes.

Evaluation of previously published models for forecasting sporulation. The sporulation index model (8) was evaluated by using spore trap and weather data for 1969, '70, '72, '78, '79, '80, and '81, years that spanned the range of disease severities observed. Three-day running means were calculated for temperature and vapor pressure deficit following the recommended protocol (8). Large increases in the number of airborne spores of *B. squamosa* tend to occur after 0600 hr and coincide with rising temperature and declining relative humidity (8,10,19). Consequently, unless otherwise specified, "days" in this study were defined as beginning at 0601 hr eastern daylight time and continuing until 0600 hr of the following calendar day. Using the 3-day running means, a sporulation index (*SI*) was obtained from a published table (8) for 1 July and each subsequent day. Sporulation forecasts issued by the *SI* model are not modified by estimates of crop development or time (8). Therefore, data before 1 July of each year were excluded from this analysis to avoid erroneous forecasts for significant sporulation before crop and disease development were sufficient to result in large spore episodes (17). As recommended, a value of *SI* ≥ 50 was considered to represent a forecast for sporulation (8). Forecasting accuracy of this and other models was assessed by determining the frequency of the following four possible daily outcomes: a correct positive forecast (forecast for sporulation followed by a minor or major spore episode), a correct negative forecast (forecast for no sporulation followed by insignificant sporulation), an incorrect positive forecast (forecast for a significant spore episode followed by insignificant sporulation), and an incorrect negative forecast (forecast for insignificant sporulation followed by a minor or major spore episode).

The DINOV submodel of BOTCAST (18) also was evaluated for accuracy in forecasting spore episodes of *B. squamosa* recorded in Orange County, NY. This analysis was conducted only on spore trap and weather data for 1985-'86, as the leaf wetness data required by BOTCAST were available for only those years. In addition, the analysis was conducted with "days" that ran from 0801 hr until 0800 hr, as specified in the BOTCAST protocol (18). For each day on or after 1 July, the DINOV was determined by using the protocol provided by Sutton et al (18). Following this protocol, a condition of DINOV = 1 for either of the two nights preceding each morning was taken to represent a forecast for sporulation for the day in question, whereas a condition of DINOV = 0 was taken to represent a forecast for no sporulation. Forecasting accuracy was assessed as indicated above.

Development of alternative model for forecasting sporulation. Seven years of spore trap and weather data (1969, '70, '72, '78, '79, '80, and '81), were used in the development of the model. The model was developed by making repeated, computerized searches through the data set to identify patterns of environmental conditions that were followed within 24 hr by spore episodes. Parameters examined included daily mean temperatures, duration above selected threshold temperatures, duration of periods of relative humidity $\geq 90\%$, and duration of periods below selected threshold values of relative humidity. Summaries of the data indicated that sporulation was infrequent after hot or dry weather. Decision rules were developed to identify such days that were too hot or too dry to promote sporulation. These decision rules were developed by evaluating and modifying decision rules in the DINOV submodel of BOTCAST (18). Following this, multiple regression analysis was used to characterize relationships between temperature, relative humidity, calendar date, and $\log_{10}$ (daily mean spore density). These decision rules and regression equations were arranged into a logical hierarchy that was used to forecast the occurrence of significant spore episodes.

RESULTS

Spore densities associated with yield loss. Yield-loss potential for *B. squamosa* was substantial ($>3\%$) in years having several days with mean spore density ≥ 10 spores per m^3 (Table 1). In both 1977 and 1981, potential yield loss and the number of days with ≥ 10 spores per m^3 were low. In 1978, a year with moderate yield-loss potential (8.1%), 9 days with 1–9 spores per m^3 and 2 days with ≥ 10 spores per m^3 were recorded. In the remaining years, yield-loss potential was high ($> 10\%$), and days with ≥ 10 spores per m^3 were frequent.

From the analysis in Table 1, it was concluded that days with mean spores densities of at least 10 spores per m^3 were associated with large increases in the severity of Botrytis leaf blight. However, in 1978, yield-loss potential was moderate (8.1%), but only 2 days with ≥10 per m^3 spores were recorded. It may be that smaller spore episodes are also important in the epidemiology of Botrytis leaf blight under conditions optimal for infection or at growth stages in which onions are particularly susceptible (2,13). Therefore, a distinction was made in all analyses between minor spore episodes (daily mean 1–9.9 spores per m^3) and major spore episodes (daily mean ≥ 10 spores per m^3).

Evaluation of previously published models for forecasting sporulation. In the 7 yr in which it was tested, the *SI* model correctly forecasted 111 insignificant spore episodes, 43 minor spore episodes, and 71 major spore episodes (Table 2). These 225 correct forecasts represent 62.7% of all forecasts issued during the 7-yr period. Forty-three (27.9%) of 154 insignificant spore episodes were not forecasted by the *SI* model. Forty-one (48.8%) of 84 minor spore episodes and 50 (41.3%) of 121 major spore episodes were not forecasted by the *SI* model (Table 2).

TABLE 1. Yield-loss potential and densities of airborne spores of *Botrytis squamosa* in a commercial onion field in Orange County, New York for 10 growing seasons

Yield-loss potential (%)[a]	Year	No. of days (1 July–15 August) with specified mean spore densities: <1 spore/m^3	1–9 spores/m^3	10–99 spores/m^3	>100 spores/m^3
1.5	1981	32	13	1	0
2.5	1977	34	12	0	0
8.1	1978	35	9	2	0
12.7	1970	6	8	29	3
13.5	1980	23	18	4	1
15.6	1979	25	16	4	1
16.1	1985	8	17	18	3
17.4	1969	3	3	17	23
17.8	1976	7	19	17	3
20.7	1972	3	9	15	19

[a] Yield-loss potential (%) = 100 ([SPRAYED-UNTREATED] /SPRAYED]), in which SPRAYED = mean bulb yield in experimental plots sprayed weekly with a protectant fungicide and UNTREATED = mean bulb yield from untreated plots.

TABLE 2. Evaluation of sporulation index (*SI*) model for forecasting spore episodes of *B. squamosa* in a commercial onion field in Orange County, New York[a]

Sporulation forecast	Ensuing spore episode[b]: Insignificant	Minor	Major
Expected (*SI* ≥ 50)	43(*27.9*)[c]	43(*51.2*)	71(*58.7*)
Not Expected (*SI* < 50)	111(*72.1*)	41(*48.8*)	50(*41.3*)

[a] Forecasts for 1 July and later for the years 1969, '70, '72, '78, '79, '80, and '81.
[b] Insignificant, minor, and major spore episodes are days when mean spore density for 24-hr period (0601–0600 hr) following forecast was <1 spore per m^3 of air, 1.0–9.9 spores per m^3, and ≥10 spores per m^3, respectively.
[c] Number of episodes (*percent of episodes with specified spore density*).

TABLE 3. Evaluation of DINOV submodel of BOTCAST for forecasting spore episodes of *B. squamosa* in a commercial onion field in Orange County, New York[a]

Sporulation forecast	Ensuing spore episode[b]: Insignificant	Minor	Major
Expected (DINOV = 1)	12(*38.7*)[c]	9(*81.8*)	13(*56.5*)
Not expected (DINOV = 0)	19(*61.3*)	2(*18.2*)	10(*43.5*)

[a] Forecasts for 1 July and later for the years 1985 and 1986.
[b] Insignificant, minor, and major spore episodes are days when mean spore density for 24-hr period (0601–0600 hr) following forecast was 1 spore per m^3 of air, 1.0–9.9 spores per m^3, and ≥ 10 spores per m^3, respectively.
[c] Number of episodes (*percent of episodes with specified spore density*).

The DINOV submodel of BOTCAST correctly forecasted 19 insignificant spore episodes, 9 minor spore episodes, and 13 major spore episodes that were recorded during the 2 yr in which it was tested (Table 3). These 41 correct forecasts represent 63.1% of all forecasts issued during the 2-yr period. Twelve (38.7%) of 31 insignificant spore episodes and 10 (43.5%) of 23 major spore episodes were not forecasted by the DINOV submodel.

Alternative model for forecasting sporulation. A five-step model designed to forecast sporulation by *B. squamosa* was developed (Fig. 1). The model is used daily after 0600 hr to calculate an inoculum production index (*IPI*), the value of which indicates whether sporulation can be expected during the next 24 hr. Steps

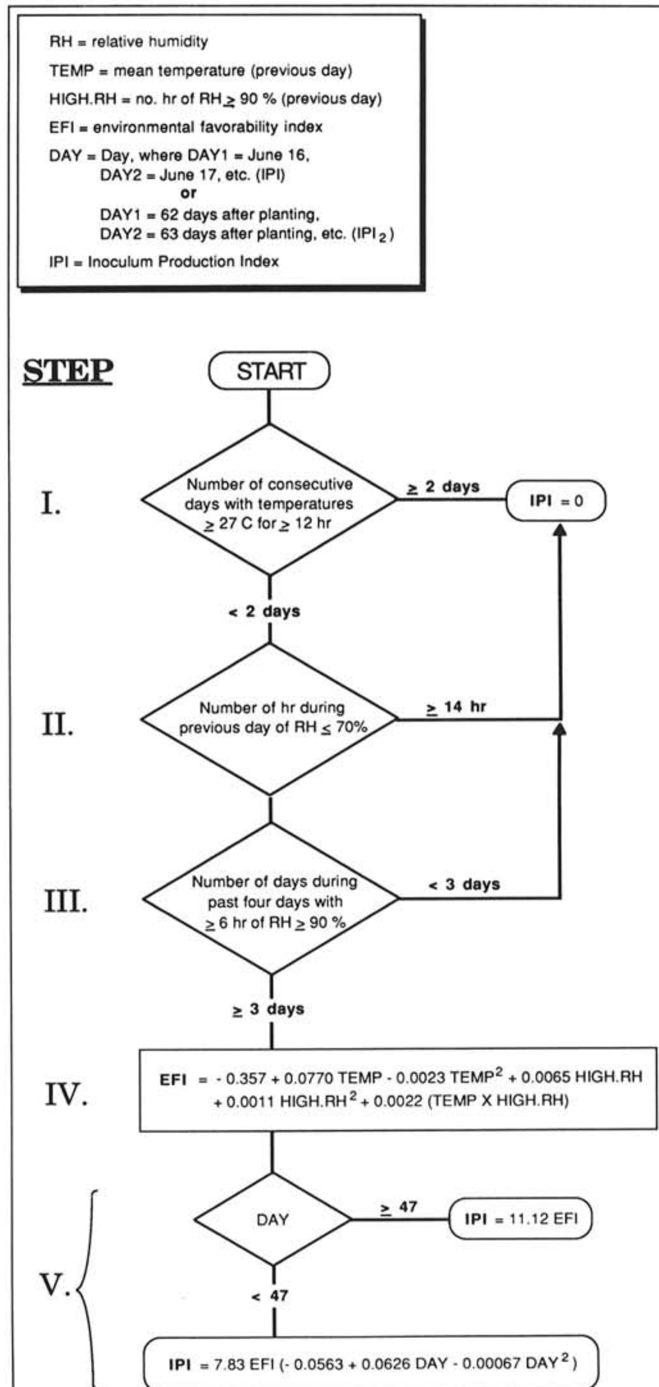

Fig. 1. Flowchart for determining daily inoculum production index (*IPI*) for *Botrytis squamosa*. Days run from 0601 to 0600 hr EDT. "DAY" in step V is defined on the basis of calendar date (*IPI*) or crop age (IPI_2). A significant spore episode can be expected within the next 24 hr when *IPI* ≥ 7.

I–III of the model identify days that are too hot or too dry to promote sporulation. If any of the threshold conditions defined in steps I–III is met, the *IPI* is zero and no sporulation is forecasted for the next 24 hr. Step IV of the model calculates an environmental favorability index (*EFI*) for sporulation by using a regression equation that relates spore density to two environmental variables determined for the previous day: mean temperature and number of hr of relative humidity ⩾ 90%. The second-order form of this regression model ($P < 0.0001$, $R^2 = 0.20$) (Fig. 1) did not result in a significant reduction in error sums of squares (14) over the first-order form. However, the second-order form was retained in the model to include assessments of curvilinear trends that were evident in plots of the raw data but that may not have been statistically significant because of considerable unaccounted-for variability in spore numbers. Step V provides the *IPI*, unless this has been previously calculated in steps I–III. The calendar date determines which of the two algorithms in step V is used on any given day. Before 1 August, which is day 47 as defined in the model, the lowermost algorithm in step V (Fig. 1) is used to calculate the *IPI*. In this algorithm, the *IPI* is calculated by multiplying the *EFI* by a scaling factor and by a regression equation relating spore density to a numerical value for calendar date. The second-order form of this regression model ($P < 0.0001$, $R^2 = 0.12$) (Fig. 1) resulted in a significant ($P < 0.0001$) reduction in error sums of squares over the first-order form. On or after 1 August, the algorithm to the right of step V (Fig. 1) is used, in which the *IPI* is calculated only on the basis of the *EFI* multiplied by a scaling factor. Scaling factors were included in step V so that the maximum *IPI* value calculated by using either algorithm would be 25, a unitless value that was selected arbitrarily. Step V was included in the model to account for the observation that progressively more sporulation by *B. squamosa* can be expected as the growing season progresses as a result of the growth of the host (17). Figure 2 illustrates the mathematical effect of step V on the *IPI* under a constant environment (constant *EFI*).

Evaluation of *IPI* model. The *IPI* that results each day from the use of the model outlined in Figure 1 will have a numerical value of 0–25. It was found that significant spore episodes (daily mean ⩾ 1 spore per m^3) were often preceded by an *IPI* of 7 or more. Therefore, sporulation forecasts issued by this model are that either significant sporulation is not expected ($IPI < 7$) or is expected ($IPI \geqslant 7$) during the next 24 hr. Use of an *IPI* of 7 as a threshold value for forecasting sporulation minimized the overall error rate (incorrect positives and incorrect negatives) as compared to other possible integer values of the *IPI*.

In the 7-yr data set from which it was developed, the *IPI* model correctly forecasted 186 insignificant spore episodes, 72 minor spore episodes, and 113 major spore episodes, which together represent 77.6% of all forecasts issued during the 7-yr period (Table 4). Sixty-four (25.6%) of 250 insignificant spore episodes were not forecasted, as were 36 (33.3%) of the 108 minor spore episodes and 7 (5.8%) of 120 major spore episodes. Forecasting accuracy of the *IPI* model was further tested with a 4-yr data set (1976, '77, '85, and '86) that was not used in development of the model. In the 4-yr independent data set, the model correctly forecasted 66 insignificant spore episodes, 32 minor spore episodes, and 39 major spore episodes, representing 67.2% of all forecasts issued during the 4-yr period (Table 4). Fifty-two (44.1%) of 118 insignificant spore episodes were not forecasted; 10 (23.8%) of 42 minor spore episodes and 5 (11.4%) of 44 major spore episodes were not forecasted.

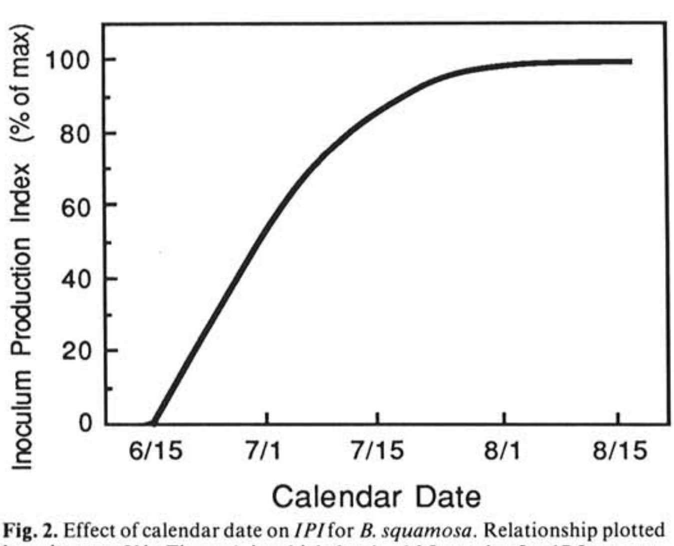

Fig. 2. Effect of calendar date on *IPI* for *B. squamosa*. Relationship plotted by using step V in Figure 1, in which day 1 = 16 June, day 2 = 17 June, etc., and environmental favorability index is held constant.

Basing sporulation forecasts on calendar date as in the original *IPI* model (Fig. 1) assumes that onion crops in New York planted in the spring are at an equivalent stage of development by 16 June, the starting point for use of the model. However, onion crops in New York may be planted anytime between the end of March and early May, changing the position of the response curve illustrated in Figure 2. Therefore, it was of interest to determine if the forecasting accuracy of the *IPI* model could be improved by relating sporulation forecasts to crop age rather than calendar date. This change in the model was made in step V (Fig. 1), in which the variable DAY was redefined as:

$$\text{DAY} = (\text{no. of days after planting}) - 61.$$

Using this definition, 16 June is day 1 for a crop planted on 15 April, a typical planting date in Orange County, NY. Crops planted before 15 April would have a correspondingly earlier increase in sporulation potential, whereas the reverse would be true for crops planted after 15 April. Sporulation forecasts made with this second version of the model are designated as IPI_2.

Data on planting date are available for only 2 of the 11 yr studied, but for those 2 yr the sporulation forecasts made with the original model (*IPI*) were compared to the forecasts made with version 2 of the model (IPI_2). Although overall error rates (false positives and false negatives) were the same for the two versions of the model, a decrease in the percentage of false negative forecasts was found by using version 2, with a corresponding increase in the percentage of correct positive forecasts (Table 5).

DISCUSSION

The *IPI* model developed here forecasted most of the significant spore episodes and nearly all of the major spore episodes recorded in a commercial onion field in Orange County, NY during 11 yr. Incorrect negative forecasts were infrequent in both the 7-yr data set used to develop the model and the 4-yr independent data set. This is important because incorrect negative forecasts represent instances in which the model indicates that no sporulation is expected–and that no control measure is necessary–when, in fact, sporulation occurs. Of the incorrect negatives that were recorded, most were minor spore episodes, which individually were not associated with dramatic yield loss. Of the unforecasted major

TABLE 4. Evaluation of inoculum production index (*IPI*) for forecasting sporulation by *B. squamosa* in a commercial onion field in Orange County, New York

Data set	Sporulation forecast	Ensuing spore episode[a]		
		Insignificant	Minor	Major
7 yr[b]	Expected ($IPI \geqslant 7$)	64(*25.6*)[d]	72(*66.7*)	113(*94.2*)
	Not expected ($IPI < 7$)	186(*74.4*)	36(*33.3*)	7(*5.8*)
4 yr[c]	Expected ($IPI \geqslant 7$)	52(*44.1*)	32(*76.2*)	39(*88.6*)
	Not expected ($IPI < 7$)	66(*55.9*)	10(*23.8*)	5(*11.4*)

[a] Insignificant, minor, and major spore episodes are days when mean spore density for 24-hr period (0601–0600 hr) following forecast was < 1 spore per m^3 of air, 1.0–9.9 spores per m^3, and ⩾ 10 spores per m^3, respectively.
[b] Data for 1969, '70, '72, '78, '79, '80, and '81. Data set used in model development.
[c] Data for 1976, '77, '85, and '86. Data set not used in model development.
[d] Number of episodes (*percent of episodes in data set with specified spore density*).

TABLE 5. Comparison of two versions of inoculum production index (*IPI* and IPI_2) for forecasting sporulation by *B. squamosa* in a commercial onion field in Orange County, New York, during 1985–1986

Model	Sporulation forecast	Ensuing spore episode[a]		
		Insignificant	Minor	Major
IPI[b]	Expected ($IPI \geq 7$)	19(*33.3*)[d]	7(*53.8*)	19(*79.2*)
	Not expected ($IPI < 7$)	38(*66.7*)	6(*46.2*)	5(*20.8*)
IPI_2[c]	Expected ($IPI_2 \geq 7$)	24(*42.1*)	9(*69.2*)	22(*91.7*)
	Not expected ($IPI_2 < 7$)	33(*57.9*)	4(*30.8*)	2(*8.3*)

[a] Insignificant, minor, and major spore episodes are days when mean spore density for 24-hr period (0601–0600 hr) following forecast was <1 spore per m^3 of air, 1.0–9.9 spores per m^3, and ≥10 spores per m^3, respectively.
[b] Sporulation forecasts based on calendar date (see text for explanation).
[c] Sporulation forecasts based on crop age (see text for explanation).
[d] Number of episodes (*percent of episodes in data set with specified spore density*).

spore episodes (total of 12 occasions in 11 yr), 10 were preceded by a forecast for sporulation on the day before the spore episode. In these cases, a fungicide application made on the previous day likely would still be effective. The remaining two unforecasted major spore episodes were both correctly forecasted by using the later version of the model (IPI_2), in which sporulation forecasts were based on crop age rather than calendar date. Because of these results it is expected that, in practice, the IPI_2 model will provide conservative forecasts of inoculum production.

As the data sets used in this study represented a number of growing seasons, it was possible to evaluate the model both with data used to develop the model as well as an independent data set. Such an analysis is often not possible in epidemiological studies because of the difficulty of obtaining data sets sufficiently large for both adequate development of a model and its independent validation. In this study, the agreement in forecasting accuracy between the original and independent data sets increases confidence in the suitability of the IPI_2 model for use during future growing seasons.

The accuracy of previously published models for forecasting sporulation by *B. squamosa* was somewhat lower than expected and provided the impetus for development of the IPI_2 model. Especially problematic were the relatively high frequencies of false negative forecasts, particularly for major spore episodes. Both the *SI* model (8) and BOTCAST predictive system (7,18) have performed well in regions where they were developed, so the inadequate performance of each of these models in New York may be due less to design flaws in the models than to differences between regions. There may be important ecological differences between populations of *B. squamosa* in Michigan, New York, and Ontario that influence spore production in the field. Likewise, there may be differences between regions in environmental factors or cultural practices that interact with temperature and relative humidity to promote sporulation. Whatever the reason for the discrepancies, these results confirm the importance of carefully evaluating predictive models before their commercial use is promoted in other regions.

Knowledge of densities of airborne spores of *B. squamosa* that were associated with significant disease development permitted a decision as to what density of airborne spores was high enough to warrant control measures and thus prediction. As a result it was possible to quantitatively assess the forecasting accuracy of the models that were evaluated. In this study it was found that days with a mean of at least 10 spores per m^3 were associated with high yield-loss potential, although daily densities as low as 1 spore per m^3 were regarded as potentially significant spore episodes in need of prediction. This is in agreement with data presented by Sutton et al (17,19), who presented data indicating that lesion production by *B. squamosa* on onion leaves was preceded by days with ≥ 1 spore per m^3, with the most dramatic increases following days with ≥ 10 spores per m^3.

The IPI_2 model described here provides a daily binary forecast as to whether a significant episode of airborne spores of *B. squamosa* can be expected within the next 24 hr. Because of great variability in daily spore trap counts, no effort was made to forecast daily spore densities. A number of other factors not accounted for in this model may contribute to variability in spore densities, factors such as: disease severity; duration of leaf wetness; rainfall duration, intensity, and timing; fungicide applications; wind speed; and possibly other factors such as intensity of sunshine, onion cultivar, and competition for necrotic foliage from other phyllosphere microflora (3,4,9,17,18,19). It may be possible to develop models that issue forecasts of expected spore densities by including additional environmental and host variables and assessments of microenvironmental conditions at the leaf surface.

It should be noted that although the IPI_2 model forecasts the occurrence of airborne spores of *B. squamosa*, it does not forecast their survival from previous spore episodes, which would be of importance in a predictive system that includes forecasts of inoculum potential. Although some data are available on survival of spores of *B. squamosa* (1), an understanding of spore survival under varied field conditions would be of value.

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