Cercospora Leaf Spot Management Decisions: Uses of a Correlation Between Rainfall and Disease Severity to Evaluate the Virginia Leaf Spot Advisory

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ABSTRACT

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Classes of a variable (MINRAIN) consisting of the number of days with rainfall ≥0.254 cm from June through September over the period 1978–1983 were correlated with areas under disease progress curves (AUDPCs) for Cercospora leaf spot of peanut. A regression model was used ($Y = -7{,}813.81 + 5{,}191$ ($\log_e$ MINRAIN) ($R^2 = 0.83$) to describe the relationship between AUDPC and MINRAIN. This model was used with precipitation data from the period 1933–1983 to estimate a cumulative probability distribution function for peanut leaf spot severity. Probabilities of disease conditions similar to those observed during 1980–1983 were estimated from the probability distribution function and used to weigh annual fungicide test results averaged over similar disease conditions. These weighted average results were then summed for each treatment to predict and compare expected long-term economic returns using the Virginia peanut leaf spot advisory system with those obtained using peanut leaf spot fungicides on the standard 14-day schedule. Predicted use of the advisory system or the 14-day schedule resulted in average increases in expected net return of 16.5 and 8.2%, respectively, compared with the unsprayed control. Use of the advisory system vs. the 14-day schedule resulted in an average increase in expected net return of $174.36/ha.

Additional key words: *Cercospora arachidicola, Cercosporidium personatum,* decision theory, disease forecast models, disease management, epidemiology.

The term "peanut leaf spot" actually refers to two of the most common and economically important diseases of peanut (*Arachis hypogaea* L.). Early leaf spot of peanut is caused by *Cercospora arachidicola* Hori, and late leaf spot is caused by *Cercosporidium personatum* (Berk. & Curt.) Deighton. These diseases occur wherever peanuts are grown and can cause yield losses as great as 50% (7).

Jensen and Boyle (9) correlated increases in peanut leaf spot severity with periods of relative humidity higher than 95% and minimum temperatures of 22.2 C or higher. They also noted that precipitation frequently occurred before and during favorable periods for peanut leaf spot infection. Smith and Crosby (16) also reported rapid increases in concentrations of spores of *C. arachidicola* in the air above peanut fields shortly after the onset of rainfall. Jensen and Boyle (10) developed a peanut leaf spot forecast model from the correlations they observed between weather and disease severity and proposed it as a method of scheduling peanut leaf spot fungicide applications. Parvin et al (13) later computerized the model. The model has more recently been adapted for scheduling peanut leaf spot fungicide applications in North Carolina (4) and Virginia (14). In Virginia, automated electronic weather stations are located in Suffolk and Blackstone to collect environmental data for leaf spot control in the eastern and western halves of the Virigina peanut production area, respectively (14). Data from these weather stations are used to issue advisories of the favorability of weather conditions for disease increase. When the advisory reports that weather conditions are conducive to infection and secondary disease spread, fungicides are applied subject to the following conditions: sprays should be applied within 1–5 days of the issuance of an advisory for disease increase, fungicides should not be applied at intervals of fewer than 10 days, foliage should be dry when sprays are applied, and fungicides must only be used at the rates specified by the manufacturers. During 1979–1982, 4.25 fewer fungicide applications were made per season based on the advisory than based on the 14-day schedule (14). Although final leaf spot severities were greater in experimental plots treated according to the Virginia advisory than in those sprayed on the 14-day schedule, yields associated with the two fungicide schedules were not significantly different (14). Both fungicide schedules significantly reduced leaf spot severity and increased yield compared with unsprayed control plots.

Peanut leaf spot severity can vary greatly among years in the North Carolina and Virginia peanut production areas. Differences in leaf spot severity over years is thought to arise from differences in environmental conditions (especially moisture levels) among growing seasons. This variation probably causes North Carolina and Virginia peanut growers to invest too many resources in peanut leaf spot management in some years and too little in others. Seasonal variations in disease severity also hinder interpretation of field research on peanut leaf spot in this region. Quantitative descriptions of peanut leaf spot severity over more than 2 or 3 yr, however, have not been compiled. Year-to-year variation in peanut leaf spot severity, therefore, has not been characterized. The objective of this study was to investigate relationships between environment and early and late leaf spot that might be useful in inferring and quantifying the long-term pattern of peanut leaf spot severity in North Carolina and Virginia. The resulting probability distribution function for disease severity could then be used to calculate expected economic returns for peanut leaf spot control options based on estimated probabilities of different classes of peanut leaf spot severity.

MATERIALS AND METHODS

Daily rainfall and minimum temperature data were obtained for Suffolk, VA, for the years 1933–1983 from records maintained at the Tidewater Research Center by Virginia Polytechnic Institute

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and State University and USDA personnel. The number of days in June through September on which minimum temperatures were ⩾20 C (MINTEMP) or rainfall was ⩾0.254 cm (MINRAIN) or both (BOTH) were counted for each of the 51 yr. Disease data were tabulated from replicated, unsprayed plots in fungicide tests conducted by using the cultivar Florigiant at various locations near Suffolk, VA, from 1978 through 1983. Although disease assessments included lesions caused by both early and late leaf spot, early leaf spot predominated. Disease progress curves were plotted for each year from assessments of percent infected leaflets made about 12, 16, and 20 wk after planting. Shaner and Finney's method (15) was used to calculate AUDPCs:

$$\text{AUDPC} = \Sigma_{i=1}^{n} [(Y_{i+1} + Y_i)/2] (X_{i+1} - X_i), \quad (1)$$

in which Y_i = the proportion of leaflets infected at the ith observation, X_i = time of the ith observation in days after planting, and n = number of disease observations made during each growing season. Pearson's correlation coefficients were obtained between AUDPCs and the number of days during June through September on which minimum temperatures were at least 20 C (MINTEMP), rainfall was at least 0.254 cm (MINRAIN), or both conditions occurred (BOTH). AUDPCs were also correlated with MINRAIN separated into 3-day intervals (CLASS), the area under a curve for the numbers of days for each month (June through September) on which minimum temperatures were at least 20 C and rainfall was at least 0.254 cm (AUWETH), and the number of advisories (two, nine, five, and seven in 1980, 1981, 1982, and 1983, respectively) indicating favorable conditions for infection and secondary spread of disease (ADVICE). AUDPCs were also regressed against CLASS. MINRAIN data were classed because we believed that certain ranges of moisture conditions might have similar effects on subsequent disease increase. The number of days during June through September on which rainfall was at least 0.254 cm (MINRAIN) was classed in various intervals. The 3-day intervals (MINRAIN) used in the regression analysis were selected by trial and error and were intended to approximate these ranges of moisture conditions. The resulting model was used along with daily rainfall data for the previous 51 yr to estimate annual leaf spot severities for each year on cultivar Florigiant. Disease severity (AUDPC) was subsequently classed as either low (θ_2 = AUDPC ⩽ 2,981) or high (θ_2 = AUDPC > 2,981). The frequencies of these classes of estimated AUDPCs over the past 51 yr were then calculated and used as probabilities of different leaf spot severities.

Economic returns from various fungicides applied according to the Virginia leaf spot advisory or the 14-day schedule were determined from leaf spot control tests conducted in Virginia from 1980 through 1983. Experiments were arranged in a randomized complete block design, with four replicates, at a single location during each year. Plots consisted of two 12.3-m-long rows spaced 0.9 m apart. Two border rows separated the plots from each other. Treatments included an unsprayed control as well as applications of benomyl (50W) at 0.56 kg/ha plus sulfur (718 g/L) at 4.68 L/ha, chlorothalonil 500F at 2.3 L/ha, cupric hydroxide plus sulfur (17.5% Cu, 15.5% S) at 4.68 L/ha, and triphenyltin hydroxide 47.5W at 0.42 or 0.56 kg/ha plus sulfur (718 g/L) at 2.34 L/ha. Fungicides were applied according to the Virginia peanut leaf spot advisory program as well as the standard 14-day schedule. Gross returns were calculated for each treatment from yield and market-grade data obtained from each year's field test. Net returns to leaf spot management were obtained by subtracting estimated costs associated with each control option from the appropriate gross returns. A more detailed description of the experimental design and calculation of economic returns has been published elsewhere (11). Expected net return [E(NR)] (3,8) for each fungicide/application schedule combination was calculated as follows:

$$\text{E(NR)} = \Sigma_{j=1}^{k} P(\theta_j)\, R_m, \quad (2)$$

where $P(\theta_j)$ = the estimated probability of the occurrence of the jth AUDPC or class of disease pressure (there being k possible classes), and R_m = the net return from one of the $1 \ldots n$ fungicide/spray schedule combinations. E(NR)s were calculated using 1980–1983 data, because these were the only years during which the Virginia leaf spot advisory was tested with a number of fungicides. E(NR)s for fungicides applied on the 14-day schedule were also calculated using 1978–1983 data as well as 1980–1983 data. E(NR)s for fungicides applied according to the advisory were only calculated from 1980–1983 data, because the advisory was not tested on chlorothalonil, cupric hydroxide plus sulfur, or triphenyltin hydroxide plus sulfur in 1978 and 1979. Benomyl plus sulfur was tested with the Virginia leaf spot advisory during 1979 as well as 1980–1983. The expected value of the advisory model was estimated by the difference between the E(NR)s calculated for the advisory and the 14-day spray schedule summed over all fungicides examined.

RESULTS

Significant correlations were obtained between AUDPCs and MINRAIN, BOTH, AUWETH, and ADVICE. The highest correlation ($P = 0.0001$, $r = 0.91$), however, was obtained between AUDPCs and MINRAIN classed in increments of three "rainy days" (CLASS) (Table 1). The following predictive model was derived:

$$\text{AUDPC} = -7{,}813.81 + 5{,}191.00 \log_e C;\ R^2 = 0.83, \quad (3)$$

where C = CLASS. Plots of residuals vs. predicted values and vs. CLASS appeared to have a random pattern. AUDPCs of 4,634, 5,085, 759, 3,577, 4,527, and 1,813 were observed in 1978, 1979, 1980, 1981, 1982, and 1983, respectively. Estimated leaf spot severity over the past 51 yr ranged from a low AUDPC of 541 for 1980 to a high AUDPC of 6,244 in 1949. The range of disease conditions observed during 1978–1983 was therefore representative of the estimated leaf spot severity for 49 of the last 51 yr (96%) (Table 2). Our results indicate that moderate to severe leaf spot severities such as those observed during 1978–1979 and 1981–1982 occur about 78% of the time. Light leaf spot severities similar to those observed in 1980 and 1983 were estimated to occur in about 1 of 6 yr, or 18% of the time. Leaf spot severities were so low in 1980 and 1983 (AUDPC ⩽ 2,981) that yields were probably not reduced by disease. Indeed, yields were reduced by drought stress in 1980. Leaf spot severities were similar in 1981 and 1982 but quite high in 1978 and 1979. Conditions were so dry in 1980 that yield, as well as disease, was depressed by lack of moisture. Similar moisture conditions to those seen in 1980 might be expected in only 1 yr of 50, or 2% of the time. The frequency of occurrence of estimated levels of leaf spot severity (AUDPCs) over the past 51 yr and the

TABLE 1. Pearson correlation coefficients (r) between area under the disease progress curve (AUDPC) for Cercospora leaf spot on peanut and environmental variables for data collected during 1978–1983

Variables	r	$P > r$
MINTEMP[a]	−0.241	0.2570[b]
MINRAIN	0.896	0.0001
BOTH	0.685	0.0002
CLASS	0.909	0.0001
AUWETH	0.540	0.0065
ADVICE	0.497	0.0500

[a] MINTEMP = number of days during June through September on which minimum temperatures were ⩾20 C. MINRAIN = number of days during June through September on which rainfall was ⩾0.254 cm. BOTH = number of days in June through September on which minimum temperatures were ⩾20 C and rainfall was ⩾0.254 cm. CLASS = MINRAIN separated into classes in intervals of 3 days. AUWETH = area under a curve for the number of days for each month on which minimum temperatures were ⩾20 C and rainfall was ⩾0.254 cm. ADVICE = number of favorable advisories issued by the Virginia peanut leaf spot advisory predicting probable increase of disease during June through September.

[b] Probabilities of larger coefficients assuming no correlation.

cumulative probability of disease severity levels are illustrated in Figure 1A and B, respectively. The chances of observing leaf spot severities (in terms of AUDPC) similar to those observed in 1978, 1979, 1980, 1981, 1982, and 1983 were estimated (Fig. 1B) to be about 21.6, 7.8, 1.9, 19.6, 19.6, and 13.7%, respectively.

Calculation of E(NR) is illustrated by the "payoff matrix" in Table 3. When the 14-day schedule was used, benomyl plus sulfur showed the highest expected mean net return. Use of peanut leaf spot fungicides on the 14-day schedule resulted in an average increase in E(NR) of 8.2% over that obtained with the unsprayed control. When the advisory system was followed, use of chlorothalonil resulted in the highest E(NR). Increases in E(NR) were significant for all advisory treatments except benomyl plus sulfur. Use of the Virginia peanut leaf spot advisory resulted in a significant average increase in E(NR) of 16.5% over that observed from the control. The average increase in E(NR) from use of the advisory vs. the 14-day schedule was $174.36/ha.

DISCUSSION

Variation in leaf spot severity across years often hinders determination of net revenue optimizing disease management tactics. A "decision-theoretic" approach to pest management suggested by several workers (5,6,12) can be applied to this problem. If disease severity can be quantitatively described in terms of characteristics relevant to agricultural production and the frequencies of each level of disease severity can be estimated and associated with the performance of various disease management tactics, then estimates of average control measure performance can be obtained. These estimates are more representative of those to be expected over the full range of disease conditions that growers might face. Our expected levels of economic value and net return for various Cercospora leaf spot fungicides and application schedules might serve as such estimates for Virginia peanut growers.

The expected economic returns calculated from probabilities of disease severity taken from the leaf spot probability distribution function and from annual leaf spot fungicide test results should be closer to the true average performance of each treatment than a simple average value taken over the 4 yr. If growers could obtain forecasts of future disease pressure, they could also use estimates of the performance of each of their management options under similar disease pressures to choose the tactics most likely to control disease and optimize economic return. If the accuracy of the leaf spot advisory in predicting disease increase were known, growers could also weigh the risks of advisory error in their decision-making process.

Probabilities of various levels of disease severity are, however, rarely available. They are also usually difficult to obtain. Anderson (1,2) suggested that when complete descriptions of the variation of an input to an agricultural response function are not available, the sparse data that do exist can sometimes be used to estimate rough probability distributions for the varying levels of that input. Carlson (5) described disease severity for peach brown rot in California using historical weather data. This was our objective in estimating the probability distribution function (Fig. 1B) for peanut leaf spot disease severity in Virginia from rainfall data. The close correlation between seasonal severity of Cercospora leaf spot and frequency of rainfall allowed us to estimate annual disease severities over a very long period of time.

Leaf spot epidemics more severe than those observed during 1980–1983 were estimated to have occurred in 17 of the past 51 yr. Evaluation of the advisory is therefore based on data from the

TABLE 2. Areas under disease progress curves (AUDPCs) for Cercospora leaf spot estimated for 1933–1983 from CLASS[a]

Year	AUDPC	Year	AUDPC	Year	AUDPC
1933	4,139	1950	4,634	1967	4,139
1934	5,085	1951	4,139	1968	4,139
1935	4,634	1952	4,139	1969	4,634
1936	3,592	1953	4,139	1970	3,592
1937	4,634	1954	2,287	1971	4,139
1938	4,634	1955	4,139	1972	2,981
1939	4,634	1956	3,592	1973	2,981
1940	3,592	1957	2,981	1974	3,592
1941	4,139	1958	4,139	1975	4,634
1942	5,085	1959	4,634	1976	3,592
1943	2,981	1960	3,592	1977	2,981
1944	4,139	1961	4,634	1978	4,634
1945	5,501	1962	2,981	1979	5,085
1946	5,085	1963	3,592	1980	541
1947	4,634	1964	4,139	1981	3,592
1948	4,139	1965	4,139	1982	3,592
1949	6,244	1966	4,139	1983	2,981

[a] CLASS = number of days during June through September on which minimum temperatures were ≥20 C, separated into classes in intervals of 3 days.

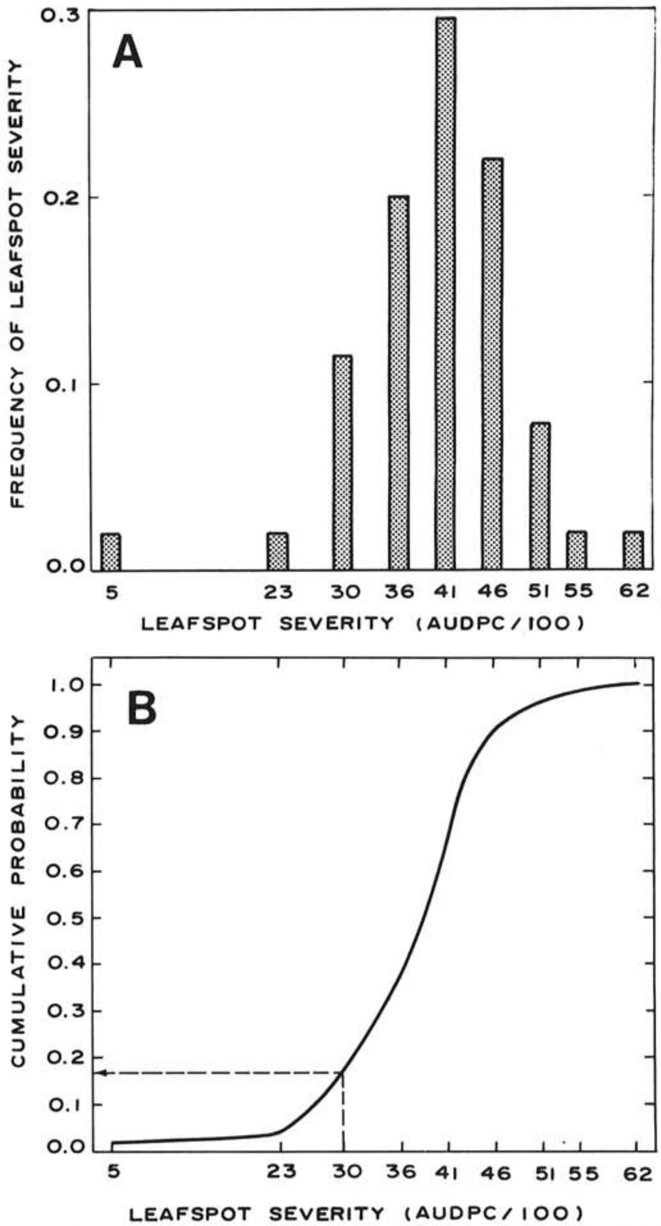

Fig. 1. Cercospora leaf spot on peanut. **A,** Frequencies of estimated leaf spot severities in terms of areas under disease progress curves (AUDPCs) vs. leaf spot severity (estimated from CLASS—the number of days in June through September on which ≥0.254 cm of rain fell, separated into intervals of 3 days per growing season). **B,** Cumulative probability curve for Cercospora leaf spot severity in terms of annual AUDPCs/100 estimated from Suffolk, VA, precipitation data from 1933 through 1983. Cumulative probabilities of AUDPCs ≤ 30 (θ_1) and AUDPCs > 30 (θ_2) were used as weights in calculating net returns for leaf spot control treatments.

TABLE 3. Payoff matrix for expected net return [E(NR)] from use of various peanut leaf spot fungicides applied according to two schedules in Virginia during 1980–1983

		Mean net return when disease severity[a] is			
Schedule	Fungicide	Low ($P = 0.1765$)[b]	High ($P = 0.8235$)[b]	E(NR)[c] ($/ha/yr)	Increase in E(NR)[d] ($/ha/yr)
Calendar	Benomyl + sulfur	1,274.06	2,648.13	2,405.60	
Advisory	Benomyl + sulfur	1,448.38	2,686.60	2,468.07	62.47[e]
Calendar	Chlorothalonil	1,129.96	2,537.67	2,289.22	
Advisory	Chlorothalonil	1,246.76	2,852.68	2,569.24	280.02[e]
Calendar	Cupric hydroxide + sulfur	1,052.96	2,540.12	2,277.62	
Advisory	Cupric hydroxide + sulfur	1,482.82	2,771.71	2,443.28	165.66[e]
Calendar	Triphenyltin hydroxide + sulfur	1,056.87[f]	2,660.10	2,209.24	
Advisory	Triphenyltin hydroxide + sulfur	1,229.18	2,649.17	2,398.52	189.28[e]
...	Untreated control	1,227.77	2,311.39	2,120.15	

[a] Disease severity was estimated in terms of areas under disease progress curves. Net returns presented are means from tests conducted under low (1980 and 1983) or high (1981 and 1982) disease severity.

[b] Disease severities were grouped into two classes, and the frequencies of these classes were estimated from the cumulative probability curve for Cercospora leaf spot (Fig. 1B).

[c] Expected net return was calculated by adding the product of mean net return and probability of similar disease conditions for each treatment (across rows in the table).

[d] Difference in E(NR) (advisory − calendar) for each fungicide.

[e] Increases in expected net return were significant at $P = 0.05$.

[f] Triphenyltin hydroxide plus sulfur applied on the calendar schedule was not tested in 1983; therefore, net return from 1980 was used in place of a mean for 1980 and 1983.

lower 67% of the disease distribution (below 4,527 in Fig. 1B). Benomyl plus sulfur was tested in 1979 as well as 1980–1983. Net returns from use of the advisory program may be higher in low- than high-disease years (about $174.32/ha for 1980 and 1983 vs. $62.47 for 1981 and 1982 for benomyl plus sulfur). In the most severe disease year observed, however (1979, AUDPC = 5,085), the net return from using the advisory with benomyl plus sulfur was $96.59/ha. If we assume that 1981 and 1982 were good representatives of the advantage of using the advisory program in high-disease years, then the expected value of the advisory program compared with the 14-day schedule is $174.36/ha.

The estimated probability density function based on rainfall frequency is not proposed as a permanent substitute for direct, long-term characterization of pathogen populations or disease severities. It is suggested as a means of "filling the gap" while such data are being taken or in the event that such information cannot be obtained. The model developed for this study obviously oversimplifies the actual situation and can probably be improved as additional information concerning interactions between Cercospora leaf spot and microenvironmental conditions are defined.

The results of this study support previous work (14) by showing that the Virginia advisory can be used to reduce the number of fungicide applications for leaf spot control without incurring disease-induced crop losses. In fact, use of the advisory in this work resulted in increased growth and net return. Leaf spot disease severity in Virginia appears to range usually from moderate to severe. Years with slight disease, however, occur often enough to be an important consideration in evaluating disease management practices. Calculation of E(NR) from the probabilities of various levels of leaf spot severity allowed us to explicitly consider the stochastic nature of disease conditions as well as treatment efficacy and cost when comparing leaf spot management alternatives. Use of the Virginia peanut leaf spot advisory program resulted in higher E(NR)s than did use of the 14-day schedule. The average increase in E(NR)s over the fungicides tested could be considered as an estimate of the potential economic value of the advisory to Virginia growers. This estimated value of the advisory, when summed over the average size of a peanut farm in Virginia (30.4 ha), could mean an additional $5,300.54 of income each year to a typical Virginia peanut grower.

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