Disease Control and Pest Management

Relationship of Precipitation Probability to Infection Potential of *Botrytis squamosa* on Onion

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ABSTRACT

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An infection index for *Botrytis squamosa* was developed that uses temperature and leaf wetness duration to categorize leaf wetness episodes as insignificant, slight, moderate, or severe potential infection periods, given the presence of inoculum. Using this infection index, it was found that the frequency and severity of potential infection periods of *B. squamosa* in a commercial onion field in Orange County, NY, increased with increasing National Weather Service (NWS) precipitation probability (*PP*). Severe potential infection periods occurred in 0, 18, 24, and 84% of the 36-hr forecast periods in which the maximum *PP* for the forecast period was $<$ 30, 30–40, 50–60, and $\geq$70%, respectively. It was concluded that a $PP \geq$ 30% could be used to forecast severe potential infection periods of *B. squamosa*. A standard meteorological score for assessing forecasting skill was used to evaluate the accuracy of *PP* forecasts in forecasting measurable precipitation ($\geq$1.3 mm) in a commercial onion field. In contrast to a reported trend among NWS forecast offices of declining forecasting skill with increasing time after issuance of a forecast, skill of *PP* forecasts for the Lower Hudson Valley in New York (which includes Orange County) remained high for 36 hr following the forecast. This indicated that the use of $PP \geq$ 30% as a decision rule for forecasting severe potential infection periods of *B. squamosa* should have equal predictive value for up to 36 hr in advance.

Botrytis leaf blight, a serious foliar disease of onion in New York, is controlled primarily through the frequent use of protectant fungicides (15). Although frequent fungicide applications often are necessary under conditions favorable for disease development, field experiments have indicated that adequate disease control often may be possible using less intensive spray schedules (21,24). Predictive systems for *Botrytis squamosa* Walker (anamorph of *Botryotinia squamosa* Viennot-Bourgin), which causes the disease, can help reduce the number of unncessary fungicide applications, and improve disease control through proper timing of fungicide applications.

Two of the predictive systems currently available for Botrytis leaf blight of onion are designed to time the initiation of a fungicide program (21,24). A third predictive system schedules fungicide applications throughout the season by forecasting the occurrence of airborne conidia of the pathogen (14). Although the latter model has proven to be accurate in forecasting such spore episodes in some areas (14), it failed to forecast 44% of the spore episodes recorded in a commercial onion field in New York (30). Therefore, it was of interest to develop a weather-based predictive system that could be used to time fungicide applications after the initiation of a spray program.

Because only protectant fungicides currently are available for control of Botrytis leaf blight, a predictive system for the disease must provide prior warning of infection periods of *B. squamosa* so that onion growers can respond and apply fungicide protection to their crop before infection takes place. Given the presence of inoculum, the two principal environmental conditions governing infection in the field by *B. squamosa* are duration of leaf wetness and temperature (13,22). Because temperatures during the growing season in New York often are favorable for *B. squamosa*, forecasting the occurrence and duration of leaf wetness periods is of primary importance in forecasting infection periods of *B. squamosa*.

Little information is available on forecasting leaf wetness duration, probably because leaf wetness is relatively unimportant compared to other concerns of meteorologists. The available models for predicting (6,7) or estimating (17,18) leaf wetness periods deal only with dew duration and do not present models for forecasting duration of leaf wetness associated with rain. Because models were unavailable for forecasting leaf wetness duration directly, the objective of this study was to examine precipitation probability forecasts issued by the National Weather Service as a means of indirectly forecasting leaf wetness episodes that are potential infection periods of *B. squamosa*.

MATERIALS AND METHODS

National Weather Service precipitation probability (*PP*) forecasts for the Lower Hudson Valley of New York, where this research was conducted, are issued by the Albany, NY, forecasting office and broadcasted by WXL 37 (162.475 MHz). *PP* forecasts were recorded daily beginning 10–13 June and continuing through 9–19 August of 1984–1986. Each morning after 0600 EDT, *PP* forecasts were tabulated for each of three separate 12-hr forecast intervals spanning a 36-hr forecast period. The first forecast interval covered from 0600 to 1800 hours eastern daylight time of the day the forecast was issued; the second forecast interval covered from 1800 hours of the day of the forecast to 0600 hours of the day following the forecast; and the third forecast interval covered from 0600 to 1800 hours of the day following the forecast.

The occurrence of leaf wetness periods was monitored using a Datapod 223 micrologger (Omnidata International, Inc., Logan, UT) located in a commercial onion field (Nowak Farms) in Orange County, NY. Temperature was monitored using a thermistor positioned 12 cm above the soil surface within the canopy and protected from direct sunlight with an aluminum shield. Leaf wetness was detected using an electrical impedance grid (9) positioned 15 cm above the soil surface within the onion canopy and inclined at approximately a 15° angle to the southeast. Frequent visual observations indicated that this sensor reliably detected the time of onset and cessation of leaf wetness due to either dew or rain to within 30 min. The occurrence of measurable rainfall (≥ 1.3 mm) was monitored using a recording rain gauge (model 551, Science Associates, Inc., Princeton, NJ).

Infection index. To assess the conduciveness of particular leaf wetness periods for infection by *B. squamosa*, an index was developed for integrating leaf wetness duration and temperature into a single measure of infection potential. The infection index was developed using data from growth chamber experiments in previous investigations (1,8,16,22,25,27,29). The data used to develop the infection index were taken from 13 experiments having from three to 64 treatments in which the effects on disease of leaf wetness duration and temperature during the leaf wetness period were studied. Experimental data were used only if durations of 18 hr or more had been studied. The disease data used to develop the infection index consisted of treatment means for all experiments in order to weight results from all experiments equally.

Because the experiments used in the development of the infection index were conducted at different times and in different locations, some with different methods of disease assessment, it was necessary to standardize levels of disease intensity from the different experiments. For each treatment mean in each experiment, a value for relative disease severity (*rds*) was calculated as

$$rds = Y_{ij} / max\, Y_{.j} \qquad (1)$$

where Y_{ij} is the *i*th treatment mean from the *j*th experiment and $max\, Y_{.j}$ is the maximum mean disease level observed in the *j*th experiment. The *rds* is, therefore, the proportion of disease in a particular treatment relative to the maximum disease observed in that experiment.

Arcsine-transformed (23) *rds* values were regressed on duration of leaf wetness, temperature during the leaf wetness period, the squares of these variables, and an interaction term. The final model ($P < 0.0001$; $R^2 = 0.550$) took the form

$$\text{ARCSINE}(rds) = -1.7805 + 0.1407\text{TEMP} - 0.0042\text{TEMP}^2 + 0.1335\text{HRLW} - 0.60025\text{HRLW}^2 \qquad (2)$$

where ARCSINE(*rds*) = arcsine-transformed *rds* values, TEMP = temperature (C) during the leaf wetness period, and HRLW = duration of leaf wetness (hr). All parameter estimates in the model were statistically significant ($P < 0.01$). A variable for the TEMP × HRLW interaction was deleted from the model because of lack of significance ($P > 0.10$).

Predicted *rds* values were generated by performing the reverse of the arcsine transformation on ARCSINE(*rds*) values generated using equation 2 for temperature × leaf wetness combinations ranging over 9–26 C and 4–26 hr of leaf wetness. These predicted *rds* values ($\hat{r}ds$) comprised a response surface which was divided into four categories representing four levels of infection. These four levels (Fig. 1) were: insignificant infection ($\hat{r}ds < 0.03$), slight infection ($0.03 \leq \hat{r}ds < 0.25$), moderate infection ($0.25 \leq \hat{r}ds < 0.50$), and severe infection ($0.50 \leq \hat{r}ds \leq 1.00$).

Relationship between *PP* and infection potential. For each 36-hr forecast period (0600 hours of the current day to 1800 hours of the following day), the infection potential of *B. squamosa* was determined for each leaf wetness episode that either began during the forecast period or that was extended in duration because of rainfall during the forecast period. Figure 1 was used to determine the level of potential infection (assuming the presence of inoculum) in each leaf wetness episode by plotting leaf wetness duration and average temperature during the leaf wetness episode. The maximum *PP* (PP_{max}) and the most disease-conducive potential infection period that occurred during each 36-hr forecast period were tabulated.

Accuracy of *PP* forecasts. The accuracy of National Weather Service *PP* forecasts for the Lower Hudson Valley in forecasting rainfall was evaluated using a standard score for assessing forecasting skill, calculated as follows. A Brier score *B* (5,11,19) was calculated for each 12-hr forecast interval using the formula

$$B = 1/n \sum_{i=1}^{n} (P_i - O_i)^2 \qquad (3)$$

where *n* is the number of forecasts examined, P_i is the forecasted *PP*, and O_i takes the value of either 1 or 0 according to the presence or absence, respectively, of rainfall during the forecast interval. For the *PP* category 0–20%, the midpoint of the category (10%)

was used as an estimate of the forecasted PP. Brier scores for each 12-hr forecast interval were compared to a control score by calculating a skill score S (11,12) as

$$S = (C - B)/C \quad (4)$$

where C is a Brier score calculated using a 13-yr estimate of the frequency of rainfall as a measure of P_i. This estimate was obtained by calculating the proportion of summer days during a 13-yr period in which rainfall ($\geqslant$1.3 mm) was recorded at the weather-monitoring station. The skill score thus allows comparison of PP forecasts to a control based on climatological records. The numerical value of the skill score can range from $\leqslant$0 (no improvement over forecasts based on climatology) to 1.0 (perfect forecasting skill for all weather-monitoring locations).

RESULTS

***PP* and infection potential.** Conditions unfavorable for infection of onion leaves by *B. squamosa* occurred in 31.3% of the forecast periods for which PP_{max} was below 30% (Table 1). Given the presence of inoculum, conditions favoring slight and moderate levels of infection occurred with frequencies of 27.1 and 41.7%, respectively, when PP_{max} was below 30%. These potential infection periods were nearly always the result of nightly dew periods that were frequently 8–12 hr in duration and occasionally as long as 13 hr. Conditions favoring severe infection were not observed during forecast periods with $PP_{max} < 30\%$. As the forecasted PP increased, weather conditions became increasingly favorable for infection by *B. squamosa* (Table 1). In particular, conditions favorable for severe infection occurred regularly when $PP_{max} \geqslant 30\%$, such that a severe potential infection period occurred 83.8% of the time when the PP_{max} was 70% or more (Table 1). When $PP_{max} \geqslant 30\%$, leaf wetness episodes of 10–20 hr or more often were recorded, and one extreme episode of 55.0 hr of continuous leaf wetness was recorded.

Accuracy of *PP* forecasts. An increasing probability of precipitation for the Lower Hudson Valley was associated with increasing frequency of rainfall in a commercial onion field in Orange County, NY, although National Weather Service precipitation probabilities generally slightly overestimated the observed frequency of rainfall (Table 2). The forecasting skill score for the first 12-hr forecast interval was 0.309, representing a level of accuracy in forecasting summertime precipitation comparable to the national average of 0.29 (11). In contrast to a national trend of declining forecasting skill in the second and third forecast intervals (0.22 and 0.16, respectively) (11), skill scores of local forecasts remained high for the second and third forecast intervals (0.278 and 0.276, respectively).

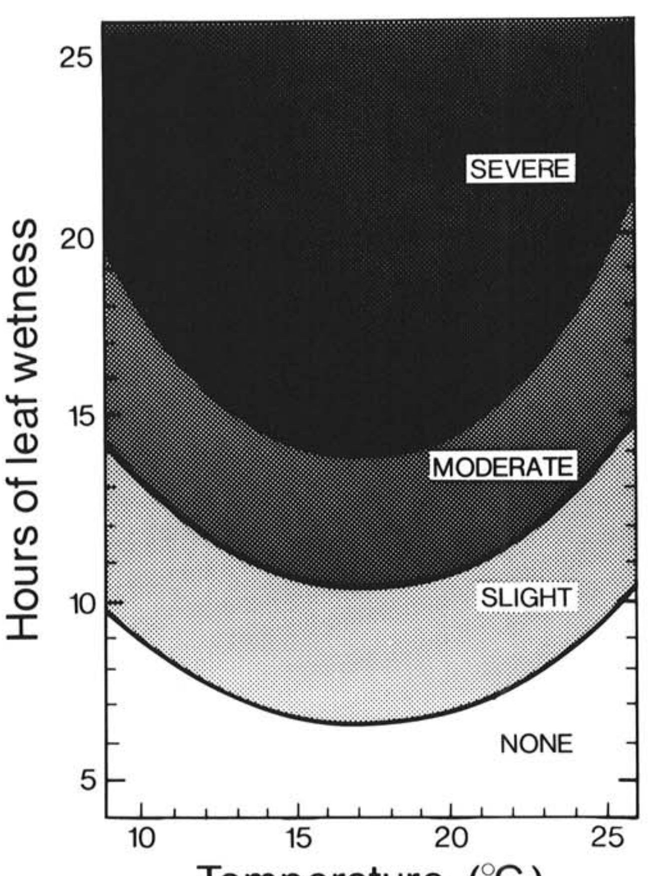

Fig. 1. Levels of potential infection by *Botrytis squamosa*, given the presence of inoculum.

DISCUSSION

Numerous predictive systems have been developed by plant pathologists in recent years for a variety of plant pathogens. Although diverse approaches have been used successfully to forecast the need for control measures, few researchers have examined the feasibility of using forecasted weather in a predictive system. Bourke (4) and others (31) used synoptic weather maps to forecast weather favorable for plant diseases. Forecasts of expected rain (8) or expected leaf wetness duration (10,26,27) were included in experiments on timing fungicides for control of Alternaria leaf blight of carrot and Botrytis leaf blight of onion, although these forecasts did not take into account probabilities of rainfall events. Precipitation probability was used as one component of several in a weather-modified fungicide schedule for controlling *Colletotrichum lagenarium* (28). However, the relationship between precipitation probability and the occurrence of infection periods of *C. lagenarium* in the field was not empirically established.

In the present study, conditions favorable for slight to moderate infection periods occurred frequently when $PP_{max} < 30\%$, but severe potential infection periods were not observed when $PP_{max} < 30\%$. Severe potential infection periods became increasingly more frequent as PP_{max} increased. In a series of related field experiments conducted over 3 yr (29), disease control achieved in field plots left unprotected until $PP \geqslant 30\%$ was equal to that achieved in plots treated weekly with fungicides. Based on the results of the present study, the observation that fungicide protection of onion plants is not necessary when $PP < 30\%$ (29) suggests that the category of severe infection (Fig. 1) is probably the level of infection toward which control measures should be directed.

Since skill of PP forecasts for the Lower Hudson Valley showed very little decline over a 36-hr forecast period, use of $PP_{max} \geqslant 30\%$ as a decision rule for forecasting severe potential infection periods can be expected to have equal predictive value over the entire 36-hr forecast period. This may not be the case in other onion production areas, because skill in forecasting the occurrence of precipitation may decline over a 36-hr forecast period (3,11,20). For this reason, use of PP as a guide to infection potential of *B. squamosa* in other

TABLE 1. National Weather Service precipitation probabilities preceding potential infection periods of *Botrytis squamosa*[a]

Precipitation probability (%)[b]	No. of 36-hr forecast periods	Infection period[c] None	Slight	Moderate	Severe
<30	48	31.3[d]	27.1	41.7	0.0
30–40	60	21.7	31.7	28.3	18.3
50–60	37	24.3	18.9	32.4	24.3
≥70	37	2.7	5.4	8.1	83.8

[a] Data for 1984–1986 growing seasons.
[b] Maximum probability of precipitation over a 36-hr forecast period beginning at 0600 EDT.
[c] Most disease-conductive infection period recorded during the forecast period, given the presence of inoculum.
[d] Percent of forecast periods in specified precipitabilitiy category.

TABLE 2. Relationship between National Weather Service precipitation probabilities and frequency of rainfall in a commercial onion field in Orange County, New York, during growing seasons of 1984–1986

	Forecast interval (hours after forecast)							
	0–12 hr		12–24 hr		24–36 hr		Combined (0–36 hr)	
Precipitation probability (%)	No. of forecasts	Proportion with rainfall[a]	No. of forecasts	Proportion with rainfall[a]	No. of forecasts	Proportion with rainfall[a]	No. of forecasts	Proportion with rainfall[a]
0—20	86	0.000	96	0.042	89	0.034	271	0.026
30	34	0.206	23	0.130	37	0.135	94	0.160
40	14	0.071	18	0.333	18	0.222	50	0.220
50	13	0.231	7	0.714	11	0.545	31	0.452
60	5	0.600	15	0.600	10	0.500	30	0.567
70	8	0.625	7	0.714	7	0.714	22	0.682
80	3	0.000	0	...	2	0.500	5	0.200
90	3	1.000	1	1.000	1	1.000	5	1.000
100	10	0.900	7	0.571	2	1.000	19	0.789

[a] Proportion of forecasts in which measurable rainfall ($\geqslant$1.3 mm) was recorded.

onion production areas would require that *PP* forecasts be evaluated under local conditions.

Although an infection index for *B. squamosa* has been developed previously (24,25), a separate index was developed here for several reasons. Considerable disagreement was found among various reports concerning the relation between temperature, leaf wetness duration, and disease (1,16,25,27). Such disagreement may be due to natural variation among isolates of the pathogen, differences between cultivars used, or subtle differences in experimental conditions. Until such effects are understood, it seems wise to develop an infection index using data from a variety of sources so that the resulting index will be appropriate for a variety of circumstances. In addition, the infection index developed in the present study was needed because the previous index (24,25) presents an irregular response surface with respect to temperature, whereas a smooth response surface is probably more realistic (2). Finally, the new infection index presented here provides four rather than three (24,25) infection categories, permitting greater resolution in measuring favorability of environmental conditions for infection.

PP forecasts were found in this study to provide a 36-hr warning of weather favorable for infection by *B. squamosa*. Specifically, a PP_{max} of at least 30% during a 36-hr forecast period beginning at 0600 hours was found to be useful for indicating when a potentially severe infection period could be expected. The value of such a decision rule in a predictive system is its simplicity and its ready availability to growers. However, a $PP_{max} \geqslant 30\%$ only indicates the potential for a severe infection period given the presence of inoculum. Therefore, the most effective use of this decision rule would be in combination with a method of forecasting the presence of significant amounts of inoculum of *B. squamosa* (30).

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