Use Of a Simulation Model to Explore Fungicide Strategies for Control of Cercospora Leafspot of Peanut[1]

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ABSTRACT

A sub-model describing persistence and efficacy of chlorothalonil fungicide was incorporated into a computer simulation model of Cercospora leafspot of peanut. The resultant model was validated using independent data sets from field trials over a two-year period. Predicted disease progress curves and area under the disease progress curve for different fungicide application schedules and rates were compared with field observations. The model was then used to compare predicted disease severity and area under the disease progress curve (AUDPC) for a calendar spray schedule vs a leafspot advisory program under different weather conditions. Predicted disease severity levels and area under disease progress curves were similar for advisory and calendar spray schedules. Results were insensitive to changes in parameters describing fungicide persistence or efficacy. The model described herein is a good estimator of the combined effects of weather and chlorothalonil treatments on disease progress, effectively ranks treatments or environmental conditions in terms of their effect on leafspot, and provides a basis for comparison of fungicide scheduling strategies. The simulation model predicted AUDPC more accurately than end-of-season disease, and AUDPC is a more reliable indicator of the effect of peanut leafspot disease on yield loss. Simulation experiments will be useful in optimizing fungicide or biocontrol strategies for long-term financial benefit to growers.

Key Words: Early leafspot, computer modeling.

Peanut leafspot diseases (early and late leafspot), caused by *Cercospora arachidicola* Hori and *Cercosporidium personatum* (Berk. & Curt.) Deighton, can result in yield losses of 50% or more, unless controlled by applications of a protectant fungicide (16). The most widely used fungicide in North Carolina is chlorothalonil. Fungicides are often applied on a 10-14 day schedule beginning about 30-60 days after planting.

Jensen and Boyle (5,6) and Parvin *et al.* (14) developed a forecast/advisory system for peanut leafspot based on daily observations of hours of relative humidity (RH) equal to or greater than (⩾) 95% and minimum temperature during the high RH period. Their system identified conditions favorable for infection and secondary spread of leafspot. Under disease-favorable conditions, an advisory to spray fields with a protectant fungicide would be issued. Thus, a grower would apply fungicide according to weather conditions instead of following a calendar schedule such as applying every 14 days. This would save on fungicide costs in some years. This advisory system is currently being used by researchers and many growers in North Carolina and Virginia. Comparisons of the advisory system with a calendar spray schedule in terms of disease severity and cost have been reported (8,9,15). These evaluations are relatively expensive, time consuming, and limited in the range of weather patterns observed. Long-term field experimentation is required to evaluate possible improvements in the advisory system.

In a previous paper (10) we described a computer simulation model for peanut leafspot. The model assumed that disease was uniformly distributed in the field, and predicted disease progress over a growing season using the same daily RH and temperature determinants described above. In this report, we describe the incorporation of a sub-model to predict the persistence and efficacy of chlorothalonil fungicide on peanuts, and resultant effects on peanut leafspot epidemics. The model was tested using data from field trials over a two-year period. Finally, we describe the use of the model as a tool to compare predicted disease severity and area under the disease progress curve associated with fungicide application on a fixed-interval (14-day) to an advisory-based spray schedule under a range of weather conditions. Sensitivity of this comparison to changes in the parameters representing fungicide persistence and efficacy was tested.

Materials and Methods

Fungicide sub-model description.

Persistence of fungicide residues was modeled as a simple exponential decay process. Thus, the fungicide residue on day t, residue $_{(t)}$, is determined by the function:

$$\text{residue}_{(t)} = k\ (\text{residue}_{(t-1)}),$$

where k is a number between 0 and 1. Initial residue concentration was arbitrarily set at 2.5 μg/cm^2 (Bruhn and Fry's estimate (2) of initial chlorothalonil residues on potato foliage).

The dose-response curve was assumed to be linear on a graph of the Log of fungicide residue concentration vs. probit of proportion inhibition because many studies have shown this response. For ease of calculation during simulation runs, the Log-probit curve was estimated by a Log-logit curve using regression technique. Thus,

$$\text{logit(inhibition)} = \alpha + \beta[\text{Log(residue concentration)}],$$

where logit(inhibition) = Ln[proportion inhibited/(1-proportion inhibited)]; Ln refers to the natural logarithm and Log refers to the base 10 logarithm.

Initial estimates of the above parameters (k, α, and β) were obtained from mathematical models and experimental results published by Bruhn and Fry (2,3) and others (11,13), as well as our own unpublished observations. The fungicide sub-model was then incorporated into the structure of the leafspot simulation model so the daily infection rate was changed as a function of fungicide residue and dose response. The leafspot disease model (10) determines a daily infection rate (R), where R = newly-infected leaflets per leaflet with sporulating lesions per day. In the model, R is a function of hours of RH>95%, minimum temperature during the period of high RH, number of

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sporulating lesions, and proportion of uninfected host leaflets remaining. To incorporate fungicide effects into the model, the reduction in proportion of germinated conidia, as calculated from the Log-logit dose response function, was applied as an equal reduction in the infection rate R. Thus, it was assumed that the effect of chlorothalonil was to reduce the daily infection rate directly through inhibition of conidial germination. In estimating persistence of residues, it was assumed that all leaflets were equally covered with the fungicide. The parameter fitting thus "averages" effects of non-uniform coverage. Simulations were run using initial fungicide parameter estimates. Model predictions were compared with observations from field trials in Virginia and North Carolina (1,7,15) where chlorothalonil was applied at different rates to control leafspot. The model was calibrated by varying parameter values in successive simulation runs and minimizing sums of squares of residuals (observed minus predicted values) for disease proportion. Weather data for model calibration were obtained from extensive, electronically collected records for Holland, VA and surrounding area and from hygrothermographs located in the test fields.

Resulting equations were:

Persistence of residues:

$$\text{residue}_{(t)} = 0.84\ (\text{residue}_{(t-1)}) \qquad (1)$$

(i.e., a residue half-life of approximately 4 days)

Dose response:

$$\text{logit(inhibition)} = 0.08 + 0.69\ [\text{Log(residue)}_{(t)}]$$

Model validation. The simulation model was tested using disease progress data obtained in 1983 and 1984 from fungicide trials in Rocky Mount or Lewiston, NC. The cultivar was Florigiant. Validation data sets were independent and different from those used to develop the model. Peanuts were planted on May 13 (1983) or May 18 (1984), in plots of four 6-m rows, with seven (1983) or five (1984) replications/treatment in a randomized block design. Chlorothalonil (BRAVO 500, SDS Biotech Corp., Painesville, OH, 44114; 50 g a.i./L formulated) was applied using a tractor-mounted sprayer. Fungicide was applied on a 14, 21 or 28-day schedule at 100%, 75%, or 50% of the recommended rate (2.48 L/ha), for a total of 9 treatments. Disease was assessed at 1-2 wk intervals from observations made on eight randomly selected stems from each plot. Proportions of defoliated leaflets and leaflets with leafspots were determined. Disease severity was calculated as:

$$\%\ \text{Disease} = [\%\ \text{defoliated leaflets} + [(1 - \text{proportion defoliated leaflets}) \times \%\ \text{leaflets with leafspot}]] \qquad (3)$$

Simulation runs were initialized for each validation experiment as follows: the first observation of mean disease severity greater than or equal to 1% and the date of observation were input to the model. An equal proportion of disease was assumed to be latent at that time. The model then predicted disease severity for each remaining day of the season. Model inputs were daily weather data, obtained from hygrothermagraphs installed in the peanut fields, and dates and rates of fungicide application. Disease progress curves generated by the simulation model were plotted against mean percent disease for the five or seven replicates at each sampling date. Confidence intervals (95%) were determined about the sample means. Area under the disease progress curve (AUDPC) for each field trial was determined by making linear interpolations between disease values for successive assessment dates, and then calculating the area under the curve. Units for AUDPC are in "percent days". For simulated epidemics, AUDPC values were calculated by summing percent day values for each day of the simulated growing season. Values for AUDPC were then compared for observed and simulated epidemics.

Comparison of fungicide strategies. The simulation model was used to compare final percent disease and AUDPC levels associated with fixed-interval (14-day) vs. advisory spraying to control peanut leafspot. Weather data from 1983 or 1984 were used to represent seasons in which weather conditions were relatively unfavorable or favorable for disease development, respectively. Since it was unknown to what extent error in the estimation of the parameters representing fungicide residue persistence (k) and the intercept (α) of the dose-response function would affect results of this comparison, sensitivity of model predictions to these parameters was explored as follows: For each weather and spray program combination, successive simulation runs were made varying the above two parameters around estimates. Simulation runs were arbitrarily initialized with visible disease levels of 1% on June 15 of each year. For calendar spray runs, the first spray was applied on June 30, and subsequent sprays were applied at 14-day intervals until September 8 (total = 6 sprays). Final evaluation and harvest were on September 22. For advisory spray runs, daily weather data were used to generate daily advisories, according to rules published by Parvin and Smith (13). However, a recommendation to spray was ignored if a field had been sprayed within the previous 10 days. Predicted percent disease and AUDPC were plotted against values of the parameters α and k for each simulation run. Thus, a three-dimentional response surface was generated for each spray program x weather combination, with percent disease or AUDPC as the dependent variable.

Results

Model validation. Disease progress curves generated by the simulation model for different fungicide rates are shown in Figs. 1 and 2, along with means and 95% confidence intervals for observed percent disease levels. Comparisons of AUDPC for observed and simulated trials are shown in Table 1.

Table 1. Area under the disease progress curve (AUDPC) for observed and simulated epidemics of Cercospora leafspot on Florigiant peanut.

Year	Schedule	Fungicide Rate[a]	Disease[b] Observed AUDPC[c] Mean	95% CI	Simulated AUDPC
1983	14-day	100%	109	25-193	101
		75%	161	64-258	102
		50%	160	63-257	103
	21-day	100%	81	25-137	108
		75%	124	72-176	108
		50%	139	61-217	109
	28-day	100%	171	70-272	119
		75%	173	120-226	120
		50%	207	70-344	121
1984	14-day	100%	1654	1072-2236	1114
		75%	2004	1477-2531	1281
		50%	2927	1977-3877	1515
	21-day	100%	2612	1522-3702	2083
		75%	2728	2025-3431	2320
		50%	3020	2466-3574	2608
	28-day	100%	2423	1974-2872	2156
		75%	2448	1155-3741	2372
		50%	2954	1769-4139	2643

[a] Rate expressed as percent of recommended rate (2.48 L chlorthalonil/ha).

[b] Observed AUDPC determined by linearly interpolating between observations taken at 1-2 week intervals over the season, and then calculating area under the resultant curve. Simulated AUDPC obtained by integration of daily predicted percent disease. Units= percent days.

[c] Means and confidence intervals for seven (1983) or five (1984) replications.

The model accurately predicted the very low levels of disease that were observed throughout most of the 1983 season, as well as the slight increases in disease observed with longer intervals between fungicide sprays and lower rates of fungicide application. According to the advisory system, three fungicide sprays were recommended. Predicted disease values generally fell near treatment means and within confidence intervals, with the exception of the last observation of the season in most treatments. Disease levels rose rapidly from very low levels at the end of the season in most treat-

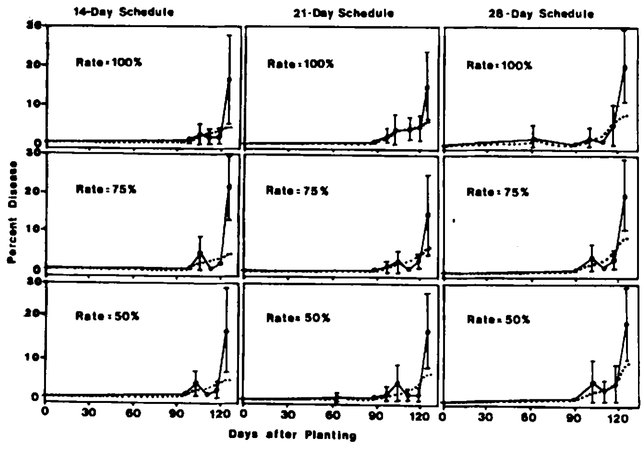

Fig. 1. Fungicide model validation, 1983: observed (solid lines) vs. predicted (dotted lines) disease progress curves for Cercospora leafspot on Florigiant peanut. Chlorothalonil fungicide was applied at 14, 21 or 28 day intervals, at rates of 100%, 75%, or 50% of the recommended application rate (2.48 l/ha). Vertical lines represent confidence intervals (95%) around observation means for seven replications.

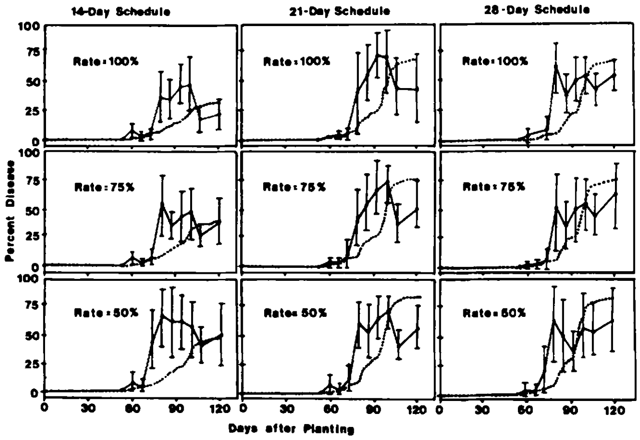

Fig. 2. Fungicide model validation, 1984: observed (solid lines) vs. predicted (dotted lines) disease progress curves for Cercospora leafspot on Florigiant peanut. Chlorothalonil fungicide was applied at 14, 21 or 28 day intervals, at rates of 100%, 75%, or 50% of the recommended application rate (2.48 l/ha). Vertical lines represent confidence intervals (95%) around observation means for five replications.

ments, although there was a large dispersion about treatment means. The model predicted a less rapid end-of-season disease increase. In all nine treatments, predicted AUDPC levels for 1983 fell within 95% confidence intervals.

The model accurately predicted periods of rapid disease increase in 1984, although initial disease increase was usually more rapid than predicted. According to the advisory system, six fungicide sprays were recommended. In all treatments, the maximum disease predicted by the model was close to the maximum level observed in the field. However, observed disease under 14- and 21-day spray schedules declined during the latter part of the season, and this response was not predicted by the model. Predicted disease levels at the last observation date were mostly above treatments means but in most cases within confidence intervals. AUDPC predictions were within confidence intervals for seven of nine 1984 treatments.

Comparison of calendar and advisory programs. Response surfaces for each spray program x weather combination are shown in Figs. 3 and 4. Generally, predicted differences in either percent disease or AUDPC values between the two fungicide scheduling systems were small or nonexistent, regardless of fungicide persistence or efficacy parameter values, and under both disease-favorable (1984) and unfavorable (1983) weather conditions. Under disease-unfavorable conditions, fungicide costs for the advisory system would have been lower, due to fewer fungicide applications three vs. six with unfavorable conditions.

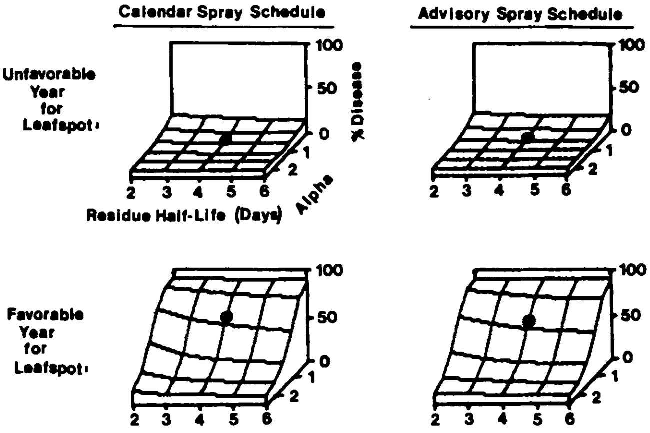

Fig. 3. Effect of varying fungicide half-life and/or efficacy (alpha = intercept of the dose-response function), on *severity* of Cercospora leafspot on Florigiant peanut, under disease-unfavorable and disease-favorable weather conditions. The point indicated represents the combination of half-life and efficacy parameters used in preceding simulation.

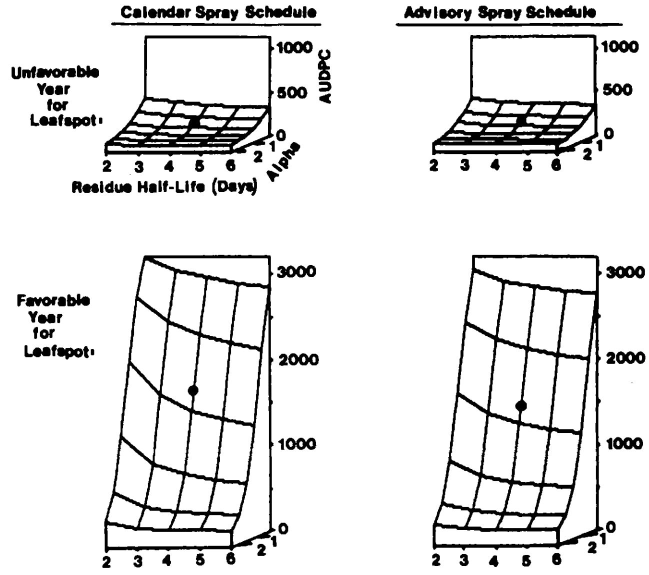

Fig. 4. Effect of varying fungicide half-life and/or efficacy (alpha = intercept of the dose-response function), on *area under the disease progress curve* for Cercospora leafspot epidemics on Florigiant peanut, under disease-unfavorable and disease-favorable weather conditions. The point indicated represents the combination of half-life and efficacy parameters used in preceding simulation.

Discussion

Disease progress curves predicted by the simulation model for different fungicide application schedules and rates were a reasonable fit with observed disease progress curves. In 1983, the model correctly predicted the very low levels of disease observed throughout most of the season, although predictions of disease at the last sampling date were in most cases below lower confidence limits. The late increase in disease observed in certain replications may have arisen from spores contributed from outside the test (border areas in the same field, or from other fields on the station). Both observed and predicted values, however, were very low compared to 1984 levels. One discrepancy was the failure of the model to predict an apparent increase in disease near the end of the 1983 season and a decrease in disease severity for some treatments, near the end of the 1984 season. The most likely cause of a reduction in disease severity is continued host growth in the absence of any disease increase. The underlying model (10) assumes that plant growth near the end of the season is negligible, which may account for the discrepancy. We do not feel that we have overstated the success of simulations in 1984; however, most predictions of end-of-season disease severity and AUDPC in 1984 fell within 95% confidence intervals. Also, the model's ranking of epidemics by treatment (fungicide rate, schedule) was consistent with experimental results. We conclude, therefore, that the model described herein is a good estimator of the combined effects of weather and chlorothalonil treatments on disease progress, effectively ranks treatments or environmental conditions in terms of their effect on leafspot, and provides a basis for comparison of fungicide scheduling strategies.

Yield loss models for Florigiant peanut altered by Cercospora leafspot are not currently available. Development of models to predict the relationship between AUDPC or disease severity (preferably at multiple points in time) and yield loss will enhance the value of this simulation model as a management tool. The simulation model predicted AUDPC more accurately than end-of-season disease (10), and AUDPC is a more reliable indicator of the effect of peanut leafspot diseases on yield loss (7). By either measure, simulated disease levels were very similar for the calendar and advisory schedules under either disease-favorable or unfavorable weather conditions. Thus, the choice of a particular yield loss model would not significantly affect one conclusion of these simulation experiments: the primary advantage of the leafspot advisory program results in fewer fungicide applications. This is more likely in years that are relatively unfavorable for leafspot development. The frequency of such climatic conditions in different peanut growing regions of the southeastern United States may be the primary determinant of the usefulness of the advisory system and its acceptance by growers. With the development of yield loss models, simulation experiments will be useful in optimizing fungicide or biocontrol strategies for long-term financial benefit to growers.

In simulation studies to compare forecast-based vs. calendar fungicide sprays for control of potato late blight, Fohner, *et al.* (4) concluded that the Blitecast forecast system (12) did not suppress late blight more effectively with fewer fungicide applications than did weekly fungicide applications. Under conditions that were moderately favorable for disease, the Blitecast system resulted in fewer fungicide sprays than the weekly schedule, but end-of-season disease was increased. It was concluded that the original version of Blitecast was not preferable to a weekly spray schedule. Fohner, *et al.* also suggested that those conclusions might also be relevant to other disease forecast systems used for protectant fungicide scheduling. Results of our peanut leafspot simulations are largely in agreement with the conclusions of Fohner, *et al.*, although in our simulations disease was generally not increased when fungicide was applied according to the leafspot forecast system. Phipps and Powell (15), however, did observe higher leafspot severity in peanut fields sprayed with benomyl plus sulfur according to the leafspot advisory, compared to a 14-day spray schedule.

The simulation model makes the assumption that loss of fungicide residues is a function only of time. Other researchers have variously reported either no effect of rainfall on chlorothalonil persistence (13), or a highly significant effect (3,11). Since rainfall is positively correlated with leafspot-favorable weather (5,9), removal of fungicide residues by rain would tend to exacerbate any adverse effects of a delay in fungicide application. Thus, in peanut-growing areas where long periods of leafspot-favorable weather can be expected in most years, the leafspot advisory system may not offer significant advantages for growers. One valuable application of a simulation model would be to evaluate weather data from an area over a number of years, and to determine how frequently disease-unfavorable years would have to occur for use of the advisory system to be profitable on average. Simulation modeling provides an effective tool to evaluate potential improvements in the forecast system under a variety of weather conditions, and may thus expedite the development of an effective system that will reduce production costs and risk, and enhance environmental quality by reducing the total use of fungicide.

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