Twenty-four-hour Rainfall, a Simple Environmental Variable for Predicting Peanut Leaf Spot Epidemics

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ABSTRACT

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Data from peanut leaf spot epidemics (caused primarily by *Cercosporidium personatum*) during the 1983–1986 growing seasons in Alabama were used to develop disease predictive models, and data from 1988 and 1989 were used to validate the models. The percentage of infected leaflets was used as the dependent variable, and independent variables included days after planting (DAP) and days with rainfall exceeding a specified minimum. Three rainfall thresholds were evaluated: 1.27, 2.54, and 6.35 mm/day. The Von Bertalanffy/Richards equation was used to develop all models. The onset of an epidemic was defined as the point when the model predicted infection of 5% of leaflets. Overall, the model based on DAP fit the data well ($R^2 = 0.76$), as did the model based on daily precipitation exceeding 2.54 mm ($R^2 = 0.77$). The model based on daily precipitation above 6.35 mm was less satisfactory ($R^2 = 0.67$), and the use of daily precipitation above 1.27 mm as the explanatory variable did not result in a model fit. Onset of the average epidemic occurred 60 days after planting in the DAP model, or after 6 days with precipitation above 2.54 mm or 5 days with rainfall exceeding 6.35 mm in the precipitation threshold models. The model based on daily precipitation greater than or equal to 2.54 mm performed better in validation tests than the other models. These results provide the rationale for the conclusion that 1-day rainfall of 2.54 mm or more is an easily measured environmental variable that may be used to schedule fungicide sprays for managing peanut leaf spot.

Early and late leaf spot of peanuts (*Arachis hypogaea* L.), caused by *Cercospora arachidicola* S. Hori and *Cercosporidium personatum* (Berk. & M. A. Curtis) Deighton, respectively, can cause considerable yield losses without fungicide management (19). Leaf spot severity, as judged by end-of-season and cumulative percentage infection and defoliation, is highly correlated with peanut yield loss (2,10). Frequent fungicide applications are needed to prevent losses from peanut leaf spot diseases (4,6).

Most peanut growers in the southeastern United States (Alabama, Georgia, and Florida) apply protectant fungicides for leaf spot control throughout the season on a 10- to 14-day schedule, starting 35–45 days after planting. Strict adherence to this schedule almost certainly results in inefficient use of fungicides during drier weather, when environmental conditions are not favorable for spore germination and subsequent leaf infection by *Cercosporidium personatum*.

Jensen and Boyle (8,9) recognized the need to base the application of protectant fungicides for controlling *Cercospora arachidicola* on the occurrence of environmental conditions favorable for infection by the pathogen. They developed an advisory system that used minimum daily temperature and number of hours of high relative humidity as inputs into the model. Periods of high relative humidity favor inoculum production and infection by leaf spot pathogens (8). They also found that precipitation commonly occurred before or during periods favorable for leaf spot infection (8). This advisory system has been modified (11,14,16,17,23) and has been used in Virginia and North Carolina, where *Cercospora arachidicola* is the major foliar pathogen of peanut. However, the model is not currently used in the Southeast, where *Cercosporidium personatum* has been the predominant foliar pathogen since the late 1970s (24). *Cercospora arachidicola* is also present in the southeastern states; however, its relative contribution to peanut leaf spot epidemics varies from year to year.

Recently, a simulation model was developed to forecast *Cercosporidium personatum* (15). In this system, an on-site, microcomputer-based weather station and forecasting unit (Neogen Corp., Lansing, MI) records inputs of temperature and duration of moisture on an artificial leaf.

These models rely on relatively expensive weather monitoring and recording equipment. Therefore, cost dictates that the equipment be centrally located or that individual mini-weather stations be used. This limitation poses several problems. First, rainfall in the southeastern peanut-growing region is characteristically spatially heterogeneous during the peanut-growing season. Second, in Alabama growers typically plant peanuts on several small fields, usually smaller than 50 acres (20 ha), often scattered over a wide geographic area. These facts suggest that leaf spot epidemics should be managed separately in each field. The high cost of purchasing and maintaining monitoring equipment, such as hygrometers and leaf wetness sensors, prohibits many growers from using this technology. An alternative environmental variable is desirable for predicting when conditions are favorable for peanut leaf spot.

We attempted to find an easily measured macrometeorological variable that correlates well with the development of leaf spot epidemics in Alabama. Our approach was designed to be inexpensive and simple. Because rainfall is easy to measure, requiring only a rain gauge, we evaluated models based only on daily precipitation that exceeded a minimum amount. We did not include temperature in our analysis because temperatures during the peanut-growing season in Alabama are almost always favorable for the growth and development of leaf spot pathogens.

MATERIALS AND METHODS

Field studies. Peanuts (cultivar Florunner) were planted in early May (3–11 May) at the Wiregrass Experiment Station at Headland, AL, in Dothan sandy loam with less than 1% organic matter and pH 6.5. Fields used in 1983 and 1984 had been planted in corn the previous year; fields used in 1985 and 1986 had been planted in peanuts the previous year. Peanuts were grown according to Alabama Cooperative Extension Service recommendations (1) for insect, nematode, and weed control.

Plots that did not receive fungicide applications (uncontrolled epidemics) during the 1983–1986 growing seasons were used in the analysis. These plots were located within 12 different replicated experiments designed to evaluate different fungicides and application rates. Plots consisted of six 10.6-m-long rows spaced 0.91 m apart. The experimental design in each case was a

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randomized complete block with six replications. Data from 1987 could not be used because of defoliation from herbicide injury.

The incidence of early and late leaf spot was monitored periodically throughout each experiment. The main stem was removed from five randomly selected plants from each plot, and the numbers of nodes, expanded leaves, defoliated leaflets, and leaflets with lesions were counted on each stem. No attempt was made to distinguish between lesions of early and late leaf spot. The percentage of infected leaflets (PI) was calculated as $[(D+I)/(4N)]\times 100$, where D = number of defoliated leaflets, I = number of infected leaflets, and N = number of nodes. The mean and the standard error over all untreated plots in each yearly experiment were calculated.

Development of models. Precipitation data recorded at the weather station operated by the National Weather Service at the Wiregrass Substation located within 1.0 km of the test location were used to develop predictive models. Because peanut seedlings must have emerged to become infected, we began the examination of the weather data 10 days after planting. Environmental variables tested were based on precipitation measured on any given day. We tested three threshold levels for daily rainfall: 1.27 mm (0.05 in.), 2.54 mm (0.10 in.), and 6.35 mm (0.25 in.). These models were compared to the development of infection versus time (days after planting). Water from rainfall and water from irrigation were not differentiated.

The incubation period (time from infection to visible lesions) for *Cercosporidium personatum* is 9–11 days (7). Thus, lesions visible on any given day are the result of infections that occurred at least 9–11 days earlier. Thus, when we determined the number of days with rainfall exceeding the threshold, we did not include the 10 days immediately preceding the date when infection was estimated. For all equations based on the number of days with rainfall, the percentage infection includes all infections, now and 10 days in the future, that appear because of the accumulated rainfall.

The Von Bertalanffy/Richards equation (20,26) was used to develop models by nonlinear regression with the multivariate secant or false-position method (5,21). This equation is of the form $PI = 1 + [-1 + (PI_0 \cdot e^{1-m}) (e^{-rX})]^{1/(1-m)}$, where PI is the proportion of leaflets infected (converted to percentage in graphs), PI_0 is the initial proportion infected (set here at 0.01), m is the shape parameter (when m approaches 0, 1, or 2, the resulting curve resembles a monomolecular, Gompertz, or logistic function, respectively), r is the growth parameter, and X is the independent variable. The shape parameter was constrained to be between 0.5 and 1, because the data favored the monomolecular or Gompertz distribution. Residuals were examined for goodness of fit and for normality (21,25). The onset point (PI_5) was defined in terms of units of the independent variable X when the model predicted a proportion of infection (PI) of 0.05. The maximum proportion of diseased leaflets was set at 1 (all leaflets diseased).

The coefficient of determination, R^2, was calculated as $1 - (\mathrm{SSE}/\mathrm{SSTO})$, where SSE and SSTO are the sum of squares error and the corrected sum of squares total, respectively (3). SSE and SSTO are used to estimate the amount of the variance in the dependent variable that is explained by the independent variable.

In addition, the residuals from the Von Bertalanffy/Richards analysis were analyzed to determine whether any additional variance could be explained by a year effect. Residuals were used as the dependent variable with year as the independent variable in analysis of variance (25). Tukey's mean separation test (J. W. Tukey, *unpublished*) was used to determine whether years were significantly different from one another.

Validation. Data from 1988 and 1989 field studies, similar to those previously described, were used to validate the models. The fields in both years had been planted to peanuts the previous year. Data were collected as described above. The observed percentage of infection was graphed versus the percentage of infection predicted by the Von Bertalanffy/Richards models. Linear regression (25) was used to determine whether points conformed to a line with a slope of 1 and an intercept of 0. Lines representing deviations of ±20% from this line were also plotted on each graph to allow visual assessment of the fit for each model.

RESULTS

All years used in the analysis were unique. Weather data indicated that 1986 was an unusually dry year.

Models developed. The model using days after planting (DAP) as the independent variable to predict leaf spot epidemics provided a good fit to the data (Table 1 and Fig. 1), as judged by the coefficient of determination ($R^2 = 0.76$) and normally distributed residuals. On average, the onset point of epidemics (5% infected leaflets) was reached at 60 days after planting (Table 1).

The model using the number of days when precipitation equaled or exceeded 1.27 mm as the independent variable resulted in widely scattered data points (Fig. 2A), and nonlinear regression failed to converge on a solution. Thus, this model was not considered further.

The model based on days with rainfall of 2.54 mm or more gave a good fit to the data (Table 1 and Fig. 2B) ($R^2 = 0.77$), and residuals were distributed normally. In this model, the onset point of the epidemic was reached after 5.8 rainfall events. The model based on days with rainfall greater than or equal to 6.35 mm was less satisfactory (Table 1 and Fig. 2C), as judged by the lower coefficient of determination ($R^2 = 0.67$), yet residuals were normally distributed. The estimated onset point for this model was after five rainfall events (Table 1).

Examination of residuals from the model using DAP as the independent variable revealed year effects (Table 2). In particular, infection in 1986 lagged behind the average by 9.5%. This deviation from expected infection can be attributed to the drought that occurred in Alabama that year. The models that used precipitation thresholds to define infection periods should explain part of this lag. In fact, the 1986 epidemic still lagged behind the average in both precipitation models, but by only 5.5 and 6.5% for thresholds of 2.54 and 6.35 mm, respectively. Also of interest was the fact that the 1984 epidemic progressed more rapidly than the average in all models.

Validation. When we compared observed infection for 1988 and 1989 with the percentage infection predicted by the DAP model, the regression line had an intercept that was significantly ($P < 0.05$ except where noted otherwise) different from 0 and a slope that was significantly different from 1; only 23 of 43 points fell within the ±20% lines (Table 3 and

Table 1. Summary statistics for Von Bertalanffy/Richards equation[a] describing peanut leaf spot epidemics during the 1983–1986 growing seasons in Alabama

Independent variable	Growth parameter r[b]	Shape parameter m[b]	PI_5[c]	R^2
Days after planting	0.039 (0.005)	0.967 (0.018)	60.0	0.76
Days with rainfall ≥ 1.27 mm[d]	—	—	—	—
Days with rainfall ≥ 2.54 mm	0.132 (0.016)	0.885 (0.043)	5.8	0.77
Days with rainfall ≥ 6.35 mm	0.166 (0.027)	0.815 (0.078)	5.0	0.67

[a] Form of equation: $PI = 1 + [-1 + (PI_0 \cdot e^{1-m})(e^{-rX})]^{1/(1-m)}$, where PI = proportion of leaflets infected, PI_0 = initial proportion infected, m is the shape parameter, r is the growth parameter, and X is the independent variable (20).

[b] The standard error of the mean is shown in parentheses.

[c] PI_5 represents the time in terms of the independent variable when infection reaches 5% in the specified model.

[d] Nonlinear regression failed to converge on a solution for this data set.

Fig. 3). For the model based on days with rainfall over 2.54 mm, the regression line had an intercept that was not significantly different from 0 ($P > 0.05$ except where noted otherwise) and a slope that was not significantly different from 1, with 32 of the 43 points falling within the ±20% lines. For the model based on days with more than 6.35 mm of rainfall, the slope of the regression line was not significantly different from 1, but the intercept was significantly different from 0; 29 of 43 points were contained within the ±20% lines.

DISCUSSION

The severity of peanut leaf spot in Alabama fluctuates from year to year primarily because of environmental variables. In our model, rainfall could explain most of the observed variation in peanut leaf spot epidemics. Daily precipitation of 2.54 mm or more was the best of the precipitation variables we examined for describing peanut leaf spot epidemics. The validation regression for this model was the only one with both an intercept that did not differ from 0 and a slope that did not differ from 1. Furthermore, in the 2 yr used for validation, this independent variable removed most of the differences between the two epidemics. Johnson et al (12) similarly found that the number of days with rainfall greater than or equal to 2.54 mm from June through September was highly correlated ($r = 0.896$) with the severity of peanut leaf spot epidemics.

The coefficients of determination and the analysis of residuals showed that none of the models accounted for all of the variation in disease data. Differences in crop rotation, differences in the relative contributions of early and late leaf spot, other macrometeorological and micrometeorological variables, the distance to the weather station (1 km), and perhaps inaccuracies in disease assessment may account for some of the remaining variation. Crop rotations of two or more years should delay the onset of peanut leaf spot epidemics (13,18). Peanuts were planted in rotated locations in 1983-1984. In both cases, the rotation lengths were less than 2 yr. However, in 1984 the leaf spot epidemic developed faster than the average epidemic. Volunteer peanut plants growing as weeds in the rotational crop and thus providing inoculum may also have contributed to variations in the severity of epidemics.

The relative importance of the two leaf spot pathogens may have affected the time of epidemic onset and the rate of disease increase. If *Cercospora arachidicola* played a more important role than usual in any epidemic, then infection and defoliation may have occurred earlier in the season that year, since the early leaf spot pathogen has a lower optimal temperature for growth and a shorter incubation period than *Cercosporidium personatum* (7). However, in all years used in model development and validation, *Cercosporidium personatum* was the primary foliar pathogen present.

Macrometeorological variables such as precipitation are indirect measures of conditions required for infection by leaf spot pathogens, namely leaf wetness. Leaf wetness for 10-12 hr/day is adequate for high levels of infection (9,22). Daily precipitation of 2.54 mm or more was correlated with periods of leaf wetness of more than 10 hr/day (*data not presented*). However, leaves are sometimes wet for more than 10 hr/day

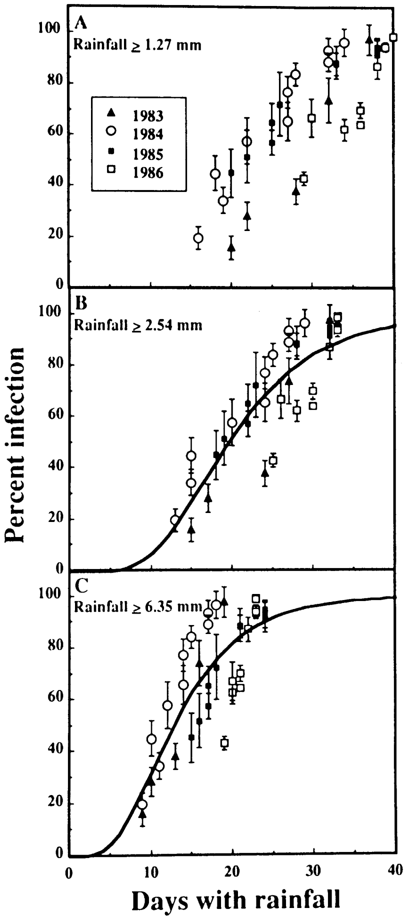

Fig. 2. Percentage of infected leaflets in peanut leaf spot epidemics during the 1983-1986 growing seasons plotted against the number of days with precipitation equal to or exceeding 1.27 mm **(A)**, 2.54 mm **(B)**, and 6.35 mm **(C)**. The curves were derived by nonlinear regression using the Von Bertalanffy/Richards equation. Bars indicate the standard error of the mean.

Table 2. Mean values for the analysis of the effect of year (independent variable) on residual percentage infection following nonlinear regression with the Von Bertalanffy/Richards equation for each independent variable

	Environmental variable[a]		
Year	**Days after planting**	**Days with rainfall ≥2.54 mm**	**Days with rainfall ≥6.35 mm**
1983	−3.7 bc	−9.5 c	0.0 b
1984	8.3 a	8.6 a	11.9 a
1985	3.3 ab	4.1 ab	−4.6 b
1986	−9.5 c	−5.5 bc	−6.5 b

[a] All analysis of variance models were significant at $P < 0.01$. Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Tukey's mean separation test (J. W. Tukey, *unpublished*).

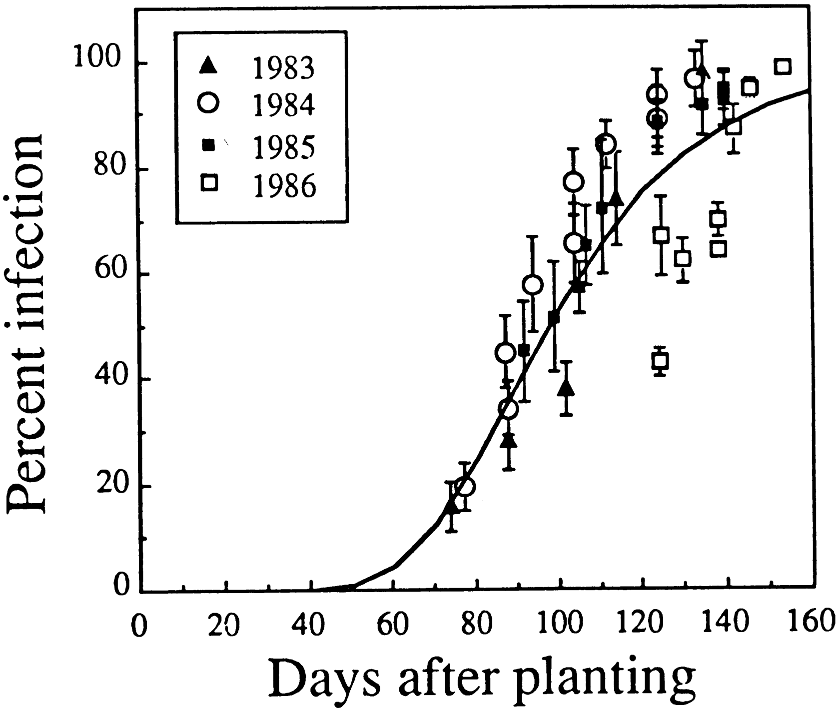

Fig. 1. Percentage of infected leaflets in peanut leaf spot epidemics during the 1983-1986 growing seasons plotted against number of days after planting. The curve was derived by nonlinear regression using the Von Bertalanffy/Richards equation. Bars indicate the standard error of the mean.

Table 3. Statistics from validation regression for peanut leaf spot prediction with data from the 1988 and 1989 growing seasons in Alabama[a]

Independent variable	Intercept[b]	Slope[b]	F value[c]	R^2
Days after planting	21.8* (3.3)	0.80* (0.06)	210	0.83
Days with rainfall ≥ 2.54 mm	1.6 (5.8)	0.91 (0.08)	129	0.75
Days with rainfall ≥ 6.35 mm	−19.4* (7.4)	1.11 (0.10)	135	0.76

[a] The dependent variable was observed percentage of infection, and the independent variable was the percentage of infection predicted by the Von Bertalanffy/Richards equation.

[b] An asterisk denotes that the value was significantly different from 0 ($P < 0.05$) for the intercept or significantly different from 1 ($P < 0.05$) for the slope, as determined by regression analysis. The standard error of the mean is shown in parentheses.

[c] All regressions were significant at $P < 0.05$.

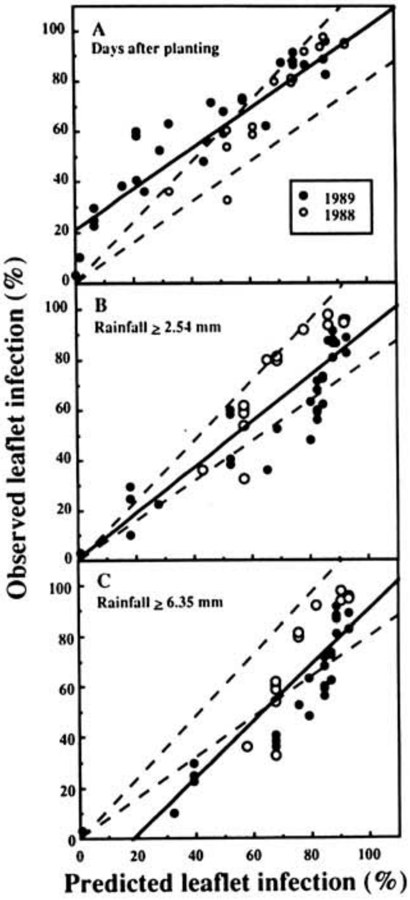

Fig. 3. Observed versus predicted leaflet infection for peanut leaf spot epidemics during the 1988 and 1989 growing seasons. Model predictions were based on the number of days after planting **(A)** or the number of days with rainfall of 2.54 mm or more **(B)** or 6.35 mm or more **(C)**. The solid lines show the results of regression analysis; the dashed lines represent points ±20% from a line with intercept 0 and slope 1.

from sources of moisture other than rainfall (e.g., fog, dew). Consequently, more direct measures of leaf wetness probably improve the prediction of favorable periods for infection; however, the increased precision probably comes at a high price in terms of the purchase and maintenance of equipment.

Temperature during the leaf wetness period also has a significant effect on the ability of leaf spot pathogens to infect peanut (8,22). Shew et al (22) found that maximum infection occurred at 20 C, with few infections above 28 C. The addition of other meteorological variables to our model might have increased precision but would have been inconsistent with our objective of using only the simplest variable to measure (rainfall).

The model based on DAP explains a large part of the variance among epidemics ($R^2 = 0.76$). This is intuitively plausible because disease epidemics do develop over time. Nevertheless, the DAP model did not perform well in predicting disease in two environmentally distinct crop years (1988 and 1989) in validation tests. In 1988, when precipitation patterns were near normal, the observed percentage of infection did not differ greatly from the DAP model prediction, with few data points falling outside the ±20% lines. In 1989, however, when precipitation was above normal in June (29.4 cm, compared to 9.7 cm in 1988), the DAP model underestimated disease progress when environmental conditions were favorable for peanut leaf spot.

The addition of more environmental variables to our model may or may not have improved prediction of epidemic progress. Our main objective was to identify one easily measured variable that would largely predict epidemic progress. Additional variables would complicate the transfer of the model information into a peanut leaf spot advisory system suitable for on-farm use by producers. Future research objectives are to develop a rule-based leaf spot advisory using daily precipitation of more than 2.54 mm to define infection periods and to evaluate the usefulness and profitability of an advisory system based on observed precipitation and weather forecast information.

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