Rhizoctonia Web Blight Development on Container-Grown Azalea in Relation to Time and Environmental Factors

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ABSTRACT

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Rhizoctonia web blight, caused by binucleate *Rhizoctonia* spp., is an annual problem in the southern United States on container-grown azaleas (*Rhododendron* spp.) that receive daily irrigation. Disease progress was assessed weekly from mid-May to mid-September on nursery-grown plants at three locations in Mississippi and Alabama in 2006, 2007, and 2008. Disease onset, defined as the appearance of blighted leaves at the exterior canopy of at least one plant, occurred on average on 20 July, and calendar date was a more precise predictor of disease onset than several combined time-weather variables. Disease progress curves exhibited weekly fluctuations around a typically exponential increase in the mean number of symptomatic leaves per plant until early to mid-September, after which web blight severity leveled off or declined due to disease-induced leaf dehiscence and the appearance of new, asymptomatic leaves. Based on the relative increase in the log-transformed number of infected leaves per plant, weekly assessment periods were classified as having slow ($\leq 0\%$), intermediate (>0 to $<10\%$), or rapid ($\geq 10\%$ increase) disease progress. Three-day moving averages (MA) of various weather variables were calculated, and lagged values (by 5 days) of the MA were used in an attempt to predict disease progress as slow, intermediate, or rapid. Of the periods assessed as having slow disease progress in the 2006–2007 data set (model development data), 90.6% (29 of 32) met at least one of the following heuristically derived criteria for the lagged MA: min. temperature $< 20.0^{\circ}\text{C}$, max. temperature $> 35.0^{\circ}\text{C}$, avg. vapor pressure deficit < 2.50 hPa, or day of the year > 240 (28 August). One or more of these same criteria were met in 5 of 16 (31.2%) assessment periods with rapid disease progress, indicating that periods with slow versus rapid disease progression could be distinguished reasonably well based on weather. Results were similar for the 2008 validation data. However, weather variables were not useful in separating periods with either slow or rapid disease progress from those having intermediate progress. Instead, weather variables were most useful when used in a negative-prognosis approach to predict disease progression as being “not rapid” (which includes slow and intermediate periods) or “not slow” (including intermediate and rapid periods). The data set was further analyzed using Classification and Regression Tree (CART) analysis to relate weekly disease progress periods to weather variables. The resulting CART model agreed with the heuristic approach in that temperature variables were more prominent than moisture variables in classifying disease progress periods. With both approaches, satisfactory accuracy was accomplished only with negative-prognoses that classified disease progress periods as not rapid or not slow based on temperature and moisture limits.

Rhizoctonia web blight occurs annually on container-grown azalea (*Rhododendron* spp.) in the southern and eastern United States, with symptoms generally most severe in July and August (5,9,12). Binucleate *Rhizoctonia* spp. (BNR; teleomorph *Ceratobasidium* D.P. Rogers) were the predominant pathogens recovered from symptomatic azalea leaves and from flats of rooted cuttings in North Carolina, although a few *R. solani* isolates were recov-

ered as well (8,9). Only BNR were isolated from symptomatic azalea leaves in Alabama and Mississippi nurseries, with anastomosis group (AG) P (=AG-U) obtained from 92% of the symptomatic leaves (14). The most common symptom is complete foliar necrosis, whereas marginal leaf necrosis occurs less frequently. Leaves typically dehisce a few weeks after becoming necrotic and may cling to the plant via the pathogen's mycelial network, hence the name web blight. During spring, a small number of necrotic leaves may appear in the interior canopy of the shrub. By early to mid-summer, disease development advances outward from within the lower, interior portion of the canopy to include an increasing number of necrotic leaves. In conducive conditions, a large portion of the lower leaves can become entirely blighted within a few days, regardless of plant size. Web blight does not appear

uniformly within a block of plants in the nursery, such that about one-third of the plants may develop severe symptoms. Whereas plants of all container sizes may be killed, mortality most commonly occurs with plants stepped up from plug tray packs to 2.7-liter containers during spring.

In azalea nurseries in southern Mississippi, Rhizoctonia web blight development is favored by air temperatures between 25 and 30°C for a mean of 6 to 8 h per day, relative humidity $\geq 95\%$ for >8 h per day, and/or leaf wetness for >6 h per day (5). Similar environmental requirements have been reported for aerial web blight diseases on other host plants such as perennial ryegrass turf (7,10), soybean (18,19), and maize (1). In azalea nurseries along the U.S. Gulf Coast, the annual occurrence of web blight indicates that environmental conditions are generally conducive to disease development in July and August. Specifically, daily irrigation results in consistently favorable moisture conditions, as indicated by the fact that the above moisture requirements were satisfied on $>92\%$ of the days from early July to early September in a previous study by Copes and Scherm (5). Because of daily irrigation, the disease may be more limited by temperature than by moisture conditions, which is supported by the observation that web blight generally does not become severe until the hot summer months.

Fungicides are the main control used to mitigate web blight on container-grown azalea, although precise timing recommendations are not available. A common practice is for producers to apply fungicide in early July, particularly when afternoon rains are prevalent or immediately following the rapid appearance of blighted leaves at the exterior of the canopy (2). Fungicide application timing may be improved if environmental conditions that favor disease development (or limit it, assuming conditions are mostly favorable in this production system) were better understood. Whereas conditions favorable for web blight have been defined previously (5), data collection was not initiated early enough to predict disease onset, and the data were not evaluated in the context of making weekly predictions of disease development. Thus, the objective of this study was to quantify seasonal web blight progression on container-grown azalea and identify environmental variables associated with disease onset and with periods char-

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acterized by having different rates of symptom progression.

MATERIALS AND METHODS

Plants and sites. Experiments were conducted at three sites (USDA-ARS Thad Cochran Southern Horticultural Laboratory [TCSHL] in Poplarville, MS, and one commercial nursery each in Lucedale, MS, and Semmes, AL) in 2006, 2007, and 2008. Sites were located within latitudes 30°46' to 30°56' N and longitudes 89°36' to 88°15' W, and were separated by distances of 98 and 23 km in an east–west direction. Azalea ‘Gumpo’ (14- to 15-month-old nursery stock) in 2.7-liter containers were purchased each year from the two nurseries participating in the study, whereby only one source of plants was used per experimental site. Thus, plant stock was uniform by site, although there was some variation in canopy size among locations and years, ranging from 28 to 45 cm wide × 23 to 30 cm high. Plants were laid out in square or rectangular patterns to form one large monitoring plot per site, with plants touching within rows and 30-cm spacing between branch tips across rows. The number of plants per site was 490 to 506, 374 to 400, and 180 in 2006, 2007, and 2008, respectively. Fungicide treatments against *Rhizoctonia* web blight were omitted to allow natural disease development.

Weather monitoring. Air temperature (T), vapor pressure deficit (VPD), leaf wetness (LW), and rainfall (Rf) were recorded 20 to 25 cm above the ground within each monitoring plot. Two sets of instruments were used per plot, with the exception of Rf being collected by only one instrument per site in 2006 and 2007. T and VPD were monitored with HOBO H8 Pro Series Temperature/Humidity data loggers (Onset, Pocasset, MA) enclosed within a radiation shield. LW and Rf were

collected with resistance-type leaf wetness grids and tipping-bucket rain gauges (Spectrum Technologies, Plainfield, IL), respectively, in 2006 and 2007. In 2008, a set of the above instruments was used at one end of each monitoring plot, and Decagon (Pullman, WA) T, humidity, LW, and Rf sensors were used at the other end of the plot. The faceplate of all wetness grids was set at a 45° angle and faced westward, with the top of the grid at 20 cm above the ground. Spectrum resistance-type wetness sensors recorded the instantaneous value of resistance on a scale from 0 (dry) to 15 (wet) every 15 min. Based on visual observations, it was determined that values ≥2 were representative of the presence of surface moisture on leaves (most wet readings typically were >10). Decagon LW sensors recorded the number of minutes within 30-min intervals when the dielectric constant exceeded 460 raw counts, which was a factory predefined value proportional to the amount of moisture present. There was excellent agreement between the two types of wetness sensors. In a preliminary comparison involving 1,008 30-min measurement periods at the TCSHL site in July 2008, both sensors simultaneously indicated dry conditions during 725 periods and wet conditions during 261 periods, giving an overall between-sensor concurrence of 97.8%. In these calculations, the Decagon sensor was considered to be wet when wetness was indicated during at least 15 min of the 30-min period.

At all sites, T, VPD, LW, and Rf readings were summarized and stored at 30-min intervals. Daily minima, maxima, averages, and totals were calculated as appropriate for each weather variable. Daily values were aggregated into 3-day moving averages (MA) for data analysis.

Disease assessment. Plants were evaluated for web blight at 6- to 9-day intervals,

typically every 7 days, from 8 May to 28 September in 2006, 23 May to 26 October in 2007, and 11 June to 18 September in 2008. Two types of disease severity assessments were made each time. The main disease severity assessment (henceforth referred to as detailed assessment) involved random selection of 15 plants per site and assessment date for detailed counts of the number of symptomatic leaves (exhibiting necrotic lesions or total leaf blight) per plant. When numbers were very high, symptomatic leaves were counted only in half or one-quarter of the canopy of the plant, and the resulting partial counts were extrapolated to the entire plant. In the latter case, the plant was visually dissected into quarters down a center radial plane from the top of the plant and aligning it with the four holes at the bottom of the container. The second disease severity assessment (henceforth referred to as exterior assessment) was a visual rating of exterior symptoms of every plant at each site ($n = 180$ to 506). Rating categories were 0 (≤5 symptomatic leaves visible), 1 (less than one-third of the exterior canopy symptomatic), 2 (between one-third and two-thirds symptomatic), and 3 (more than two-thirds symptomatic). Exterior assessments were made from a distance of 2 to 3 rows (1.1 to 1.7 m) from the plant being evaluated, with the sun at an oblique angle to the assessor to obtain maximum light intensity without casting a shadow on the subject plant. Means of detailed and exterior assessments were calculated for each date and site to generate disease progress curves. Since insufficient disease developed at the Alabama nursery site in 2007 (≤10 symptomatic leaves on most assessment dates), this data set was omitted from subsequent analyses.

Analysis of disease onset. Disease onset was defined operationally as the day of the year when at least one plant at a given

Table 1. Onset of *Rhizoctonia* web blight epidemics on container-grown azalea in relation to time-weather variables^a

Year	Site ^b	Day of disease onset	Days from MA ₃ T _{min} > 20 to disease onset ^c	Hours T 20–30°C from MA ₃ T _{min} > 20 to disease onset	Hours LW ^d from MA ₃ T _{min} > 20 to disease onset	Hours T 20–30°C, LW from MA ₃ T _{min} > 20 to disease onset
2006	TCSHL	192	49	905.0	666.5	601.0
	MS-N	207	65	1131.5	678.5	620.0
	AL-N	207	65	1158.5	747.0	656.5
2007	TCSHL	200	43	800.5	629.5	505.0
	MS-N	199	45	822.5	534.5	419.5
2008	TCSHL	197	52	960.0	473.8	418.0
	MS-N	205	63	1109.7	n/a ^e	n/a
	AL-N	198	56	1094.7	n/a	n/a
Mean		200.6	54.8	997.8	621.6	536.7
Range		15	22	357.8	273.2	238.5
CV ^f		2.65	16.2	14.4	16.2	19.4

^a Disease onset was defined as the day of the year when blighted leaves appeared first at the exterior canopy of at least one plant based on visual assessment of each plant ($n = 180$ to 506).

^b TCSHL = USDA-ARS Thad Cochran Southern Horticultural Laboratory, Poplarville, MS; MS-N and AL-N = commercial nurseries in Lucedale, MS, and Semmes, AL, respectively.

^c MA₃T_{min} > 20 = day of year when 3-day moving average of daily minimum temperature exceeded 20°C for the first time.

^d LW = leaf wetness.

^e Missing data.

^f CV = coefficient of variation.

site had a score of ≥ 1 based on the exterior assessment. (Other definitions of disease onset, such as the day when the average number of symptomatic leaves per plant in the detailed assessment reached 10 or 20% of the maximum number of symptomatic leaves at the same site, were also explored and yielded similar conclusions.) The mean and coefficient of variation (CV) of the day of disease onset was then calculated based on the eight site-year combinations. The goal of the subsequent analysis was to identify combined time-weather variables that would result in a lower CV (i.e., greater precision) than time alone when averaged across the eight site-year combinations. Since container-grown azaleas do not exhibit distinct phenological stages during spring and summer, it was not possible to define a plant phenology-based biofix for calculating such combined time-weather variables. Instead, we used the date when the 3-day MA of minimum temperature first exceeded 20°C ($\text{MA}_3T_{\min} > 20$) as the operational starting point for our computations. This choice was based on the assumption that pathogen activity early in the season would be limited by cool night-time temperatures similar to the effect of minimum temperature on brown patch development of ryegrass turf (7). The following time-weather variables were then derived and compared with calendar date (day of the year) alone for minimizing CV of disease onset across the eight data sets (Table 1): (i) number of days from $\text{MA}_3T_{\min} > 20$ to disease onset; (ii) number of hours between 20 and 30°C (considered favorable for web blight development [3,15]) from $\text{MA}_3T_{\min} > 20$ to disease onset; (iii) number of hours with leaf wetness from $\text{MA}_3T_{\min} > 20$ to disease onset; and (iv) number of hours with leaf wetness and simultaneously temperatures between 20 and 30°C from $\text{MA}_3T_{\min} > 20$ to disease onset.

Analysis of disease progress. Inspection of disease progress curves (Fig. 1) revealed weekly fluctuations around a typically exponential increase in the mean number of symptomatic leaves per plant until early to mid-September, after which web blight severity leveled off or declined due to disease-induced leaf dehiscence and the appearance of newly expanded leaves. Thus, the analysis of disease progress in relation to weather was restricted to the period up to day of year 258 (15 September), which was also typical of previously reported epidemics (5). Mean web blight severity values were $\log_{10}$ -transformed, and changes between subsequent weekly values along the transformed disease progress curve were classified as slow ($\leq 0\%$), intermediate (from >0 to $<10\%$), or rapid ($\geq 10\%$). Thus, the dependent variable for analysis consisted of categorical values for 122 weekly assessment periods from the eight site-year combinations. Periods early in the season when the mean number of

symptomatic leaves was consecutively ≤ 10 were omitted from the analysis because it was felt that small week-to-week variations in the number of symptomatic leaves would have a disproportionate influence on the resulting weekly percent change when overall disease severity was very low. With this modification, the final data set for analysis consisted of 111 weekly assessment periods classified as

having slow, intermediate, or rapid disease progress.

In the first step of the analysis, a heuristic approach was applied to relate weekly, categorical disease progress periods to weather variables based on visual inspection of the data and noting specific weather factors associated with slow disease progress. The analysis was initially restricted to the combined data from 2006 and 2007

Fig. 1. Temporal progress of *Rhizoctonia* web blight severity on container-grown azalea at three sites near **A**, Poplarville, MS, **B**, Lucedale, MS, and **C**, Semmes, AL in 2006 (dotted line), 2007 (dashed line), and 2008 (solid line).

(78 weekly assessment periods) so that the 2008 data (33 assessment periods) could be used for validation. The weather data for analysis consisted of the aforementioned 3-day MA that were lagged by 5 days relative to the weekly disease assessments to account for the fact that web blight progression would likely be related to environmental conditions that occurred a few days prior to symptom expression. (Seven- and three-day lag periods were also explored and yielded similar conclusions.) Using this heuristic approach, periods of slow disease progress were found to occur often when one or more of the following conditions were met for the lagged 3-day MA: min. T < 20.0°C, max. T > 35.0°C, avg. VPD < 2.50 hPa, or day of year > 240. Based on these associations, periods having low disease risk were defined as satisfying at least one of these weather-based conditions, with high disease risk assumed for periods when none of the four conditions were met. Cross-classification tables were produced (PROC FREQ in SAS v. 9.1; SAS Institute, Cary, NC) for 2006–2007 (development data) and 2008 (validation data) to determine how well weather-based disease risk (low versus high) predicted actual disease progress periods (slow, intermediate, and rapid).

As a complement to the heuristic approach, Classification and Regression Tree (CART) analysis was applied to identify weather variables that support the division of the data set into the three disease progress classes. CART performs a dichotomous stepwise division of the data set to identify cut-off values of independent variables associated with the grouping of the dependent variable (6). The analysis was conducted using the *Ctree* macro for Microsoft Excel developed by Angshuman Saha (GE Global Research, Bangalore,

India). Independent variables consisted of the aforementioned lagged 3-day MA of weather variables. Data from 2006–2007 and from 2008 were used as development and validation data, respectively. *Ctree* settings used to define limits for splitting of leaf nodes (dichotomous decision branch points) included minimum node size (percentage of the total number of records needed to define a node), maximum purity (percent records needed to comprise the majority disease progress class), and maximum depth (number of major leaf nodes allowed). Different combinations of weather variables and leaf node settings were explored to generate a classification tree that accurately predicted the actual disease progress classes in both development and validation data sets, while resulting in a manageable number of leaf node splits and biologically reasonable classification cut-offs. Accuracy of prediction of disease progress classes was assessed using cross-classification tables.

RESULTS

Disease onset. Disease onset (defined as the first plant at a given site having a score of ≥ 1 based on the exterior assessment) occurred between days 192 (11 July) and 207 (26 July) across the eight site-year combinations, with a mean of 200.6 (20 July), a range of 15 days, and a CV of 2.65% (Table 1). The day of the year when the 3-day MA of minimum temperature first exceeded 20°C ($MA_3T_{min} > 20$) varied from 142 to 157 with a mean of 145.9 (26 May), resulting in periods between 43 and 65 days from $MA_3T_{min} > 20$ to disease onset (Table 1). Thus, based on both the range (22 days) and the CV (16.2%), the number of days from $MA_3T_{min} > 20$ was less precise than simply day of the year in predicting disease onset. Similar conclusions applied to all other time-weather

variables examined (number of hours between 20 and 30°C from $MA_3T_{min} > 20$ to disease onset; number of hours with leaf wetness from $MA_3T_{min} > 20$ to disease onset; and number of hours with leaf wetness and simultaneously temperatures between 20 and 30°C from $MA_3T_{min} > 20$ to disease onset), which had CV values ranging from 14.4 to 19.4% (Table 1). Thus, the most parsimonious and most precise predictor of disease onset was simply that web blight would occur on 20 July, regardless of site and year. Conclusions were similar when disease onset was defined based on detailed leaf counts on 15 plants per site (*data not shown*), although disease onset was observed between 1 and 2 weeks earlier for the latter assessment because it accounted for symptomatic leaves in the interior of the canopy which were obstructed during the exterior assessment.

Disease progress. Based on the counts of diseased leaves (detailed assessment), *Rhizoctonia* web blight increased steadily between the end of June and mid-September (Fig. 1), with weekly fluctuations of a rising and falling pattern of the number of symptomatic leaves superimposed on this overall trend. The highest mean number of diseased leaves per plant (in 2006, 2007, and 2008, respectively) was 202.6, 148.5, and 98.7 at the Mississippi research station; 300.9, 210.7, and 43.9 at the Mississippi nursery; and 167.2, 16.0, and 65.3 at the Alabama nursery. As stated previously, the 2007 Alabama nursery data set was omitted from further analysis because of insufficient disease development.

Based on the relative increase in the log-transformed number of infected leaves per plant in the 2006–2007 development data set, 32, 30, and 16 of the weekly assessment periods were classified as having slow, intermediate, and rapid disease progress, respectively (Table 2). Of the periods with slow disease progress in 2006 and 2007, 90.6% (29 of 32) met at least one of the following heuristically derived criteria for the lagged 3-day MA: min. T < 20.0°C, max. T > 35.0°C, avg. VPD < 2.50 hPa, or day of year > 240 (Table 2). One or more of these same criteria were met in only 5 of 16 (31.2%) assessment periods with rapid disease progress, indicating that periods with slow versus rapid disease progression could be distinguished reasonably well based on weather. However, this approach did not predict the intermediate disease progress class well (Table 2), resulting in low overall accuracy (~50%) for both the low-risk (29 of 56) and high-risk (11 of 22) predictions (Table 2). Accuracy was improved considerably when the prediction approach was reversed, e.g., rather than predicting disease progress as rapid, it was predicted as “not slow” (which included both rapid and intermediate disease progress classes). Using this negative-

Table 2. Accuracy of weather-based disease risk (classified as low or high) as determined heuristically in predicting weekly epidemic progression of *Rhizoctonia* web blight as slow, intermediate, or rapid on container-grown azalea at three sites in southern Mississippi and Alabama from 2006 to 2008 ($n = 8$)

Weather-based disease risk ^a	Epidemic progress ^b			Accuracy (%) ^c	Accuracy of negative prognosis (%) ^d
	Slow	Intermediate	Rapid		
2006 and 2007 (development data)					
Low	29	22	5	51.7	91.1
High	3	8	11	50.0	86.4
2008 (validation data)					
Low	8	8	2	44.4	88.9
High	3	7	5	33.3	80.0

^a Disease risk was considered low when one or more of the following conditions were met (all are 3-day moving averages lagged for 5 days relative to the corresponding disease assessment period): minimum temperature < 20.0°C, maximum temperature > 35.0°C, average vapor pressure deficit < 2.50 hPa, or day of the year > 240; otherwise disease risk was considered high.

^b Disease progress curves for the average number of symptomatic leaves per plant were log₁₀-transformed, and relative week-to-week changes ≤ 0 , from >0 to <10, and $\geq 10\%$ classified as slow, intermediate, and rapid disease progress, respectively.

^c Relative number of cases where high (or low) weather-based disease risk was associated with rapid (or slow) disease progress.

^d Relative number of cases where low (or high) weather-based disease risk was associated with disease progress that was “not rapid” (or “not slow”). Here, “not rapid” includes slow and intermediate disease progress classes, and “not slow” includes intermediate and rapid classes.

prediction approach, when weather-based disease risk was low, 91.1% (51 of 56) of assessment periods displayed disease progression that was “not rapid”. Similarly, when weather-based disease risk was high, 86.4% (19 of 22) of disease assessment periods had disease progress that was “not slow”. Thus, the heuristic weather-based disease risk classification predicted broad patterns of web blight development very well. Results were similar for the 2008 validation data, although accuracy was somewhat lower than for the 2006–2007 development data (Table 2).

The most parsimonious CART model used four weather variables (all 3-day MA lagged 5 days relative to the corresponding disease progress periods): max. T, min. T, daily number of hours between 20 and 30°C, and daily number of LW hours. *CTree* settings were minimum node size = 15% of total number of records, maximum purity = 65%, and maximum depth = 10. The resultant classification tree utilized cut-off values for max. T = 32.4°C, min. T = 22.2°C, daily hours between 20 and

30°C = 17.3 h, and daily hours of LW = 14.2 h (Fig. 2). For the 2006 and 2007 development data, accuracy was 72.0% (26 of 36) for slow disease progress when CART-predicted risk was low, 70.0% (14 of 20) for intermediate disease progress when predicted risk was moderate, and 50.0% (11 of 22) for rapid disease progress when predicted disease risk was high (Table 3). Accuracies were somewhat lower for the 2008 validation data.

To better compare the CART predictions with those of the heuristic approach, the moderate and low-risk CART predictions were combined into a joint low-risk category, resulting in a 2 × 3 cross-classification table (Table 4). For both the development data and the validation data, prediction accuracies of the heuristic and CART approaches were very similar, i.e., between 40 and 50% when disease progress was predicted as slow or rapid, and between 80 and 90% when a negative-prognosis was applied to predict disease progress as “not rapid” or “not slow” (Tables 2 and 4).

DISCUSSION

Somewhat surprisingly, calendar date was a better predictor for onset of *Rhizoctonia* web blight than weather or combined time-weather variables. Across the eight site-year combinations, disease onset, defined as symptoms visible at the exterior canopy, occurred on average on 20 July with relatively low variability among data sets. This relative uniformity could be explained by the standardized plant material (same cultivar, container size, and plant age) and the consistently conducive environment in the Gulf Coast region (high temperatures, periods of frequent rainfall, and daily irrigation). However, based on personal observations by the senior author, the time of disease onset can be more variable in commercial nurseries where plant size, spacing, location within the nursery, and cultivar are less controlled than was the case in the current study. Early disease onset in commercial nurseries is usually observed in younger plants recently transplanted from propagation material that overwintered in greenhouses; in plants

Fig. 2. Classification and Regression Tree (CART) model for classifying epidemic progression of *Rhizoctonia* web blight on container-grown azalea at three sites in southern Mississippi and Alabama from 2006 to 2007 into slow, intermediate, and rapid weekly disease progress periods ($n = 78$) based on weather factors. Corresponding negative-prognosis classes (where “not rapid” includes the slow and intermediate disease progress classes and “not slow” includes intermediate and rapid classes) are also shown. All weather variables are 3-day moving averages lagged for 5 days relative to the corresponding disease assessment period.

with larger, denser canopies in 6.6- to 11.5-liter containers; and in plants located in wetter areas of the nursery. While increased plant spacing does not prevent disease development (5), tightly grouped plants as well as other factors may elevate humidity, which promotes early disease onset. In contrast, later disease onset has been observed on less susceptible cultivars. Furthermore, as discussed in more detail below, potential differences in inoculum level in the form of mycelium density on plant stems may be related to differences in the time of disease onset in commercial conditions. As such, the relatively fixed calendar date of disease onset in our study needs to be interpreted with caution, although it does indicate that weather variables may play more of an interactive in-

fluence than a direct role in affecting the time when web blight becomes noticeable on container-grown azalea.

Although disease onset was relatively predictable, it was not possible to accurately predict subsequent epidemic progression based on weather, i.e., whether increases in the number of diseased leaves were slow, intermediate, or rapid. This was due primarily to low accuracy in predicting the intermediate disease progress class. Weather variables proved more useful in a negative-prognosis sense to predict when disease progress was “not rapid” (i.e., slow or intermediate) versus “not slow” (i.e., rapid or intermediate). While not as useful for disease management decision-making as models that explicitly predict the rate of disease development, negative-prognosis

models have been applied previously to diseases where the dominance of factors other than weather made a precise prediction of epidemic development impossible (16,17).

Both the heuristic approach and CART analysis for selecting weather factors that influence disease progression similarly emphasized temperature variables over moisture variables and had similar overall prediction accuracies. All sites in this study would have experienced similar meso-scale weather conditions, with the largest difference being rainfall and timing of daily irrigation. Yet moisture variables provided relatively poor explanation of weekly changes in disease severity. Inherently, daily application of overhead irrigation in container-grown azalea may negate a dominant effect of moisture variables on web blight development. Conversely, temperature was more consistently associated with low disease risk, specifically cooler minimum and hotter maximum temperatures that would be less favorable for pathogen growth. In growth chamber studies with *R. solani* and BNR, mycelium growth was favored by temperatures between 24 and 30°C and was very slow at 35 to 40°C (11,15). Furthermore, whereas moisture was an influential variable in other models for web blight diseases caused by *Rhizoctonia* spp., temperature was significant also (7,10,18,19). On soybean, temperature has been shown to regulate aggressiveness of *R. solani* causing web blight (13).

Web blight on azalea develops as a more or less continuous process consisting of three simultaneously occurring subprocesses, i.e., mycelium growth along limbs of the shrub, infection cushion development, and leaf necrotization (symptom development). The limited predictability of symptom development based on weather, as revealed in the present study, may be due to differential effects of weather variables on the three subprocesses. We previously showed that BNR can be recovered from azalea limbs during all seasons of the year (4). The frequency of pathogen recovery implies that mycelium actively colonizes limbs during the summer months, but it is not known if weather influences mycelium growth more directly than infection cushion development or symptom expression. In the current study, we only assessed symptom development since analysis of mycelium colonization of stems and leaves as a component of temporal disease development was beyond the scope of the experiment.

The original goal of this study was to develop a simple, weather-based model that predicts web blight symptom development. This effort was only partially successful in that satisfactory accuracy was accomplished only with a negative-prognosis system that classified disease progress periods as “not rapid” or “not

Table 3. Accuracy of weather-based disease risk (classified as low, moderate, or high) as determined with a Classification and Regression Tree (CART) analysis in predicting weekly epidemic progression of *Rhizoctonia* web blight as slow, intermediate, or rapid on container-grown azalea at three sites in southern Mississippi and Alabama from 2006 to 2008 ($n = 8$)

Weather-based disease risk ^a	Epidemic progress ^b			Accuracy (%) ^c
	Slow	Intermediate	Rapid	
2006 and 2007 (development data)				
Low	26	7	3	72.2
Moderate	4	14	2	70.0
High	2	9	11	50.0
2008 (validation data)				
Low	6	5	1	50.0
Moderate	4	8	4	50.0
High	1	2	2	40.0

^a CART classification tree utilized the following cut-off values (all are 3-day moving averages lagged for 5 days relative to the corresponding disease assessment period): max. temperature = 32.4°C, min. temperature = 22.2°C, daily hours between 20 and 30°C = 17.3 h, and daily hours with leaf wetness = 14.2 h (Fig. 2).

^b Disease progress curves for the average number of symptomatic leaves per plant were log₁₀-transformed, and relative week-to-week changes ≤0, from >0 to <10, and ≥10% classified as slow, intermediate, and rapid disease progress, respectively.

^c Relative number of cases where low weather-based disease risk was associated with slow disease progress, moderate risk associated with intermediate disease progress, and high risk associated with rapid disease progress.

Table 4. Accuracy of weather-based disease risk (classified as low or high) as determined with a Classification and Regression Tree (CART) analysis in predicting weekly epidemic progression of *Rhizoctonia* web blight as slow, intermediate, or rapid on container-grown azalea at three sites in southern MS and AL from 2006 to 2008 ($n = 8$)

Weather-based disease risk ^a	Epidemic progress ^b			Accuracy (%) ^c	Accuracy of negative prognosis (%) ^d
	Slow	Intermediate	Rapid		
2006 and 2007 (development data)					
Low	30	21	5	53.6	91.1
High	2	9	11	50.0	90.0
2008 (validation data)					
Low	10	13	5	35.7	82.1
High	1	2	2	40.0	80.0

^a CART classification tree utilized the following cut-off values (all are 3-day moving averages lagged for 5 days relative to the corresponding disease assessment period): max. temperature = 32.4°C, min. temperature = 22.2°C, daily hours between 20 and 30°C = 17.3 h, and daily hours with leaf wetness = 14.2 h (Fig. 2). Moderate and low-risk CART predictions were combined into a joint low-risk category, resulting in a 2 × 3 cross-classification table.

^b Disease progress curves (average number of symptomatic leaves per plant) were log₁₀-transformed and relative week-to-week changes <0, from >0 to <10, and ≥10% classified as slow, intermediate, and rapid disease progress, respectively.

^c Relative number of cases where low (or high) weather-based disease risk was associated with slow (or rapid) disease progress.

^d Relative number of cases where low (or high) weather-based disease risk was associated with disease progress that was “not rapid” (or “not slow”). Here, “not rapid” includes slow and intermediate disease progress classes, and “not slow” includes intermediate and rapid classes.

slow” based on temperature and moisture limits. An alternative approach for deciding fungicide applications is being investigated by combining the negative-prognosis with a scouting protocol that utilizes different predetermined disease severity thresholds for initiating fungicide applications.

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