Disease Control and Pest Management

Modification of the Peanut Leaf Spot Advisory for Use on Genotypes with Partial Resistance

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ABSTRACT

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The effects of modification of the peanut leaf spot advisory program were evaluated on six peanut genotypes in three field experiments in North Carolina in 1985 and 1986. Relative humidity-temperature index values from the Jensen and Boyle model were modified by factors of 0.85 and 0.70. The average numbers of fungicide applications were 7.0, 5.3, 4.0, and 2.6 for the 14-day schedule, standard advisory, 0.85 modified advisory, and 0.70 modified advisory treatments, respectively. Individual comparisons among all genotype-spray schedule combinations indicated that either of the advisory modifications could be used with three genotypes with leaf spot resistance, NC5, NCGP343 × NC5 (Entry 86), and NC6, without resulting in significantly greater AUDPCs, AUDEFCs, and infection rates than the nonmodified advisory. However, comparisons across all genotypes and locations indicated that the modified advisories resulted in significantly larger area under the disease progress curves (AUDPCs), area under the defoliation curves (AUDEFCs), and apparent infection rates but no significant reduction in yield. Yield loss models developed for each genotype had similar slopes indicating uniform yield responses to leaf spot among varieties.

A peanut leaf spot forecasting technique was developed by Jensen and Boyle for the effective and economical control of early leaf spot caused by *Cercospora arachidicola* Hori and late leaf spot caused by *Cercosporidium personatum* (Berk. & Curt.) Deighton (8,9). This technique was developed to replace the routine application of fungicides with a system that recommended fungicide application only during periods when environmental conditions were favorable for disease development. The variables affecting disease development were the number of hours of relative humidity at or above 95% in each 24-hr period and the minimum temperature during that period of high humidity. Combinations of these two variables corresponded to a qualitative classification of the relative favorability of conditions for disease development. These included rapid, moderate, slow, and little or no rates of infection increase and were assigned severity index values of three, two, one, and zero, respectively. Smith et al (20) first reported the successful control of early leaf spot using this technique for scheduling fungicide applications. This system was computerized by Parvin et al (16), which then served as the foundation for work conducted later in North Carolina, South Carolina, and Virginia (1,2,4,17). Field studies have compared the effects of an advisory recommended fungicide schedule and 14-day schedules on disease development, yield, and economic return (12,17). These studies indicated that the advisory program will consistently result in a greater amount of disease than a 14-day schedule; however, yields from these two treatments have not been significantly different (17). As a result, economic analysis indicated that the advisory program consistently results in a greater financial return to the grower due to reduced inputs (12). The leaf spot advisory was developed for use on varieties susceptible to leaf spot. Thus, as resistant genotypes become available, control of leaf spot may require even fewer fungicide applications than those recommended by the advisory. The objectives of this work were to: 1) create modified versions of the Jensen and Boyle leaf spot advisory and compare the responses of resistant and susceptible genotypes using several epidemiological parameters, 2) compare different genotype spray schedule combinations with standard control practices, and 3) develop disease loss models for the peanut genotypes used in this study.

MATERIALS AND METHODS

Model modification. Seven sets of historic weather data (1982–1985) from four sites in North Carolina and Virginia were collected. Daily advisory index values were calculated between 1 July and 31 October for each, and the recommended spray applications were enumerated. To modify the advisory for use on genotypes with disease resistance, the index values for each day were arbitrarily multiplied by factors of 0.95, 0.90, 0.80, 0.75, and 0.7, which resulted in consecutively longer periods of relative humidty greater than 95% and/or higher minimum temperatures during a particular period before the advisory recommended a fungicide application. The 0.85 and 0.70 modifications were chosen since they resulted in an average of 0.9 and 1.9, respectively, fewer fungicide applications than the nonmodified advisory.

Field studies. Plots were established in 1985 at the Peanut Belt Research Station at Lewiston, NC, plotted in a randomized complete block design with 30 treatments in four blocks. Treatments consisted of factorial combinations of six genotypes and five spray schedules. This experiment was repeated in 1986 at the Lewiston location and at the Upper Coastal Plain Research

Station at Rocky Mount, NC. In the latter experiments, a split-plot design was used with fungicide schedules being the main plot treatments and genotypes being the subplot treatments to eliminate tractor damage on those treatments not receiving a fungicide application. The genotypes used were: Florigiant, NC2, NCGP3033 × NC2 (Entry 64), NC6, NCGP343 × NC5 (Entry 86), and NC5. Spray schedules in 1985 included: every 14 days, when called for by the advisory, the 0.85 adjusted advisory, the 0.70 adjusted advisory, and a nonsprayed control. In 1986, nonsprayed plots were removed from the design to prevent possible positive interplot interference. However, to quantify disease development on nonsprayed plants for relative comparisons, monitor plots were established approximately 30 m away from the main experiment. Disease assessments were made in these plots on the same schedule as main plots. Chlorothalonil formulated as 500 g/L flowable was applied at the rate of 1.23 kg a.i./ha, according to the above schedules, with a tractor-mounted hydraulic sprayer. Four rows were sprayed simultaneously with three nozzles per row. Spray nozzles delivered 140 L/ha at 276 kPa. Fungicide applications were initiated approximately 45 days after planting. Plots consisted of four 12.2-m-long rows planted 0.9 m apart. Lateral borders consisted of four rows, and within-row-borders consisted of four rows, 7.5 m long. All borders were planted with the cultivar Florigiant, and chlorothalonil was applied on a 14-day schedule. All plots were planted between 7 and 16 May. Peanuts were dug 153–158 days after planting with a commercial digger-inverter. Plots were harvested 7–10 days after digging with a peanut combine. Pods and seeds were weighed after being cleaned and dried to approximately 10% moisture.

Estimates of the percentage of leaves with lesions caused by *C. arachidicola* and the percent defoliation were recorded eight to nine and five times, respectively, throughout the season, beginning approximately 35 days afte planting. Estimates of percent leaves with lesions were made by two assessors on the entire length of the two center rows of each plot. Diagrams of 45–50 leaflets with 2, 10, 20, 45, 75, and 100% of the leaflets with lesions were used as an aid in estimations. Defoliation percentages were determined by counting the number of nodes and the number of missing leaflets on two randomly selected stems in the two center rows of each plot. Averages of the two observations from each plot were used for subsequent data analysis. Arc sine transformation was performed on data to reduce possible heterogeneity of variance components. The area under the disease progress curves (AUDPC) and area under the defoliation curves (AUDEFC) for each plot were calculated with the equation of Shaner (18). AUDPC data were also regressed against time expressed as days after planting. The regression coefficient or apparent infection rate (21) was used to represent a measure of the overall progression of the epidemic. The logistic, $\ln y/(1-y)$ Gompertz, $-\ln(-\ln y)$, and monomolecular $1/(1-y)$ models were used to linearize the disease progress curves. Coefficients of determination (R^2 values) and root mean squares were used to select the model providing the best fit. Also, plots of residuals vs. predicted values were examined for any systematic pattern. Stepwise multiple regression was used to identify those assessment dates that best accounted for difference in AUDPC values.

Two ANOVA models with blocks nested within location were used to compare AUDPC, AUDEFC, and infection rate values. First, the main effects of genotype, spray schedule, and their interaction were examined in a factorial arrangement; secondly, all of the genotype-spray schedule combinations were examined in a one-way ANOVA so that modified spray schedule and newly developed genotype combinations could be compared individually with the Florigiant-Advisory and Florigiant 14-day treatment. The latter treatment is the most commonly used genotype by fungicide spray schedule used in North Carolina.

Yield loss models were developed by simple linear regression with AUDPC values as the independent variable with data from the 1985 experiment, since this was the only test that included nonsprayed controls. Nonsprayed plots were necessary to demonstrate the effects of high AUDPC values on yield. Covariance analysis was used to compare heterogeneity of slopes and *y*-intercepts. Data sets for equations that did not have significantly different intercepts or slopes were combined. All of the above statistical tests were performed on tranformed and nontranformed data. SAS (Statistical Analysis System, Cary, NC) was used for all statistical analysis.

RESULTS

Naturally occurring epidemics in field plots at Lewiston started in July in both years, but epidemics at Rocky Mount did not begin until late August. For this reason, apparent infection rates were not calculated from this latter experiment. Nonsprayed plots planted with the susceptible genotype Florigiant had greater than 90% of the leaflets infected with *Cercospora arachidicola* by 18 August 1985 and 20 September 1986. AUDPC values for nonsprayed Florigiant plots were 3,805, 3,360, and 1,772 for the Lewiston 1985 and 1986 and the Rocky Mount locations, respectively. No significant levels of late leaf spot were observed in plots at Lewiston, but at Rocky Mount, lesions caused by *Cercosporidium personatum* comprised an estimated 40% of the assessment at the end of the season.

Modifications of the advisory resulted in fewer fungicide applications in each experiment (Table 1). The average numbers of applications for the three experiments were 7.0, 5.3, 4.0, and 2.6 for the 14-day, advisory, 0.85 advisory, and 0.70 advisory, respectively.

Transformation did not change the conclusions drawn from data analysis; therefore, only nontransformed data are reported.

Area under disease progress curves. Genotype and spray schedule had significant effects on epidemic development ($P = 0.05$). Comparisons of AUDPC values for genotypes across all spray schedules for the three tests indicated that Florigiant, #64, and NC2 were very susceptible genotypes, whereas #86 and NC5 were very resistant and NC6 showed moderate resistance (Table 2, Fig. 1). Each of the spray schedules had significant effects on AUDPC values across genotypes, with the smallest value

TABLE 1. Number of fungicide applications for four treatments

Year and location	Fungicide schedule: 14-Day	Advisory[a]	0.85 Advisory[b]	0.70 Advisory[b]
1985 Lewiston	7	6	5	4
1986 Lewiston	7	5	4	2
1986 Rocky Mount	7	5	3	2

[a] Fungicide was applied according to the Jensen and Boyle system of accumulating severity-index values.
[b] Fungicide was applied according to the Jensen and Boyle system of accumulating severity-index values adjusted by factors of 0.85 or 0.70.

TABLE 2. Effects of genotype and spray schedule on area under disease progress curve[w]

Genotype	Spray schedule: 0.70 Advisory[x]	0.85 Advisory[x]	Advisory[y]	14-Day	Mean[z]
Florigiant	1,063	1,086	686	409	811 a
#64	1,167	879	550	356	742 a
NC2	918	687	786	575	738 a
NC6	689	564	440	375	517 b
#86	531	408	305	251	374 bc
NC5	510	318	370	141	335 c
Mean	813 a	657 b	523 c	351 d	

[w] Mean of four replications at three locations.
[x] Fungicides were applied according to the Jensen and Boyle system of accumulating severity-index values adjusted by values of 0.85 or 0.70.
[y] Fungicides were applied according to the Jensen and Boyle system of accumulating severity-index values adjusted by values.
[z] Mean area under disease progress curves followed by the same letter were not significantly different with LSD at P = 0.05.

occurring with the 14-day treatment and successively greater values occurring with the advisory, 0.85 advisory, and the 0.70 advisory. Genotype × spray schedule interactions were not significant. F values were 14.3 ($Pr > F = 0.0001$), 19.66 ($Pr > F = 0.0001$), and 0.74 ($Pr > F = 0.75$) for genotype, spray schedule, and genotype × spray schedule interactions, respectively.

Assessments of percent leaflets with lesions made 129 days after planting accounted for 85% ($R^2 = 0.85$) of the variation in final AUDPC values. Assessments made 129 and 120 days after planting combined resulted in R^2 values of 0.93.

Area under defoliation curves. Spray schedules had significant effects on AUDEFCs. Both of the modified advisories resulted in significantly greater AUDEFCs across genotypes than the 14-day or the nonmodified advisory treatments and these latter two were not different from each other (Table 3). Genotypic effects and genotype × schedule interactions were not significant. F values were 0.16 ($Pr > F = 0.97$), 6.33 ($Pr > F = 0.0004$), and 0.99 ($Pr > F = 0.47$) for genotype, spray schedule, and genotype × spray schedule interactions, respectively.

Apparent infection rates. The logistic model resulted in the highest coefficients of determination, lowest root mean square, and the most random residual plots when calculating infection rates. Analysis of variance of infection rates gave results similar to AUDPCs but was slightly less sensitive in showing significant treatment differences (Table 4). Both modified advisories had significantly higher infection rates than the advisory or the 14-day treatments. Florigiant, #64, and NC2 had higher infection rates than NC6, #86, and NC5. F values were 52.62 ($Pr > F = 0.0001$), 14.72 ($Pr > F = 0.0001$), and 1.12 ($Pr > F = 0.341$) for spray schedule, genotype, and spray schedule interactions, respectively.

Yield. Mean yields for modified advisories were not significantly lower than advisory on the 14-day treatment (Table 5). Florigiant and NC6 had the highest yield across all spray schedules, and #64, NC2, and NC5 had significantly lower mean yields.

Comparisons of new genotypes and schedules with current recommendations. Comparisons across all genotype-spray schedule combinations indicate that the resistant genotypes, NC5, #86, and NC6, did not have significantly greater AUDPC, AUDEFC, or rate values than Florigiant-advisory (F-AD) treatment under any of the spray schedules tested, including all of the modified advisories (Table 6). The variety NC2 had values greater than the F-AD treatment only when the 0.70 modified advisory was used. Although the values for Florigiant and #64 under the advisory were greater than those values under the 14-day schedule, these values were not statistically significant (Table 6).

Comparisons across all treatment combinations indicate that NC5 did not have greater AUDPC, AUDEFC, and rate values than the Florigiant-14-day (F-14) treatment under the 14-day schedule, standard advisory, or the 0.85 advisory, and NC6 did not have greater values under the 14-day or advisory spray schedules

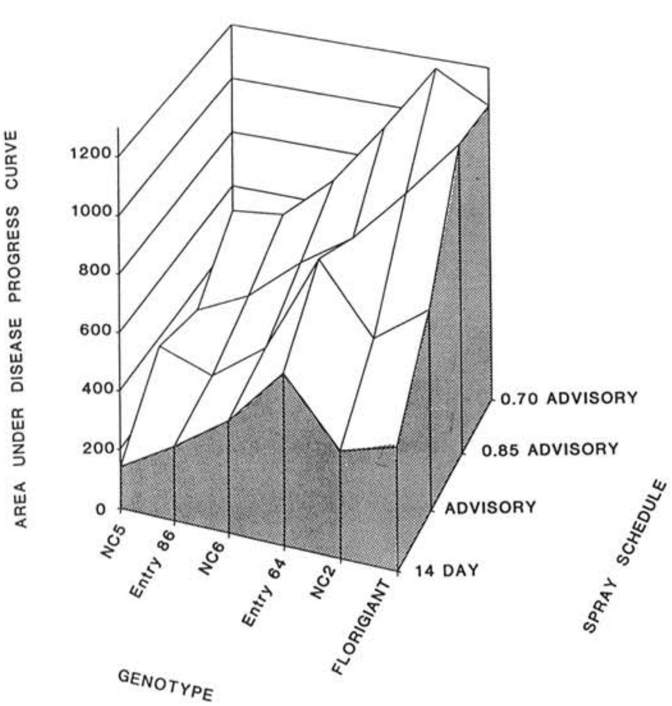

Fig. 1. The effect of genotype and spray schedule on areas under the disease progress curve of *Cercospora arachidicola* on *Arachis hypogaea*.

TABLE 3. Effects of genotypes and spray schedule on area under defoliation curves[w]

Genotype	Spray schedule				
	0.70 Advisory[x]	0.85 Advisory[x]	Advisory[y]	14-Day	Mean[z]
Florigiant	975	996	785	635	848 a
#64	942	924	766	748	845 a
NC2	821	884	760	892	893 a
NC6	915	961	843	715	858 a
#86	866	988	926	764	886 a
NC5	1,023	812	859	757	863 a
Mean	924 a	927 a	823 b	752 b	

[w] Mean of four replications at two locations.
[x] Fungicides were applied according to the Jensen and Boyle system of accumulating severity-index values adjusted by factors of 0.85 or 0.70.
[y] Fungicides were applied according to the Jensen and Boyle system of accumulating severity-index values.
[z] Mean area under defoliation curves followed by the same letter were not significantly different with LSD at P = 0.05.

TABLE 4. Effects of genotypes and spray schedule on apparent infection rate[w]

Genotype	Spray schedule				
	0.70 Advisory[x]	0.85 Advisory[x]	Advisory[y]	14-Day	Mean[z]
Florigiant	0.059	0.062	0.044	0.026	0.048 a
#64	0.063	0.058	0.048	0.027	0.027 a
NC2	0.060	0.049	0.050	0.033	0.048 a
NC6	0.040	0.045	0.035	0.020	0.035 b
#86	0.047	0.039	0.027	0.015	0.032 b
NC5	0.041	0.035	0.038	0.017	0.033 b
Mean	0.052 a	0.048 a	0.041 b	0.023 c	

[w] Mean of four replications at two locations.
[x] Fungicides were applied according to the Jensen and Boyle system of accumulating severity-index values adjusted by factors of 0.85 or 0.70.
[y] Fungicides were applied according to the Jensen and Boyle system of accumulating severity-index values.
[z] Mean yields followed by the same letter not significantly different with LSD at P = 0.05.

TABLE 5. Effect of genotype and spray schedule on yield[w]

Genotype	Spray schedule				
	0.70 Advisory[x]	0.85 Advisory[x]	Advisory[y]	14-Day	Mean[z]
Florigiant	4,249	4,243	4,110	4,106	4,175 a
#64	3,561	3,660	3,954	3,775	3,734 d
NC2	3,816	3,897	3,662	3,878	3,759 d
NC6	3,622	4,261	4,298	4,075	4,051 ab
#86	3,913	3,880	3,906	4,153	3,941 bc
NC5	3,893	4,059	3,814	3,650	3,854 cd
Mean	3,809 b	3,980 a	3,949 ab	3,936 ab	

[w] Mean of four replications at three locations in kilograms per hectare.
[x] Fungicides were applied according to the Jensen and Boyle system of accumulating severity-index values adjusted by factors of 0.85 or 0.70.
[y] Fungicides were applied according to the Jensen and Boyle system of accumulating severity-index values.
[z] Mean infection rates followed by the same letter were not significantly different with LSD at P = 0.05.

(Table 7). NC2 resulted in greater values under all spray schedules.

Yield loss models. Equations for NC2, NC5, #64, and #86 did not have significantly different slopes or y-intercepts; thus, these data sets were combined. Equations for Florigiant, NC6, and the above group had significantly different y-intercepts, but slopes were not different, indicating that the effects of disease on yield did not vary among genotypes, but that the yielding capacity at any given level of disease did vary for each of the models. Thus, three models were developed.

For NC2, NC5, #64, and #86:

$$y = -0.467x + 3432 \quad R^2 = 0.66 \quad F = 144.5 \quad Pr > F = 0.0001 \quad \mathrm{df} = 75;$$

for Florigiant:

$$y = -0.436x + 4288 \quad R^2 = 0.64 \quad F = 30.32 \quad Pr > F = 0.0001 \quad \mathrm{df} = 18;$$

and for NC6:

$$y = -0.58x + 3609 \quad R^2 = 0.68 \quad F = 40.1 \quad Pr > F = 0.0001 \quad \mathrm{df} = 18,$$

where y = yield in kg/ha and x = the AUDPC value.

DISCUSSION

The advisory and two modifications of the advisory for use on genotypes with partial resistance resulted in consecutively fewer numbers of fungicide applications in each experiment than the 14-day treatment. The average numbers of applications for the three experiments were 7.0, 5.3, 4.0, and 2.6 for the 14-day, advisory, 0.85 advisory, and 0.70 advisory schedules, respectively. Comparisons across all genotype × spray schedule combinations indicated that the modified advisories used on the moderate or highly resistant genotypes (NC6, NC5, and #86) did not have significantly greater amounts of disease than the Florigiant-advisory treatment. However, when comparisons of all combinations were made with the Florigiant 14-day treatment, only NC5 had similar AUDPC, rate, and AUDEFC values when the modified advisory was used, and only NC6 had similar values when the advisory was used. Nevertheless, mean yield across all the genotypes grown were not significantly lower in any of the advisory programs than the 14-day treatment.

TABLE 6. Genotype-spray schedule combinations that did not have significantly different area under disease progress curve, area under defoliation curve, and rate values when compared with the Florigiant-advisory treatment

	Spray schedule			
Genotype	14-Day	Advisory[y]	0.85 Advisory[z]	0.70 Advisory[z]
Florigiant	X	X		
#64	X	X		
NC2	X	X	X	
NC6	X	X	X	X
#86	X	X	X	X
NC5	X	X	X	X

LSD value = 302, 148, and 0.0120 for AUDPCs, AUDEFCs and rates, respectively.

[y]Fungicides were applied according to the Jensen and Boyle system of accumulating severity-index values.

[z]Fungicides were applied according to the Jensen and Boyle system of accumulating severity-index values adjusted by factors of 0.85 or 0.70.

TABLE 7. Genotype-spray schedule combinations that did not have significantly different area under disease progress curve, area under defoliation curve, and rate values when compared with the Florigiant 14-day treatment

	Spray schedule			
Genotype	14-Day	Advisory[y]	0.85 Advisory[z]	0.70 Advisory[z]
NC2				
Florigiant	X			
#64	X			
#86	X			
NC6	X	X		
NC5	X	X	X	

LSD values = 303, 148, and 0.0120 for AUDPCs, AUDFCs, and rates, respectively.

[y]Fungicidies were applied according to the Jensen and Boyle system of accumulating severity-index values.

[z]Fungicides were applied according to the Jensen and Boyle system of accumulating severity-index values adjusted by factors of 0.85 or 0.70.

Changes in predictive models have also been reported by Fry (5,7) who worked with Blitecast (15), a system for prediction of epidemics of late blight of potato. That system was modified for use on resistant genotypes by allowing greater numbers of Blight units to accumulate on resistant genotypes than susceptible genotypes before fungicide applications were recommended. Those modifications also resulted in fewer applications of fungicide on resistant genotypes and provided similar late blight control as compared with the routine application of fungicide on susceptible genotypes. This approach to model modification, as well as the one presented here, should result in a model more sensitive to resistance factors.

The most appropriate epidemiological parameter in assessing leaf spot epidemic developments has been questioned. In this report, AUDPC, rate, and AUDEFC values were used to monitor disease development. In comparisons across all genotypes, the modified advisories resulted in larger mean AUDPC, rate, and AUDEFC values than nonadjusted advisory or the 14-day schedule, yet mean yields were not statistically different. In comparisons across all spray schedules, Florigiant, #64, and NC2 had the highest AUDPCs. NC6 had intermediate values, and #86 and NC5 both had significantly lower AUDPC values than the susceptible genotypes. Comparisons of infection rates placed genotypes into two groups. Florigiant, #64, and NC2 had higher rates than #86 and NC5. However, mean AUDEFC values among genotypes were not significantly different. Thus, AUDPC, rate values, and AUDEFC values should be considered most to least sensitive epidemiological parameters in detecting treatment differences in early leaf spot epidemics. These observations are similar to reports by Fry (6) and Johnson et al (10,11) on the relative leaf spot susceptibility of peanut genotypes used in the present study and on the sensitivity of various epidemiological parameters. Johnson et al (11) compared resistance components of 20 peanut genotypes and included five of the six genotypes used in the present study. The relative ranking of mean AUDPC for the genotypes was similar to our results. Fry (6) made comparisons between the use of AUDPC and rate values in monitoring late blight epidemics. He concluded, as we did, that AUDPC values were more reliable than rate values for the quantification of effects of fungicides or resistance on the development of epidemics. Johnson et al (10) reported on the effects of fungicides and partial resistance on epidemics of *Cercospora arachidicola* in North Carolina. In that study, apparent infection rates were consistently different among genotypes, whereas rates for percent defoliation were not different among those same treatments. This suggests, as do our data, that the progress of defoliation during a Cercospora epidemic is a less sensitive parameter than percent infection.

In this study, disease assessments made 120 and 129 days after planting correlated very well with final AUDPC values, while Johnson et al (11) reported that assessments made 103 days after planting correlated with final values. These differences indicate the natural variation in early leaf spot epidemics between years or locations and show that no one date can be identified as the single most appropriate time for assessing disease. We feel that this is additional evidence supporting the use of AUDPC as an epidemiological parameter.

The crop loss models had similar slopes for each of the genotypes. These results indicate that the effect of disease on yield loss is not significantly different among genotypes. Analysis of variance of yield data as well as comparisons among intercepts of disease loss models indicated that some genotypes, such as Florigiant, have greater yield capacity under similar levels of disease pressure than many of the more resistant genotypes. We are reluctant to draw such conclusions as we made no attempts to maximize the yields of specific genotypes. Many of the genotypes used in this study have different yield capabilities due to maturity dates, soil type, amount of irrigation, and susceptibility to other diseases. Our experimental design was intended to investigate the effects of disease on yield of different genotypes as indicated by the comparison of slopes of disease loss models but not to compare overall yield capabilities among genotypes.

The results presented provide further verification that the peanut leaf spot advisory system can result in decreased fungicide applications without the risk of yield loss due to early leaf spot damage. Furthermore, we have demonstrated that it is possible to further reduce sprays on lines with adequate resistance by a simple modification of the Jensen and Boyle algorithm.

Future improvements in this system might involve the determination of the most appropriate time interval between emergence of peanut plants and the initiation of the advisory program. Presently, this is an arbitrary date (20 June) set to precede the first occurrence of lesions. The development of lesions early in the season was observed to be an important factor in leaf spot epidemic in this and other studies in regard to all measured epidemiological parameters (19). Epidemics at different locations in the state do not start at the same time for reasons other than weather. This is probably due to the availability of initial inoculum.

Simulation models have been useful in exploring similar modifications in other disease prediction systems (3,7). Thus, with the current availability of a simulation model for early leaf spot (13,14), this and other variables in the systems might be addressed.

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