DEVELOPMENT OF A WEATHER-BASED ADVISORY FOR SCHEDULING FUNGICIDE APPLICATIONS TO MANAGE CERCOSPORA LEAF SPOT OF PEANUT IN OKLAHOMA

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CHAPTER I

INTRODUCTION

Early leaf spot, caused by the fungus *Cercospora arachidicola*, is the most widely distributed and damaging foliar disease of peanut (*Arachis hypogaea* L.) in Oklahoma. The fungus infects peanut petioles, stipules, leaves, stems, and pegs (37). Other peanut foliar diseases, late leaf spot caused by *Cercosporidium personatum* Deighton, web blotch caused by *Phoma arachidicola*, and peanut rust caused by *Puccinia arachidis*, sporadically occur in Oklahoma but do not cause yield losses.

Early leaf spot causes peanut yield loss by leaf spotting, leaf necrosis, and early defoliation, which reduce effective leaf area, and by loss of pods at harvest from weakening of pegs by direct Cercospora infection or by premature senescence. *Cercospora* fungi produce a nonspecific toxin - cercosporin (2). Cercosporin, a red photosensitizing polyketide, produces superoxide and singlet oxygen in the presence of light and oxygen (10). These active oxygen species cause peroxidation of cell and organelle membrane lipids, resulting in membrane permeability, ion leakage, and cell death (45). Early infection of peanut plants by *C. arachidicola* reduces dry root mass and pegs, and nodule numbers (31). A significant correlation was found between leaf necrosis and loss in total chlorophyll which infers reduced photosynthesis (30). Ketring and Melouk (27) demonstrated the production of ethylene from infected peanut plants which enhanced leaflet abscission. Ethylene is a plant hormone known to enhance plant senescence. Alderman et al (5) described the sequential plant defoliation from old to young leaves and suggested that leaf spot lesions accelerated natural defoliation. All these factors apparently contribute to the damaging effects of early leaf spot.

The perfect state, *Mycosphaerella arachidis* Deighton, has been described for early leaf spot fungus (37). However, it is rarely observed, thus ascospores probably do not serve as primary inoculum (37, 43). Conidia of the imperfect state, *C. arachidicola*, serve as both the primary and secondary inoculum that drive leaf spot epidemics. The fungus overwinters in soil on infected crop debris. *C. arachidicola* can survive up to 22 weeks in soil as dormant mycelia, but only seven weeks as conidia (39).

Early in the growing season, conidia produced on crop residue provide the initial inoculum. Wind, rain, irrigation, and insects are major vectors for inoculum dissemination (37). On peanut leaves, conidia germinate and form germ tubes which enter the plant through open stomata or directly penetrate epidermal cells. Macroscopic symptoms of early leaf spot usually develop within 10-14 days of infection when environmental conditions are favorable (37). Small recognizable necrotic flecks are first observed which enlarge to become light to dark brown spots, often surrounded by chlorotic halos. Secondary conidia are then produced on fungal stroma, that forms on the adaxial leaf surface under humid conditions, and serve as inoculum for secondary infections (43). Several disease cycles often occur during a growing season (43).

Annual peanut yield losses caused by leaf spot diseases range from 0.75% to 6.0% in the U.S. (44). However, peanut yield loss may exceed 50% where leaf spot incidence is high and control measures are not implemented or in countries where fungicides are not commonly used (17, 18, 37). Backman et al (6) described a linear relationship for the Florunner cultivar between peanut yield and leaf spot incidence. Yield losses amounted to 15.7 kg/ha for each percent increase in leaf spot incidence and losses were even greater when infection exceeded 40% (6).

Agronomic practices provide partial control of early leaf spot. Crop rotation and deep plowing are effective in reducing primary inoculum and delaying leaf spot onset. Kucharek (28) reported that crop rotation reduced early-season leaf spot by 88-93% which allowed growers to delay their first spray. Horne (16) suggested that leaf spot pathogens require high oxygen levels and survive poorly when crop residues are buried 18 cm or more.

The use of peanut cultivars with genetic resistance to *C. arachidicola* is effective for control of early leaf spot (15). Identification of resistance sources and breeding resistant cultivars have been objectives in peanut disease research during the past twenty years. Peanut genotypes from many countries and wild peanut species have been extensively screened for resistance to *C. arachidicola*. Complete resistance has been identified only in wild species, however, no commercially acceptable cultivars have been developed with this resistance (32). Partial resistance, a type of resistance that results in a slower rate of disease development, has been identified in commercial cultivars (12, 14, 24, 25, 33, 40, 46). The nature of resistance has been studied. Abdou et al (1) found direct growth of germ tubes toward open stomata for highly susceptible cultivars, a few germ tubes grow toward the stomata for partially resistant cultivars, and no growth of germ tubes toward the stomata for immune entries. Anatomically, partial resistance was reported to be associated with the thickening and swelling of the cell wall around the infection site and the deposition of pectic substances on the cell walls and in intercellular spaces after fungal penetration (1). Genetically, resistance was found to be quantitatively inherited (47). Epidemiologically, the rate-reducing components of partial resistance are often expressed as a reduced number of lesions per leaflet, necrotic area per leaflet, sporulation, percentage of lesions sporulating, and infection frequency; longer latent and incubation periods; and reduced defoliation. These components of partial resistance were quantified on many commercial cultivars in greenhouse tests using a detached leaf technique (12, 14, 33, 40, 46). Field studies using virginia-type cultivars with varying susceptibility demonstrated a positive correlation between leaf spot progress and resistance components such as latent period, sporulation, percentage of lesions sporulating, and defoliation rate identified in greenhouse tests (25). The economic contribution of partial resistance appears to be from increased yield and gross value (24).

The early leaf spot pathogen is ubiquitous in peanut growing areas. When weather conditions favor leaf spot development, fungicide applications are needed to avoid yield loss (15, 43). Repeated sprays are often necessary because of the polycyclic nature of this disease, the degradation of fungicides over time, and the need to protect new plant growth. A conventional 14-day spray schedule has been extensively used in the U.S. since the early 1970's (43). Five to seven sprays per season provide full protection against early leaf spot and without any yield loss. However, the numerous sprays result in high production costs, may pose environmental risks, and may lead to the development of fungicide resistance in early leaf spot fungus when systemic fungicides are used.

A more efficient management approach would be to spray only when weather conditions are favorable for infection. In the mid-1960's, Jensen and Boyle (20) defined the meteorological parameters conducive to leaf spot development. These are the duration of relative humidity above 95% (RH≥95%) and the minimum temperature during the period of high humidity. These parameters were later incorporated into a leaf spot forecasting model to predict leaf spot epidemics (21). A weather-dependent infection index of 0-3, where 0 is not favorable and 3 is most favorable, was assigned to identify favorableness of various daily temperature and RH combinations for infection (21). This model relies on minimum temperatures to regulate the duration of high humidity necessary to favor infection. Within the minimum temperature range of 60-80°F, longer periods of high humidity are required when temperatures are lower and shorter high humidity periods are required when temperatures are higher to favor Cercospora infection (21). Jensen and Boyle were pioneers in the use of weather conditions to forecast peanut diseases.

Parvin et al (35) adapted and computerized the Jensen and Boyle model to provide a worded advisory and to schedule fungicide applications to coincide only with disease-favorable weather. Smith et al (42) reported that the Jensen and Boyle model could facilitate effective chemical control of early leaf spot with the judicious use of fungicides. The Jensen and Boyle model was validated in Virginia on virginia-type cultivars over four years and the advisory averaged 4.25 fewer sprays than 14-day schedule with no difference in yield (36). Moreover, both the Jensen and Boyle model and the 14-day schedules suppressed leaf spot progress and improved yields compared to the untreated control (36). The Virginia study concluded that the suppression of leaf spot disease with the advisory schedule was a result of improved spray timing rather than the number of fungicide applications. They also implied that the Jensen and Boyle model may indirectly improve yields over the 14-day schedule by reducing crop injury caused by spray equipment and the severity of diseases enhanced by vine injury (36). Johnson et al (23) reported annual increases of $192-260/ha in economic returns from use of the advisory compared to the 14-day schedule over the four-year study. The increased economic returns were attributed to increases in yield as well as decreased costs of control. Matyac and Bailey (29) have since modified the Jensen and Boyle advisory for cultivars with partial resistance. The daily infection index was adjusted by arbitrary coefficients of 0.85 or 0.70 to increase the spray threshold. This modification further reduced sprays by up to three times per growing season without significantly increasing leaf spot incidence or reducing yield compared to the Jensen and Boyle advisory (29).

The Jensen and Boyle advisory was introduced to commercial growers in Virginia to improve leaf spot control efficacy in the early 1980's (35, 36). However, in some years leaf spot control with the advisory was diminished late in the growing season compared to that of the 14-day schedule (36). These high levels of leaf spot incidence caused concern among growers using the advisory program (8, 29, 38), and suggested a need to improve the Jensen and Boyle advisory.

A new advisory was recently developed in Virginia based on the growth responses of *C. arachidicola* to specific environmental conditions. The model assigns time duration values (TDV) to weather parameters conducive to infection. These parameters are the duration of RH ≥ 95% when temperature is between 16 and 30°C (8). Justification of this new advisory is that short periods of favorable temperature and humidity, which do not translate into a favorable advisory in the 2-5 day period accounted for by the Jensen and Boyle model, actually accumulate over time to support leaf spot increase. Scheduling fungicide applications on Florigiant peanut, a leaf spot-susceptible virginia cultivar, at a threshold of cumulative TDV=48, resulted in leaf spot control equal to that of a 14-day schedule and better than that with the Jensen and Boyle advisory with a similar reduction in the number of sprays (8). Adjustment of the TDV threshold was suggested for use on cultivars of varying susceptibility or with fungicides differing in efficacy (8).

The effects of temperature and moisture on the peanut infection process by *C. arachidicola* have been studied in depth. Oso (34) reported that conidia of *C. arachidicola* require a saturated or near-saturated atmosphere to germinate at optimum temperatures of 20-30°C. Germination began 2-6 hr after inoculation of leaves at 16-31°C with RH≥95% (3, 34). A high percentage of conidia germinated by 48 hours at 16-25°C (1, 3, 13), but only a small portion germinated at 28-31°C (3). Germ tubes elongated at RH 93-100%, but germination was terminated at RH 30-40% (3). Further studies reported that sporulation increased with prolonged leaf wetness period and was greatest at 24 and 28°C and least at 16 and 32°C (4). Jewell (22) found a significant correlation between leaf spot incidence and cumulative hours of RH$\geq$95% in the field. These studies provided the fundamental data for the development of the Virginia advisory.

AU-Pnuts, a simple rule-based advisory, was developed for early and late leaf spot control on runner cultivars in Alabama. This advisory uses a combination of daily rainfall or irrigation and five-day average precipitation probabilities to schedule fungicide applications (11, 19). It requires only a rain gauge and obtains precipitation probabilities from national weather service radio to conduct. Validation of this model indicated a significant correlation between leaf spot incidence and the number of precipitation events of at least 2.54 mm (11). Modification of this advisory for partially resistant cultivars further reduced fungicide applications (19).

Development of the AU-Pnuts advisory was, to a certain extent, based on documented research. Jensen and Boyle documented that precipitation frequently occurred before and during favorable periods for peanut leaf spot infection (20). Smith and Crosby (41) observed a rapid increase in aerial concentration of conidia with the onset of rainfall. Johnson et al (26) found a significant correlation between the occurrence of a minimum of 0.254 cm rainfall and leaf spot disease severity. In contrast, Alderman et al (5) observed many leaf spots were devoid of conidia after heavy rainfall. They implied that the reported association of rainfall with increased disease was probably an indirect result of increased leaf wetness duration or high humidity within the canopy that favored infection and sporulation (5).

Various leaf spot advisories have been released for commercial use in Alabama and Virginia/Carolina peanut production areas for Florunner and Virginia type peanut cultivars (7, 8, 11, 36). Careful examination and possible modification of these existing advisories is necessary before release in Oklahoma. In Oklahoma, growers commonly grow Spanish and runner peanut cultivars, where Spanish cultivars are more susceptible and runner cultivars are partially resistant to early leaf spot (17). Adjustment of the thresholds may be necessary to provide optimal leaf spot control on these cultivars. Previous research on leaf spot forecasting in Oklahoma has demonstrated a promising utility of leaf spot forecasting for scheduling fungicide applications (9). These studies demonstrated a reduction in the number of sprays with no loss in yield with the Jensen and Boyle advisory (9). However, leaf spot incidence often exceeded 70% on Spanish cultivars, a level that would likely cause grower concern, and perhaps yield loss would unexpectedly occur. It is necessary, through controlled environment experiments and field experiments, to identify an optimal advisory/threshold and to substantiate the identified advisory. Hence, the overall objective of this project, funded in part by the Samuel Roberts Noble Foundation, was to develop an effective weather-based early leaf spot advisory for Oklahoma.

Two chapters of this thesis are written in journal manuscript format that are complete without supporting materials. Chapter II, entitled "Effect of Temperature and Exposure Period to High Relative Humidity on Infection of Peanut Cultivars by *Cercospora arachidicola*", describes the effects of temperature and post-inoculation exposure period to RH$\geq$95% on the expression of infection components on three commonly grown peanut cultivars in Oklahoma - Spanco, Florunner, and Okrun. Chapter III, entitled "Comparison of Leaf Spot Advisory Systems for Managing Early Leaf spot of Peanut in Oklahoma", describes field studies comparing the performance of several early leaf spot advisories and identifies the optimal advisory system/threshold for each of the three peanut cultivars.

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CHAPTER II

Effects of Temperature and Exposure Period to High Relative Humidity on Infection of Peanut Cultivars by *Cercospora arachidicola*

ABSTRACT

The environmental conditions required for infection of spanish (susceptible) and runner (partially resistant) peanut cultivars by *Cercospora arachidicola* were determined in dew chambers. Plants of the spanish cultivar Spanco (susceptible) and the runner cultivars Florunner and Okrun (partially resistant) were exposed to temperatures of 18-30°C and interrupted 12-hr periods of relative humidity $\geq$95% that totaled 12-84 hours following inoculations. Components of infection that included the number of lesions/leaf, lesion size, infection efficiency, and incubation period were quantified following further incubation at RH 70-85%. Maximum lesions/leaf and infection efficiency occurred at 24°C. Few infections were observed at 27 and 30°C over exposure period to RH$\geq$95%. The minimum infection requirements of exposure to RH$\geq$95% were 24, 36, and 48 hours for Spanco, Florunner, and Okrun, respectively. Lesions/leaf, lesion size, and infection efficiency linearly increased with the prolonged exposure period to RH$\geq$95% until 72 hours over all the temperatures. *C. arachidicola* developed more lesions/leaf on Spanco than on Florunner and Okrun. Lesions were large, intermediate, and small on Spanco, Florunner, and Okrun, respectively. A polynomial regression model,

$y = b_0 + b_1W + b_2TW + b_3T^2W + b_4T^4W$, in which y is the square root of (lesions/leaf+1), T is the temperature, and W is the exposure period to RH$\geq$95% well described the functional relationship of lesions/leaf with temperature and exposure period to RH$\geq$95% for Spanco and Florunner. The model predicted maximum infection at 22°C and low infection at 18 and 30°C for the two cultivars.

INTRODUCTION

Early leaf spot caused by the fungus *Cercospora arachidicola* Hori, is the most damaging foliar disease of peanut (*Arachis hypogaea* L.) in Oklahoma. Yield loss of 50% or more may result from failure to control leaf spot (11, 12). The conventional strategy for control of leaf spot in Oklahoma is the application of fungicide on a 14-day schedule. Excellent disease control is normally achieved following this control program. However, the numerous fungicide applications result in high production costs and increase the potential of environmental pollution. Jensen and Boyle identified the weather parameters conducive to leaf spot epidemics (14). These are the hours of relative humidity (RH) above 95% and the minimum temperature during the high humidity period. They further developed a leaf spot forecasting model (15). This model was adapted and computerized for scheduling fungicide sprays by Parvin et al (21). The original Jensen and Boyle model has been modified and employed for scheduling fungicide applications in Virginia and North Carolina on Virginia-type cultivars (16, 22). Benefits of the Jensen and Boyle model are a reduction in the number of fungicide applications and lower costs of production (22).

However, scheduling fungicide applications with the Jensen and Boyle model often resulted in a high incidence of leaf spot and defoliation late in the growing season which has concerned growers (22). As a result, recent efforts have been made to improve the Jensen and Boyle model. An empirical model based on the biological response of conidia of *C. arachidicola* to environmental parameters has been developed in Virginia (4). The model utilizes time duration values (TDV), a parameter to quantify the conduciveness of daily weather condition to infection by *C. arachidicola*. One TDV represents one hour of RH$\geq$95% when the temperature is between 16 and 30°C (4). This model accumulates daily TDVs until a threshold value is reached when sprays are recommended. Field tests with virginia cultivars using a threshold of 48-TDVs has resulted in leaf spot control similar to that of a 14-day schedule with similar reductions in the number of sprays to the Jensen and Boyle model (4, 23). Adjustment in TDV threshold was suggested for use on peanut cultivars with different reactions to early leaf spot or the use of fungicides other than chlorothalonil (4).

In Oklahoma, seventy percent of the peanut acreage is planted with spanish cultivars while the remainder is cropped to runner cultivars. Runner cultivars, including Florunner and Okrun, are partially resistant to early leaf spot, with fewer lesions per leaflet, less necrotic area per leaflet, and fewer conidia produced per lesion than spanish cultivars (9). In the field, runner cultivars exhibit delayed leaf spot onset and lower leaf spot incidence, defoliation percentage, and area under the disease progress curve compared to spanish cultivars (5, 31). Research on the components of partial resistance to *C. arachidicola* in runner cultivars has been limited. The adaptability of the Virginia model enables growers to adjust the spray threshold value for a particular peanut cultivar. Validation trials of this model on spanish and runner cultivars in Oklahoma have identified different optimal thresholds (31). Validation of these TDV thresholds on spanish and runner cultivars under controlled conditions is needed to reinforce the field studies.

The effects of temperature and moisture on the infection process on peanut by *C. arachidicola* have been studied in depth. Oso (19) reported that conidia of *C. arachidicola* require a saturated or near-saturated atmosphere to germinate at optimum temperatures of 20-30°C. A high percentage of conidia germinated by 48 hours at 16-25°C (1, 2, 8), but only a small portion germinated at 28-31°C (2). Further studies reported that sporulation increased with prolonged daily leaf wetness period and was greatest at 24 and 28°C, intermediate at 20°C, and least at 16 and 32°C (3). Jensen and Boyle's leaf spot forecasting (15) indicated that minimum temperatures $\leq$ 19°C with 12-hr per day of RH$\geq$95% are unfavorable for leaf spot development. In greenhouse inoculations using detached leaves, 24-hr exposure to continuous misting enabled lesions to develop and lesion numbers increased with prolonged mist periods up to 8 days for late leaf spot (27). Shew et al (28) found maximum infection at 20°C with exposure to at least 12 hr/day RH>93% for late leaf spot. They also implied that cultivars differing in leaf spot susceptibility could differ in the length of the high relative humidity period necessary for infection (28).

Previous infection studies with *C. arachidicola* used continuous exposure to high humidity or in dew (1, 2, 9, 18, 19, 24). The cyclic wet-dry-period regime was only used for study on germination and sporulation for *C. arachidicola* and on infection for *C. personatum* (2, 3, 28). Alderman et al (2) reported that germ tubes of *C. arachidicola* elongate under both moderate- (RH 65-85%) and high-humidity (RH≥95%) regimes. They also found that germ tubes resume growth after a dry period at a rate similar to that under continuous dew. This experiment was designed to simulate cyclic high-moderate relative humidity regime in the field. The objectives of this study were to determine the requirement of temperature and interrupted exposure periods to relative humidity ≥ 95% on infection of spanish and runner cultivars by *C. arachidicola*, and to quantify cultivar effects on some components of infection.

MATERIALS AND METHODS

Seeds of the spanish cultivar Spanco and the runner cultivars Florunner and Okrun were planted into 12-cm-diameter plastic cups containing sand, soil, and shredded peat moss in a 2:1:1 (v/v/v) mixture. Plants (one per pot) were grown in the greenhouse at 20-30°C for 40-60 days until inoculation. Hoagland's (6) nutrient solution was applied to plants twice to prevent nutrient deficiency. Four single-conidial isolates of *C. arachidicola* from various peanut production area in Oklahoma were compared in a preliminary infectivity assay and no difference was detected. Therefore, one isolate was used in this study. The isolate was cultured on potato-carrot-agar (PCA) acidified to pH 5.5 with lactic acid (6). Sporulation was induced by maintaining culture under a 14-h photoperiod of 800 lux fluorescent light at 25 C for 10-12 days. The isolate was stored on silica gel at 4°C (6) and inoculum for each assay was obtained by re-culturing onto acidified PCA plates. Conidial suspensions were prepared by flooding the 10-12-day-old PCA cultures with sterilized distilled water containing two drops/100ml Amway surfactant and filtered through cheese cloth. The concentration of conidial suspension was adjusted to 40,000/ml with a hemacytometer (28).

The youngest second and third fully expanded leaves of each plant were inoculated using a modification of a procedure described by Evans et al (7). Briefly, a clear plastic cylinder, 20 cm long and 9 cm diameter, was vertically attached to a ring stand. A DeVilbiss No. 152 atomizer (The DeVilbiss Company, Somerset, PA) was attached to the top of the cylinder. Inoculation times were regulated by attaching a timer to the atomizer pump. The upper surface of each peanut leaf was inoculated for five seconds. Inoculum deposition was determined by inoculating glass slides in the same manner as inoculating leaves and counting conidia in a 1 cm^2 area under microscope. This was repeated 30 times while placing the glass slides in various positions within the outlet of the cylinder. This calibration procedure was repeated three times. Density of inoculum deposition was assumed to be the mean number of conidia/cm^2 collected on the glass slides. A procedure to determine the mean leaf area of the youngest second and third leaves for cultivars of Spanco, Florunner, and Okrun was also repeated three times. Thirty leaves of each cultivar were measured at one time with a video imaging area meter system (Delta-T Devices, Cambridge, England). These leaves were produced in the same manner as those to be inoculated. The number of conidia deposited onto each leaf (2,500-3,500) was considered to be the mean number of conidia deposited per unit area multiplying by the mean leaf area for each cultivar.

Plants were exposed to various temperatures and periods of relative humidity (RH) ≥ 95% using dew chambers (Model I-60DL, Percival, Boone, IA). Because only two dew chambers were available, experiments were conducted over time by temperature. The order of temperature treatments were assigned at random and were repeated once. Within each temperature treatment of 18, 21, 24, 27, and 30°C, plants were exposed to seven cumulative leaf wetness periods of 12, 24, 36, 48, 60, 72, and 84 hours in increments of 12 hours per day. Two dew chambers were used for each temperature treatment. One dew chamber (high-RH) was set for a 12-hr night period of RH ≥ 95% which supported infection and a 12-hr day period of RH 70-85% during the day. The leaf wetness periods were observed fewer than the periods of RH ≥ 95% at all temperatures. The RH regime in the high RH chamber was used to simulate the cyclic nature of high RH periods in the field. The other chamber (moderate-RH) was set for a 24-hr period of RH about 70-85% during day and night. Temperature and relative humidity in each chamber were monitored with a seven-day recording hygrothermograph (5020-A, Weathertronics). Plants were inoculated at 4:00-6:00 pm and were then placed in the high-RH chamber. Inoculated plants were at first placed in the high-RH chamber in group by cultivar. After exposure to the specified periods of RH ≥ 95%, three plants of each cultivar were transferred at random to the moderate-RH chamber to stop the infection process where they were randomly arranged and incubated for symptom development. The experimental design was a split-split-plot design with dew chamber temperature as the whole plot treatment, cultivar the split-plot treatment, and exposure period to RH ≥ 95% the split-split-plot treatment.

The number of lesions per leaf were counted every 3-4 days starting 11 days after inoculation. Inoculated leaves were harvested 30 days after inoculation and lesion size was determined by measuring the diameter of the three largest lesions per leaf (28). Infection efficiency was calculated by dividing the number of lesions per leaf by the number of conidia deposited onto each leaf. Incubation period was obtained by modifying Shaner's method (26). Briefly, a line was plotted using lesions/leaf against days after inoculation. The time when 50% of the total number of lesions/leaf appeared was derived from the line as the incubation period.

Several transformations including angular, logarithmic, square-root, and proportion of the maximum number of lesions/leaf observed were applied to data of the number of lesions/leaf in an attempt to stabilize the variances. However, the square-root transformation, y = (lesions/leaf + 1)$^{0.5}$ was retained for its random pattern of variances vs. means (10). Analysis of variance was performed using the SAS GLM procedure for all infection components assessed (25). Fisher's LSD test was used to separate means for the sub-plot effect of cultivar. The functional relationship between lesions/leaf and the continuous effects of temperature and exposure period to RH$\geq$95% were examined using the CONTRAST function in the GLM procedure (25). These relationships were used to construct a polynomial regression model describing the functional relationship of y with temperature and exposure period to RH$\geq$95% by incorporating all the significant terms in orthogonal contrasts (29). SAS REG (25) procedure was used to approximate the response surface. The regression equation was computed by using observed data for each temperature and high-RH period combination. The fit of regression model was evaluated by the *F*-test, visual inspection of residual plots, size of standard errors associated with the estimated regression parameters, the coefficient of determination (R^2), and adjusted R^2 for degree of freedom (17).

RESULTS

Leaf spot lesions did not develop on leaves exposed to 12 hours of RH≥95% for the three cultivars at all temperatures in the experiments. Therefore, these data were excluded from analysis. Analysis of the two experiment repetitions yielded similar results and comparable error mean squares. Experimental repetitions were therefore combined in further analysis to give a total of six observations comprised of the mean of two leaves per plant. For number of lesions per leaf (lesions/leaf), the effects of cultivar and exposure period to RH≥95% were significant at $P=0.05$ (Table 1). Counts of number of lesions/leaf were three times more on Spanco (15.27) than on Florunner (5.00) and Okrun (2.02) but not differing between Florunner and Okrun over temperatures and exposure periods to RH≥95% (Table 2). There was a linear increase for lesions/leaf in response to the increasing exposure period to RH≥95% over all temperatures for the three cultivars (Fig 1). Lesions started to develop on leaves exposed to 24, 36, and 48 hours of RH≥95% for Spanco, Florunner, and Okrun, respectively (Fig 1). Lesions/leaf increased sharply at 36 hours or more for Spanco while increases in lesions/leaf were gradual for Florunner and Okrun. The effects of temperature and the interaction of cultivar and exposure period were significant at $P=0.10$ (Table 1). Lesions/leaf were the most at 24°C and the least at 30°C and lesions/leaf were more at 18 and 21°C than at 27 and 30°C for the three cultivars (Figure 2). Increases in lesions/leaf from 18 to 24°C were sharp for Spanco and gradual for Florunner and Okrun while decreases in lesions/leaf from 24 to 27°C were sharp for spanco and Florunner and gradual for Okrun (Fig 2).

Cultivar and exposure period to RH≥95% had significant effects (P=0.05) on lesion size (Table 1). Lesions were the largest (1.33 mm) for Spanco, intermediate (1.02 mm) for Florunner, and the smallest (0.65 mm) for Okrun (Table 2). Lesions were smallest at 24 hours exposure to RH≥95% and linearly increased with the prolonged exposure period until 60 hours for all three cultivars (Fig 3). Lesion size did not differ from 60 to 84-hr exposure to RH≥95% for the three cultivars (Fig 3).

The effects of temperature, cultivar, and exposure period to RH≥95% were significant ($P\leq0.05$) and the interaction of cultivar and exposure period was significant ($P\leq0.10$) for infection efficiency. Changes in infection efficiency in response to temperature and exposure period to RH≥95% were almost the same as changes in lesions/leaf. This was mainly attributed to the consistent inoculum deposition for the three cultivars and the similar leaf area of the three cultivars grown in greenhouse, especially during the age of 40-60-day old.

The main effects of temperature, cultivar, and exposure period to RH≥95% and their interactions did not significantly impact incubation period (Table 1). Lesions were first observed at 11-14 days after inoculation for Spanco and 14-17 days after inoculations for Florunner and Okrun over temperature treatments. However, incubation period did not differ between Spanco and runner cultivars over temperatures and exposure periods to RH≥95% (Table 2).

The interaction of temperature and exposure period to RH≥95% is not significant on lesions/leaf for the combined data of the three cultivars (Table 1). However, such interaction is significant on lesions/leaf for Spanco and Florunner ($P \leq 0.01$) but not for Okrun ($P=0.52$). The influence of temperature and exposure period to RH≥95% on lesions/leaf for Spanco and Florunner was best described by the following model:

$$y = b_0 + b_1W + b_2TW + b_3T^2W + b_4T^4W$$

in which y is the square root of (lesions/leaf+1), T is the temperature, and W is the exposure period to RH≥95%. Significant effects on y incorporated into the model were the linear, quadratic, and quartic effects of temperature and a linear effect of exposure period to RH≥95%. Estimates of parameters were listed in table 3. W is a linear function to y. ($b_1 + b_2T + b_3T^2 + b_4T^4$) is equivalent to the slope in simple linear regression and can be used to compare the differences in slopes between temperatures within each cultivar and between cultivars at each temperature. The slopes were 0.0288, 0.0813, 0.0814, 0.0524, and 0.0209 for Spanco, and 0.0179, 0.0514, 0.0447, 0.0231, and 0.0154 for Florunner at temperatures from 18 to 30°C, respectively. The rankings of slopes at each temperature were greater for Spanco than for Florunner. Among temperature treatments, the slopes were the highest at 21°C for Florunner and at 21 and 24°C for Spanco. The models predict maximum infection at 22-23°C and low infection at 18 and 30°C for the two cultivars (Fig 4). The models were significant at $P \leq 0.0001$ and a random pattern of residuals was observed across the predicted means for the two cultivars. The coefficient of determination R^2 and adjusted R^2 were 0.52 and 0.51, and 0.58 and 0.57 for Spanco and Florunner, respectively.

DISCUSSION

Requirements for infection by *C. arachidicola* differed for the three peanut cultivars. The minimum exposure period to RH$\geq$95% required for infection of Spanco, Florunner, and Okrun were 24, 36, and 48 hours, respectively. Field experiments in Oklahoma over a three-year period identified that 36 and 48-hr TDVs of the Virginia model, with similar leaf spot control and yields to the 14-day schedule, were optimal thresholds for Spanco and runner cultivars, respectively, for scheduling chlorothalonil (1.26 kg/ha) applications to control early leaf spot (31). Tolerance of leaf spot to a level that does not cause yield loss was considered in identifying thresholds in the Field. In the dew chamber, however, we only looked for the minimum exposure period to RH$\geq$95% for infection. The optimal thresholds identified in the field and minimum exposure to RH$\geq$95% for infection identified in the dew chamber are closely matched.

The significant ($P \leq 0.10$) interaction of cultivar and exposure period to RH$\geq$95% found in this study suggested that cultivars differing in susceptibility to early leaf spot respond differently to the duration of exposure to RH$\geq$95% and have different minimum exposure periods to RH$\geq$95% for infection. Data reported here supported the inference by Shew et al (28) that the length of the high relative humidity period necessary for infection depend upon the level of partial resistance in the host plant. These results strengthen the need using cultivar-specific thresholds in leaf spot forecasting with the Virginia model on spanish and runner cultivars.

In this study, we observed a significant number of leaf spot lesions at 21-24°C and little infection at 27-30°C. Alderman et al (2) previously found a higher percentage of conidial germination at 16-25°C with a 48-hr continuous dew period than at 28-32°C and germ tube elongations were greater at 19-25°C and germ tubes were longest at 22°C (2). Jensen and Boyle leaf spot forecasting predicted that minimum temperatures below 19°C with 12-hr per day of RH≥95% are unfavorable for leaf spot development (15). Infection data reported here were very similar to Alderman et al's findings except that infection at 18°C was very low. The lower infections at 18°C was similar to Jensen and Boyle's leaf spot forecasting model. The polynomial regression models derived here agreed well with previous germination studies with predicted maximum infections at 22-23°C and low infection at 18 and 30°C for the three cultivars. The rankings of slopes at each temperature were the same as rankings of other infection components for Spanco and Florunner.

An incubation period of 12 days for *C. arachidicola* with continuous exposure to RH≥95% using detached leaf technique has been reported (2, 18, 30). Waliyar et al (30) observed incubation period of 12-16 days for cultivars differing in susceptibility to early leaf spot. Nevill (18), however, found no differences in incubation period for such cultivars. We found the incubation period averaged about 17 days across various combinations of temperature and exposure period to RH≥95% for the three cultivars. Our data should be more meaningful in estimating early leaf spot development in the field where weather conditions are variable. The differences in incubation period are mainly due to using different experimental designs for evaluating incubation period between studies. In our case, using intact plants exposed to interrupted high-humidity regime rather than using detached leaves with continuous exposure to high humidity to evaluate incubation period may account for the differences.

Alderman et al (2) observed an infection efficiency of 85% and implied that infection efficiency could be a function of both humidity and stomatal behavior. Abdou et al (1) observed fewer germ tubes grew toward stomata on partially resistant cultivars compared to susceptible cultivars. Nevill (18) reported an infection efficiency of 2% for *C. arachidicola* and not affected by cultivar. Nevill (18) implied that competitions between conidia for infection sites at high conidial concentration and lesion fusions may exist to produce apparent low infection rate. Alderman et al and Nevill both used inoculum made of conidia freshly collected from sporulating lesions. We observed the highest infection efficiencies of 1.3%, 0.4%, and 0.1% at 24°C across exposure periods to RH≥95% for Spanco, Florunner, and Okrun, respectively, with inoculum made of re-cultures from the conidia stored in silica gel. We also found that infection efficiency is dependent upon temperature, exposure period to RH≥95%, and cultivar. Conidial suspensions of concentration at 40,000 conidia/ml or above were used in various studies (18, 28, 30). With deposition of 2,500-3,500 conidia/leaf in this study, it was possible that competition for infection sites occurred between conidia and we observed lesion fusion during the assessment of infection components. *C. arachidicola* infects leaf through stomata (1). In our experiments, the high humidity periods inside the high-RH chamber only occurred at night when no light was provided and when photosynthesis ceased and stomata were close. The perhaps closed stomata may not have permitted the conidial penetration and reduced the chance of successful infection, hence low infection efficiency.

Results reported here indicated that runner cultivars are partially resistant to early leaf spot. Fewer lesions/leaf, smaller lesions, and lower infection efficiency along with lower sporulation (9) compared to spanish cultivars were associated with the partial resistance of Florunner and Okrun. These components of partial resistance, as Parlevliet (20) stated, reinforce each other and apparently contribute to the lower epidemic rate of early leaf spot on runner cultivars in the field (5, 31). Incorporation of varietal resistance into leaf spot model was previously done on an empirical basis (13, 16) and was suggested for the Virginia model (4). The similarities between optimal thresholds of the Virginia model identified in the field in Oklahoma (31) and the minimum infection requirement of exposure periods to RH$\geq$95% for Spanco and runner cultivars identified in this study substantiate each other and provide us an objective basis of incorporating partial resistance into the Virginia leaf spot model. Applying fungicide on different thresholds for cultivars differing in leaf spot susceptibility would enable us to promote a full utility of the Virginia model with further reduction in production costs. The Virginia model is expected to be implemented for spanish and runner cultivars in 1994 upon the operation of the oklahoma MESONET, a network of automated, computer-linked weather stations with at least one station per county. This system has the capability to deliver weather-based pest advisories to a large number of growers in the state.

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Table 1. Analysis of variance of two runs experiment with five temperatures and six exposure periods to RH$\geq$95% on three peanut cultivars.

Source[a]	df	Mean Squares: Square Root[b]	Lesion Size(mm)	Infection Efficiency	Incubation Period(days)
Experiment (Exp)	1	1.41	6.08	7.78×10^{-6}	55.91
Temperature (Temp)	4	24.43*	2.14	1.16×10^{-4}**	9.23
Error (A)	4	0.19	1.68	3.00×10^{-8}	1.72
Cultivar (CV)	2	232.43**	42.32**	1.12×10^{-3}**	18.64
CV*Temp	8	5.43	0.02	2.97×10^{-5}	7.71
Error (B)	10	1.01	0.01	1.25×10^{-6}	2.00
Hrs of RH$\geq$95% (HRH)	5	257.80**	89.06**	1.27×10^{-3}**	100.00
HRH*TEMP	20	9.23	1.21	5.25×10^{-5}	6.84
HRH*CV	10	47.85*	0.61	4.09×10^{-4}*	0.01
HRH*TEMP*CV	40	0.54	0.05	5.57×10^{-6}	4.53
Temp*Exp	4	0.19	1.68	3.00×10^{-8}	1.72
Error (C)	75	0.46	0.28	7.38×10^{-6}	11.34

[a] data is analyzed as a split-split-plot design with temperature as main-plot, cultivar as sub-plot, and exposure period to RH$\geq$95% as sub-sub-plot.

[b] Square root of (lesions/leaf + 1).

** significant at $P\leq0.05$ and * significant at $P\leq0.10$.

Table 2. Effect of cultivar on components of infection of peanut leaves by *Cercospora arachidicola.*

	Means			
Cultivar [1]	Lesions /Leaf(No.)	Lesion Size (mm)	Infection Efficiency [2]	Incubation Period (days)
Spanco	15.27 a	1.33 a	0.004233 a	16.98 a
Florunner	5.00 b	1.02 b	0.001895 b	17.25 a
Okrun	2.02 b	0.65 c	0.000712 c	17.62 a
LSD $_{p=0.05}$*	3.34	0.19	0.001000	...

* Means within a column followed by the same letter do not differ significantly according to Fisher's LSD test at $P \leq 0.05$. Values represent the mean of two experimental repetitions with five temperatures, six exposure period to RH$\geq$95%, and three replications.

[1] Spanco is a spanish cultivar and Florunner and Okrun are runner cultivars.

[2] Number of lesions per leaf divided by number of conidia deposited onto each leaf.

Table 3. Parameter estimates of the regression equation describing the effects of temperature and exposure period to RH$\geq$95% on the square root of (lesions/leaf+1) .

Cultivar[a]		Parameter estimate	Standard error
Spanco[b]	b_0 *(intercept)*	0.258602	0.37598107
	b_1 (W)	-2.309550	0.50496390
	b_2 (TW)	0.249973	0.05798850
	b_3 (T^2W)	-0.007192	0.00184152
	b_4 (T^4W)	1.61×10^{-6}	0.00000052
Florunner[c]	b_0 *(intercept)*	0.388715	0.19086527
	b_1 (W)	-2.018161	0.25634288
	b_2 (TW)	0.226112	0.02943763
	b_3 (T^2W)	-0.006840	0.00093484
	b_4 (T^4W)	1.74×10^{-6}	0.00000027

[a] Spanco is a spanish cultivar and Florunner is a runner cultivar.

[b] Significant at $P\leq0.01$ level for all parameters except intercept in which *Prob*> | T | = 0.4925

[c] Significant at $P\leq0.0001$ level for all parameters except intercept in which *Prob*> | T | = 0.0432

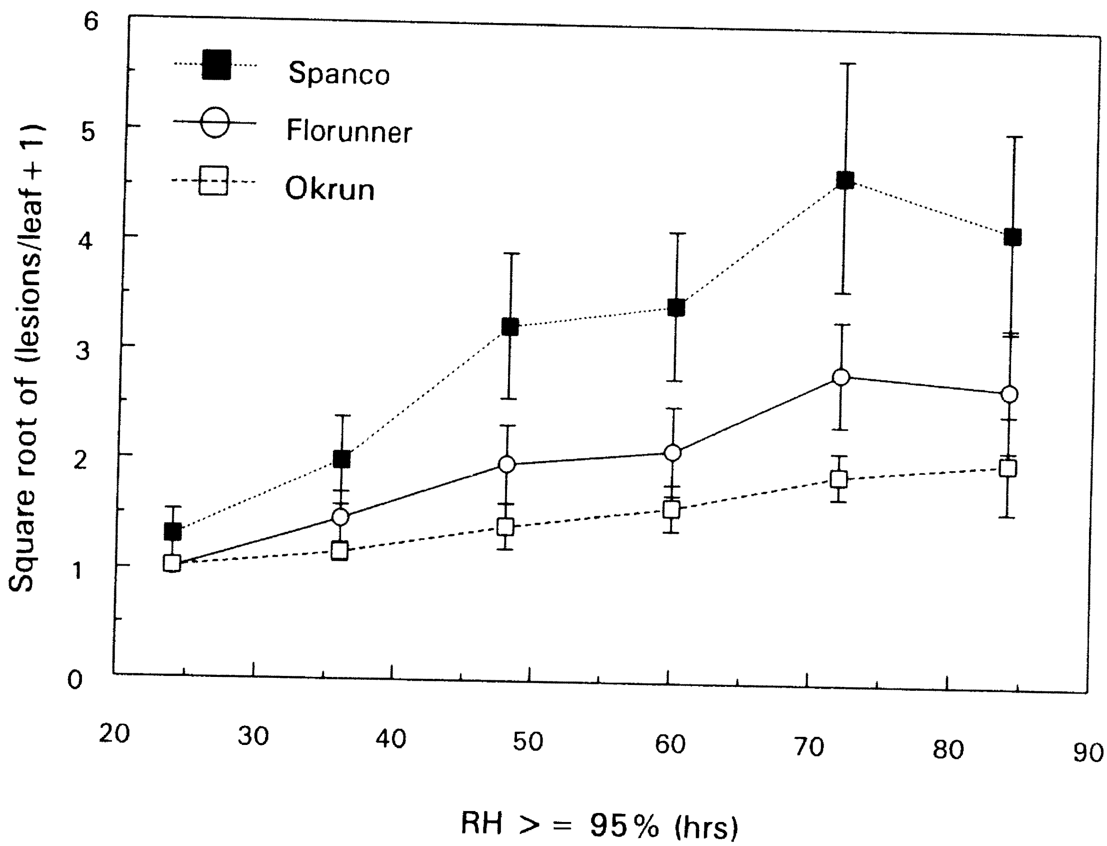

Figure 1. The effect of exposure period to relative humidity ≥ 95% on the number of lesions/leaf for infection of three peanut cultivars. Data points represent mean square root of (lesions/leaf+1) at 30 days after inoculation from two experimental repetitions with five temperatures and three replications. Error bars represent 95% confidence intervals.

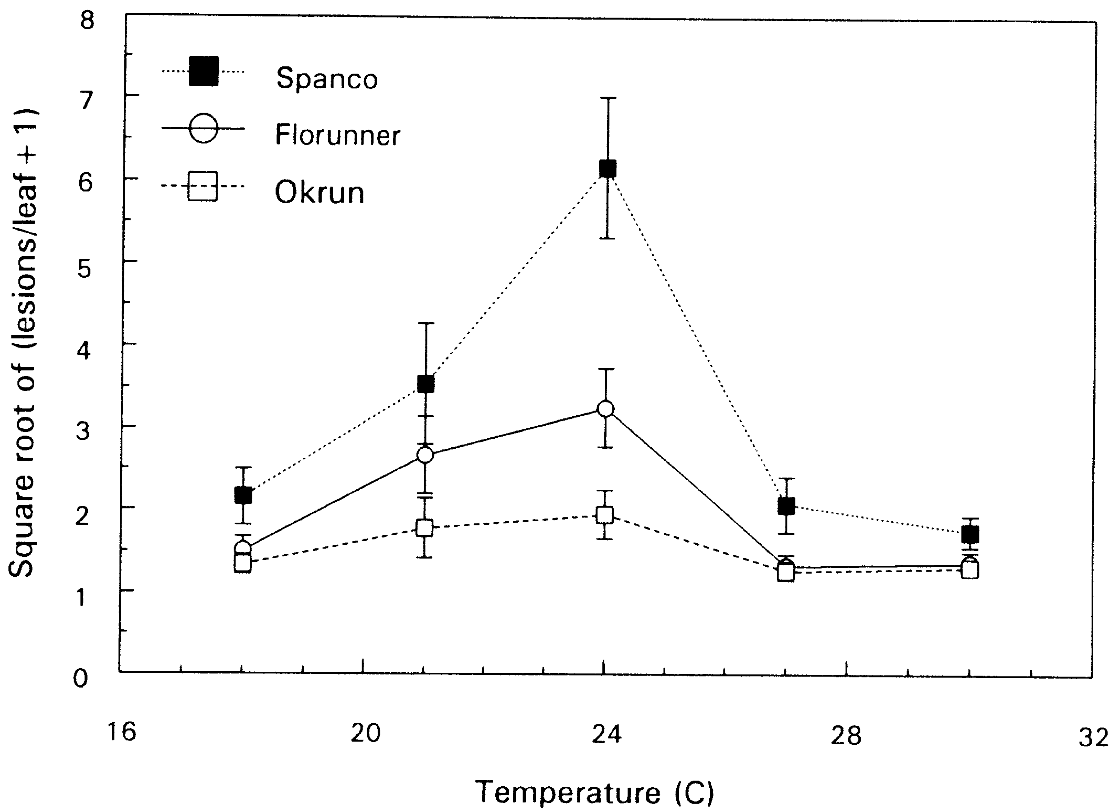

Figure 2. The effect of temperature on the number of lesions/leaf for infection of three peanut cultivars. Data points represent mean square root of (lesions/leaf+1) at 30 days after inoculation from two experimental repetitions with six exposure period to RH≥95% and three replications. Error bars represent 95% confidence intervals.

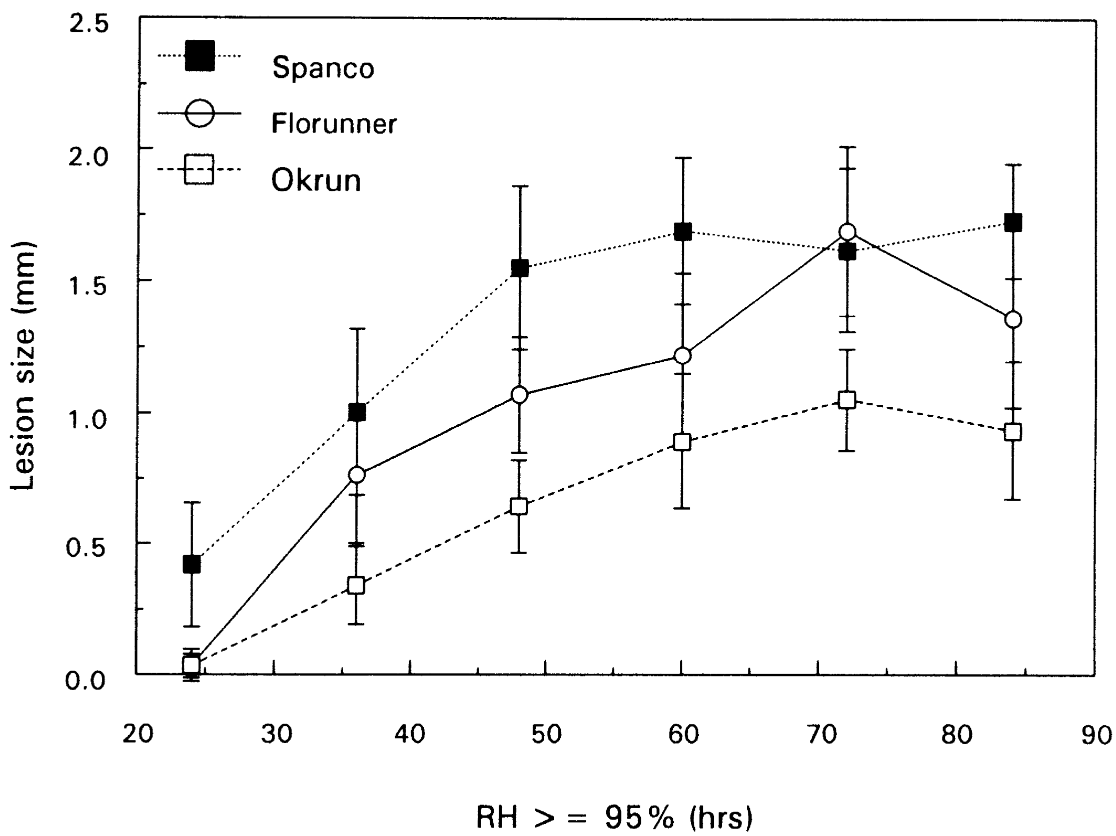

Figure 3. The effects of exposure period to relative humudity ≥ 95% on size of the three largest lesions per leaf for infection of three peanut cultivars. Data points represent the mean diameters of the three largest lesions per leaf at 30 days after inoculation from two repetitions with five temperatures, six exposure periods to RH≥95%, and three replications. Error bars represent 95% confidence intervals.

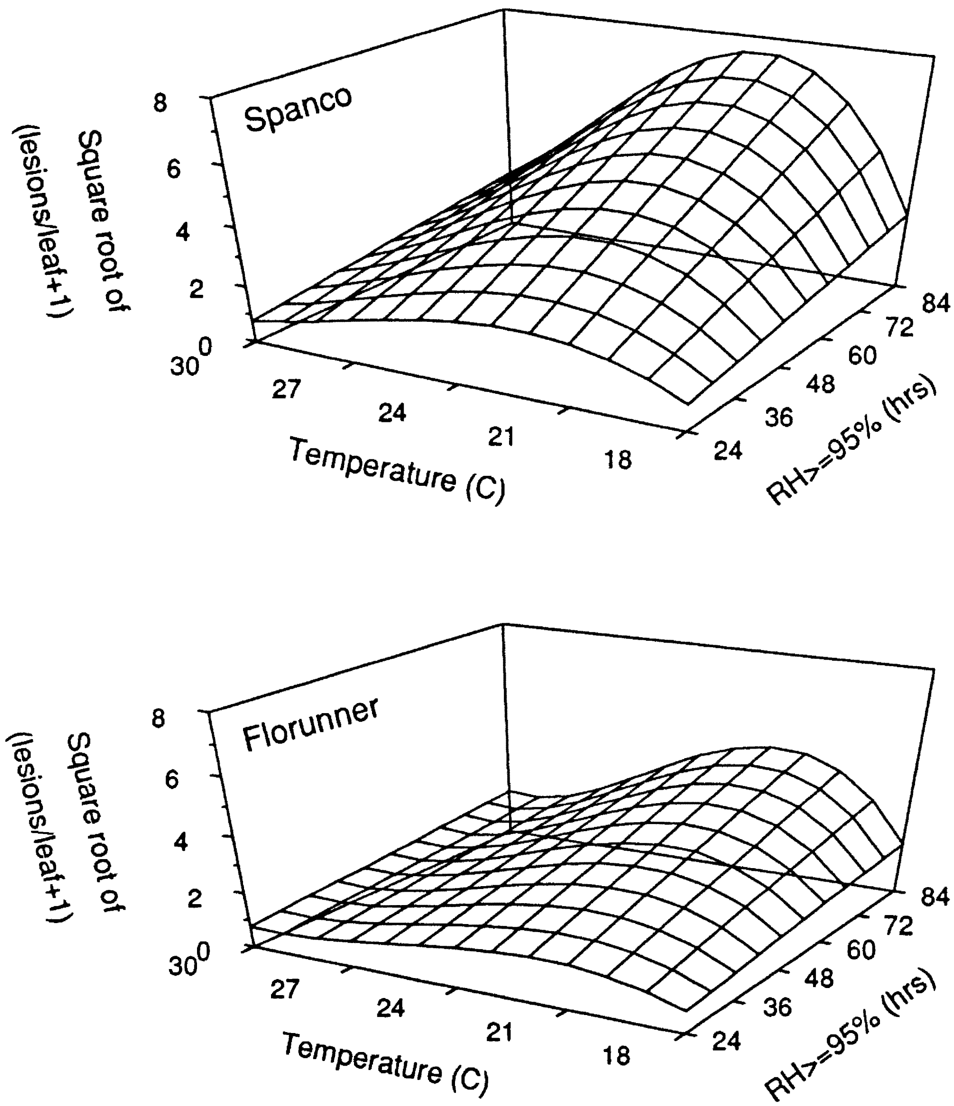

Figure 4. Response surfaces of predicted values for square root of (lesions/leaf+1) as a funtion of temperature and exposure period to RH$\geq$ 95% for Spanco and Florunner.

CHAPTER III

Comparison of Leaf Spot Advisory Systems for Managing Early Leaf Spot of Peanut in Oklahoma

ABSTRACT

Weather-based leaf spot models for scheduling chlorothalonil (1.26 kg/ha) sprays to peanut for management of early leaf spot were compared to a 14-day schedule and a non-sprayed control in 1991, 1992 and 1993. The Jensen and Boyle (JB) model based on daily duration of relative humidity (RH) $\geq$95% and minimum temperature during the high RH period, a modified Jensen and Boyle model for cultivars with partial resistance, the Virginia model based on biological response of conidia of *C. arachidicola* to weather conditions, and the AU-Pnut model based on actual precipitation and precipitation probabilities (1993 only) were compared on spanish (Spanco) and runner (Florunner and Okrun) cultivars. Leaf spot incidence was assessed at 2-week intervals and defoliation was assessed at harvest. Leaf spot incidence was 66% on Spanco and 56% on Florunner for the non-sprayed control in 1991 and did not reduce yields on Spanco and Florunner. Leaf spot incidence for the control plots was 100% and 97% on Spanco and 73-84% on Florunner and Okrun in 1992 and 1993 and yields were reduced in both years for Spanco but not for Florunner and Okrun. The effect of leaf spot treatments were significant ($P \leq 0.05$) on leaf spot incidence, defoliation percentage, and area under the disease progress

curve (AUDPC) for all cultivars over the three years except on Florunner in 1991. On Spanco, the Virginia model with thresholds of 36 infection hours (RH$\geq$95% and 16 $\leq$ temperature $\leq$ 30°C) in 1991 and 1993 and 36 and 48 infection hours in 1992 resulted in leaf spot incidence and AUDPC the closest to these disease measures of the 14-day schedule of all leaf spot models compared and defoliation and yields similar to these measures of the 14-day schedule and with 3-4 fewer sprays. The Virginia model with thresholds of 36 and 48 infection hours in 1992 and 1993 resulted in leaf spot control and yields the same as the 14-day schedule with 3-4 fewer sprays for Florunner and Okrun. The AU-Pnut model in 1993 provided leaf spot control similar to the 14-day schedule on Spanco and equivalent to the 14-day schedule on runner cultivars. The JB model did not schedule any sprays in 1992 and only one spray in 1993 and resulted in leaf spot measures either equal to or close to those of the control and the similar yield to that of the control. This is the first report of failure of the JB model to adequately schedule sprays for the control of early leaf spot on Spanco. Over the three years, the Virginia model with thresholds of 36 infection hours for Spanco and 48 infection hours for Florunner and Okrun provided the best leaf spot control of all leaf spot models compared and hence were the optimal thresholds for use on spanish cultivar Spanco and runner cultivars Florunner and Okrun.

INTRODUCTION

Early leaf spot, caused by the fungus *Cercospora arachidicola* Hori, is the primary foliar disease of peanut (*Arachis hypogaea* L.) in Oklahoma. Peanut yield losses exceeding 50% have resulted from failure of control leaf spot in Oklahoma (8). Other foliar diseases including late leaf spot, caused by *Cercosporidium personatum* Deighton, web blotch, caused by *Phoma arachidicola*, and rust, caused by *Puccinia arachidis*, sporadically occur in Oklahoma and usually do not cause yield loss. Agronomic practices such as crop rotation, deep plowing, and destruction of peanut debris have been reported to be effective in reducing primary inoculum and delaying leaf spot onset (12). Growing resistant cultivars also provides partial leaf spot control, however, no commercially acceptable cultivars are highly resistant (14). As a result, fungicides are widely used for the control of leaf spot diseases (7, 21). In Oklahoma, fungicide sprays are often applied on a 14-day schedule and excellent leaf spot control is usually achieved. However, up to six sprays are made in a growing season which increases production costs and the potential for environmental pollution (21).

Peanut infection by *C. arachidicola* is affected by weather conditions. Jensen and Boyle (10) first described the weather variables conducive to leaf spot development. These are the duration of relative humidity (RH) $\geq$ 95% and the minimum temperature during the period of high relative humidity. Based on infection indices assigned to the combination of hours of high relative humidity in a 24-hr period and minimum temperature, they developed an early leaf spot forecasting model (11). Parvin et al (15) adapted and computerized this model to issue a worded daily advisory for scheduling fungicide applications. This model has been validated and used commercially in the Virginia/ Carolina production area since the early 1980's (2, 16). Matyac and Bailey (13) modified the Jensen and Boyle's model to further reduce fungicide applications for peanut cultivars with partial resistance by increasing the spray threshold as a result of decreasing daily infection indices by arbitrary coefficients 0.85 and 0.70.

Studies validating the Jensen and Boyle model have shown that while yields do not differ between model and 14-day schedules, leaf spot incidence is often higher using this model (2, 4, 16, 17). This has caused grower concern and been responsible for efforts to improve leaf spot forecasting. A pathogen growth response model has been recently developed in Virginia based on an empirical study of the biological response of *C. arachidicola* to weather parameters (3). This Virginia model assigns time duration values (TDVs) to infection hours of $RH \geq 95\%$ and temperature between 16 and 30°C and accumulates TDV to different levels as the thresholds for scheduling fungicide applications. When lethal conditions to germinating conidia occur, consisting of eight or more consecutive hours of $RH < 40\%$ or five or more consecutive hours of temperature above 37°C, cumulative TDVs are reset to zero. Validation of this model with threshold of $TDV = 48$ on Virginia type peanuts resulted in leaf spot control equal to that of a 14-day schedule and better than with the Jensen and Boyle model with a similar reduction in the number of sprays (3). Adjustment in the action thresholds of the Virginia model has been suggested for use on partially resistant cultivars (3).

AU-Pnut, a simple rule-based model, uses a combination of daily rainfall or irrigation events and a five-day average precipitation probability to schedule sprays (5). It only requires a rain gauge and acquires rainfall probabilities from national weather service radio to implement. This model has been released commercially in

Alabama for the cultivar Florunner.

In Oklahoma, 70% of peanut acreage is planted to spanish cultivars and 30% is cropped to runner cultivars. Runner cultivars, including Florunner and Okrun, are partially resistant to early leaf spot, with fewer lesions per leaf, less necrotic area per leaflet, and reduced sporulation than spanish cultivars (6). In the field, runner cultivars exhibit delayed leaf spot onset and lower leaf spot incidence, defoliation percentage, and AUDPC compared to spanish cultivars (4). The feasibility of using the Jensen and Boyle leaf spot model has been demonstrated on spanish and runner cultivars in Oklahoma, where most of the acreage is irrigated (4). However, leaf spot control was better on runner cultivars than on spanish cultivars where leaf spot incidence of 75% and defoliation of 50% were observed on several occasions for spanish cultivars which approached unacceptable levels. The development of the Virginia model and the AU-Pnut model provide alternatives for the Jensen and Boyle model for scheduling fungicide applications. The objective of this study was to compare the existing leaf spot models on spanish and runner cultivars that differ in leaf spot susceptibility and identify the cultivar-specific leaf spot models.

Materials and Methods

Weather-based leaf spot models were compared in 1991-1993 with the 14-day schedule and a non-sprayed control at the Perkins research farm. Seeds of cultivars Spanco and Florunner were planted on May 17 in 1991. Seeds of cultivars Spanco, Florunner, and Okrun were planted on May 17 and 27 in 1992 and 1993, respectively. The areas of the field planted to Spanco and Florunner in 1991 had been previously cropped to peanut and were continuously planted to Spanco and Okrun in 1992. The area where Florunner was planted in 1992 was previously fallowed. The experiment was repeated in 1993 at the same sites as in 1992. Fields received sprinkler irrigation as necessary to prevent moisture stress. Except for early leaf spot treatments, recommended practices for crop and pest management were followed (20).

For each cultivar, the experimental design was a randomized complete block design with four blocks. Plots consisted of four 7.6-m-long rows spaced 0.92 m apart. The fungicide chlorothalonil was used to control early leaf spot in all spray programs compared. Chlorothalonil (Bravo 720) was applied at the rate of 1.26 kg/ha to all four rows of each plot using a CO_2-pressurized wheelbarrow sprayer equipped with three TX-10 nozzles per row. The sprayer was calibrated to deliver 310 L/ha water at 275 kPa.

The spray programs compared in 1991 were the Jensen & Boyle model (JB), the Virginia model with thresholds of 36, 48, 72, and 96 cumulative TDVs (VA 36-96), a 14-day schedule, and a non-sprayed control. In 1992, the Virginia model with threshold of 60 TDVs and the JB model modified for cultivars with partial resistance by multiplying daily infection index by coefficient 0.85 (0.85*JB) and 0.70 (0.70*JB) were also compared (13). In 1993, leaf spot models compared were the same as in 1992 except that the 0.70*JB model was replaced by the AU-Pnut model. A simplified Jensen & Boyle model was used (2). Daily infection indices from 0-3, where 0=unfavorable and 3=very favorable, were determined from the Jensen & Boyle nomogram using hours of RH$\geq$95% and the minimum temperature (T) during the high RH period as input variables. The nomogram was refined to increase the infection index by 0.5 along T/RH combinations that bordered a higher infection index (2). A two-day sum of daily infection indices $\geq$ 3.5 was used as the spray threshold. For the 0.85*JB and 0.70*JB models, the threshold was increased when daily infection indices were reduced by multiplying the coefficients 0.85 and 0.70. The AU-Pnut model was arbitrarily modified using only rain and irrigation events of 2.54 mm to schedule fungicide applications. The first spray was made at the start of observing symptoms. Subsequent sprays were made at three counts of rain events ten days apart from the previous spray. For the Virginia model, cumulative TDVs were reset to zero whenever lethal conditions occurred (3). Temperature and relative humidity were continuously monitored from late June through harvest using a CR21X datalogger (Campbell Scientific, Logan UT) equipped with a fan psychrometer. The fan psychrometer was set at 1.2 m above ground. The datalogger was programmed to output hourly air temperature, relative humidity, and precipitation and was situated in field border under irrigation.

Plots were evaluated for incidence of early leaf spot on a 14-day intervals beginning at 48, 45 and 50 DAP in 1991, 1992 and 1993, respectively. Leaf spot incidence, expressed as the percentage of infected and defoliated leaflets, was visually estimated in three 1-ft row lengths randomly selected in each of the two center rows. Final estimations of leaf spot incidence and defoliation percentage were made within a week before harvest. Yields were also taken from the center two rows of each plot. Plots were dug and inverted, dried in the field for two days, and threshed with a Liliston 1580 peanut combine equipped with a sacker. Digging dates in 1991 were

Sept. 30 (136 days after planting, DAP) for Spanco and Oct. 21 (157 DAP) for Florunner; in 1992 were Oct. 12 (138 DAP) for Spanco and Oct. 23 (149 DAP) for runner cultivars; and in 1993 were Oct. 11 (147 DAP) for Spanco and Oct. 25 (161 DAP) for runner cultivars. Pods were then sacked, dried to ca. 10% moisture, cleaned and weighed. Grade of kernel was determined on samples taken from each plot and the corresponding value was determined according to the ASCS loan schedules for each market type.

In 1991 the first spray for the 14-day schedule was made 49 DAP for both cultivars and in 1992 and 1993 the first spray for the 14-day schedule was made 37 and 49 DAP for Spanco and runner cultivars, respectively. Calculation of the leaf spot model treatments also started at the same time. Thereafter, leaf spot model treatments were applied when the respective thresholds were exceeded but not within 10 days of the previous spray. Leaf spot model treatments were sprayed as soon as possible (within 3-5 days) after of a favorable advisory. All spray schedules were maintained until 2-3 weeks before anticipated harvest.

Leaf spot treatments varied slightly from year to year and the interaction of year and those treatments which were tested in all three years were significant ($P \leq 0.05$), therefore, data are reported separately by year. Analysis of disease incidence data were performed on the mean of the six sub-samples taken per plot. Area under the disease progress curve (AUDPC) was calculated as a measure of disease progress and amount (19). Leaf spot incidence, defoliation percentage, AUDPC, and yield data were subjected to analysis of variance using the ANOVA procedure of SAS (18). Wherever treatment effects were significant, means were separated with Fisher's least significant difference (LSD) test at $P=0.05$ (22). Simple correlation analysis was used to determine the relation between leaf spot incidence, defoliation percentage, AUDPC and yield (18). Regression analysis was employed to determine the relationship between leaf spot incidence, defoliation percentage, AUDPC and TDVs of the Virginia model (18). Unless otherwise indicated, differences described below are significant at $P \leq 0.05$.

Results

In 1991, leaf spot pressure was moderately low as leaf spot incidence, defoliation percentage, and AUDPC were 66%, 29%, and 1510, and were 56%, 14%, and 790 for the control plots on Spanco and Florunner, respectively. The onset of early leaf spot occurred at 91 DAP for Spanco and delayed until 105 DAP for Florunner (Figure 1). The effects of spray programs compared were significant on leaf spot measures but not on yields for Spanco (Table 1). For Spanco, leaf spot incidence, defoliation percentage, and AUDPC were 2%, 0, and 257 for the 14-day schedule. Use of the VA 36 program resulted in leaf spot incidence (18%) and AUDPC (705) the closest to and defoliation percentage (3%) similar to those of the 14-day schedule of all leaf spot models compared and lower than those of the control (Table 1). Use of the VA 48 program resulted in leaf spot measures higher than those of the VA 36 program. Leaf spot incidence, defoliation percentage, and AUDPC for the VA 72 and 96 programs were similar to those of the control but higher than those of the VA 36 program (Table 1) for Spanco. Use of the JB model, however, resulted in leaf spot incidence (56%), defoliation (24%) and AUDPC (1232) similar to those of the control (Table 1). Both the VA 36 program and the JB model scheduled three sprays and two sprays were made for the VA 48 program compared to seven sprays for the 14-day schedule on Spanco. For Florunner, Spray programs compared did not impact leaf spot incidence, defoliation percentage, AUDPC, and yield. This was mainly due to its partial resistance to leaf spot and low leaf spot pressure in 1991.

Severe leaf spot occurred in 1992. Leaf spot incidence, defoliation percentage, and AUDPC in the control plots were 100%, 90%, and 4582 for Spanco, 80%, 18%, and 2016 for Florunner, and 84%, 21%, and 2514 for Okrun, respectively. Onset of leaf spot for the control was 58 DAP for Spanco and delayed until 86 DAP for Florunner and Okrun. The effects of spray programs were significant on leaf spot measures for all three cultivars. Leaf spot incidence, defoliation percentage, and AUDPC for the 14-day schedule were 12%, 5%, and 269 for Spanco, 1%, 0, and 62 for Florunner, and 1%, 0, and 44 for Okrun, respectively. Yields were different between leaf spot treatments for Spanco but not for Florunner and Okrun.

Use of the Jensen and Boyle, 0.85*JB, and 0.70*JB models did not schedule any sprays in 1992. Leaf spot incidence at harvest, defoliation percentage, and AUDPC for these treatments were similar to those of the control and higher than those of the 14-day schedule for the three cultivars, Spanco (Table 1), Florunner (Table 2), and Okrun (Table 3). Yields of 3258-3359 kg/ha for these treatments were similar to 3360 kg/ha of the control and were reduced by 32-35% compared to 4989 kg/ha of the 14-day schedule for Spanco. Yields did not differ between leaf spot treatments on Florunner and Okrun.

Uses of all VA 36-96 programs reduced leaf spot incidence, defoliation percentage, and AUDPC compared to these measures of disease for the control, but were greater than those of the 14-day schedule for all three cultivars. For Spanco, use of the VA 36 and 48 program had respective leaf spot incidence of 24% and 29% and AUDPC of 994 and 976 which were the lowest of the VA thresholds tested and similar defoliation (10% and 11%) to that of the 14-day schedule (Table 1). Use of the VA 60-96 programs had leaf spot incidence, defoliation percentage, and AUDPC lower than those of the control but higher than those of the VA 36 program (Table 1). Number of sprays were 4 for the VA 36 program, 3 for the VA 48-72 programs, and 2 for the VA 96 program compared to 7 of the 14-day schedule. Yields of 4500-4642 kg/ha for the VA 36-60 programs did not differ from 4989 kg/ha of the 14-day schedule and yields for the VA 72-96 programs were reduced by 20-28% compared to the 14-day schedule (Table 4). Yields positively correlated with leaf spot measures. The correlation coefficients for yields were 0.83 with leaf spot incidence at harvest, 0.85 with defoliation percentage, and 0.90 with AUDPC.

For Florunner and Okrun, use of the VA 36 and 48 programs resulted in leaf spot incidence (2-4%), defoliation (0-2%), and AUDPC (85-187) similar to these disease measures of the 14-day schedule (Table 2, 3). Uses of the VA 60 and 72 programs reduced leaf spot incidence to 17-27% and AUDPC to 576-1364 compared to the control but higher than those of the VA 36 and 48 programs. Defoliation of 3-6% were similar to 2% of the VA 48 program. Use of VA 96 program resulted in these measures higher than the 14-day schedule and the VA 48 program. 3 fewer for the VA 36, 4 fewer for the VA 48, and 5 fewer sprays for the VA 60-96 programs were scheduled compared to the 7 of the 14-day schedule. Yields from plots subjected to various leaf spot treatments did not differ for the two cultivars. However, positive correlations between yields and leaf spot measures were observed for Florunner. The respective correlation coefficients for yields were 0.56 with leaf spot incidence at harvest, 0.63 with defoliation percentage, and 0.66 with AUDPC.

Moderate severe leaf spot occurrence was observed in 1993. Respective leaf spot incidence, defoliation percentage, and AUDPC for the control were 97%, 76%, and 4001 for Spanco, 83%, 16% and 3595 for Florunner, and 73%, 15%, and 3288 for Okrun. Early leaf spot onset started at 67 DAP for Spanco and 86 DAP for Florunner and Okrun (Fig. 3). Leaf spot treatments significantly affected leaf spot incidence, defoliation percentage, and AUDPC for all three cultivars. Use of the 14-day schedule resulted in leaf spot incidence, defoliation percentage, and AUDPC of 13%, 4%, and 457 for Spanco, 6%, 1%, and 221 for Florunner, and 2%, 1%, and 133 for Okrun, respectively. However, differences in yields were only observed between leaf spot treatments for Spanco.

Use of the Jensen and Boyle model resulted in only one spray while use of 0.85*JB model did not schedule any sprays in 1993. Leaf spot incidence, defoliation percentage and AUDPC were similar to those of the control for the JB model and were the same as those of the control for the 0.85*JB model on Spanco (Table 1). Uses of both the JB and 0.85*JB models resulted in leaf spot incidence (69-82%), defoliation (12-16%), and AUDPC (2907-3390) the same as these disease measures of the control plots and higher than those of the 14-day schedule for Florunner and Okrun (Table 2, 3). Yields of 3727-3955 kg/ha for these two treatments were similar to 3564 kg/ha of the control and were reduced by 14-19% compared to 4598 kg/ha of the 14-day schedule for Spanco (Table 4).

The effect of using the VA 36-96 programs was significant in reducing leaf spot occurrence on all three cultivars. For Spanco, use of the VA 36 program had the lowest leaf spot incidence (41%), defoliation (24%), and AUDPC (1336) of all VA thresholds tested (Table 1). Uses of the VA 48-96 programs resulted in leaf spot incidence, defoliation percentage, and AUDPC higher than these disease measures of the 14-day schedule and the VA 36 program and lower than these measures of the control (Table 1). Number of sprays made were 3 for the VA 36 program, 2 for the VA 48-72 programs, and 1 for the VA 96 program compared to seven for the 14-day schedule. Yields of 4084-4557 kg/ha for the VA 36-60 programs were similar to 4598 kg/ha of the 14-day schedule and yields for the VA 72 and 96 programs were reduced to 3654-3890 kg/ha (Table 4). Yields correlated well with leaf spot measures. the observed correlation coefficients for yields were 0.73 with leaf spot incidence at harvest, 0.76 with defoliation percentage, and 0.80 with AUDPC.

Uses of the VA 36 and 48 programs had leaf spot incidence of 15-19%, defoliation of 3-5%, and AUDPC of 543-677 that are similar to these measures of the 14-day schedule for Florunner (Table 2). However, use of the VA 36-60 programs resulted in leaf spot incidence of 7-15%, defoliation of 2-7%, and AUDPC of 374-540 for Okrun which were the same as these measures of the 14-day schedule. Uses of the VA 60-96 programs on Florunner and the VA 72 and 96 programs on Okrun resulted in these leaf spot measures higher than those of VA 48 program (Table 2, 3). While yields did not differ between leaf spot treatments, 4 fewer sprays for the VA 36 and 48 programs, 5 fewer sprays for the VA 60 program, and 6 fewer sprays for the VA 72 and 96 programs were made compared to 7 sprays of the 14-day schedule.

AU-Pnut model was tested only in 1993 and scheduled 4 sprays on all three peanut cultivars. Leaf spot incidence of 42%, defoliation of 25%, and AUDPC of 1638 were similar to those of the VA 36 program and were close to those of the 14-day schedule while yield of 4598 kg/ha was the same as that of the 14-day schedule for Spanco. For Florunner and Okrun, use of the AU-Pnut model resulted in leaf spot incidence (11-14%), defoliation (2-3%), and AUDPC (362-633) equal to these measures of the 14-day schedule.

Discussion

Comparison of the performances of leaf spot models over the three-year period resulted in the identification of cultivar-specific thresholds of the Virginia model for the three cultivars. For Spanco, we found that use of the VA 36 program resulted in the lowest leaf spot incidence and AUDPC among all models tested over the three years and a similar yield to that of the 14-day schedule. Hence, VA 36 was the most effective model in terms of leaf spot control. Use of the VA 48 program resulted in similar leaf spot control to those of the VA 36 program in 1992, but less control in 1991 and 1993 while yields were similar to that of the 14-day schedule. Use of the VA 36 and 48 programs resulted in 3.7 and 4.7 fewer sprays over the three years, respectively. Because Spanco is susceptible to early leaf spot and vulnerable to yield loss, the VA 36 program appears to be the least risky model for Spanco.

Early leaf spot did not affect yields on Florunner and Okrun over the three-year period, although leaf spot incidence at harvest reached 56% in 1991 and 70-80% in 1992 and 1993 for the control. This might be that early leaf spot was unable to exceed the disease level of causing yield loss on runner cultivars because of the effect of partial resistance in reducing number of infections, lesion sizes, infection efficiency, sporulation, and delaying leaf spot onset (4, 6, 24). Florunner and Okrun had lower leaf spot incidence and defoliation percentage at harvest in all three years and leaf spot onset was delayed 14 days in 1991, 28 days in 1992, and 19 days in 1993 compared to Spanco. In this study, use of the VA 36 and 48 programs had leaf spot control similar to the 14-day schedule without difference in yields. Test of the VA 60 program in 1992 and 1993 resulted in the leaf spot control equal to the 14-day schedule in one of the two years but not differing in yields in either year. Compared to seven sprays in a season with the 14-day schedule, the reduction in number of sprays was 3.3, 4, and 5 for VA 36, VA 48, and VA 60, respectively. Our study suggested that VA 48 is the optimal program for runner cultivars and it may be possible to extend the threshold to 60 hours and further reduce the number of sprays.

The Jensen and Boyle model was effective in 1991 but failed to schedule any sprays in 1992 and scheduled one spray in 1993. The modified JB models for cultivars with partial resistance failed to schedule any sprays in either year. The utility of the JB model in Oklahoma in scheduling sprays for the control of early leaf spot has been demonstrated on spanish and runner cultivars (4). Damicone et al (4) also found that use of the JB model was less effective on spanish cultivars and suggested a need to develop a better model for spanish cultivars. In this study, however, we found that the JB model was not effective on Spanco in Oklahoma. For Florunner and Okrun, use of the JB model did not result in yield loss. However, leaf spot incidence reached 70-80% at harvest which may exceed the acceptable or tolerant disease level to some growers. Therefore, it would also be risky to use this model on runner cultivars.

The Jensen and Boyle model is based on daily infection indices assigned to the combinations of period of RH≥95% and the minimum temperature during this period (11). Failure of the JB model to schedule adequate sprays in 1992 and 1993 on Spanco were primarily due to the low night temperatures that occurred these years while relative humidity was above 95%. Two-day periods of at least one day with 10 hours of RH≥95% occurred nine times in 1992 and eight times in 1993 from mid-June to mid-September. However, the minimum temperatures during these periods ranged from 48 to 66°F in 1992 which were too low to result in high infection indices. In 1993, there was only once that the minimum temperature was above 70°F which supported high infection indices and hence scheduled one spray.

Arbitrarily using the minimum temperatures may underestimate the overall role of temperature in regulating the hours of high relative humidity necessary for infection by ignoring the cumulative effect of moderate temperatures that favor infection by *C. arachidicola*. Alderman et al (1), based on biological study of *C. arachidicola*, suggested that using the mean temperature rather than minimum temperature may offer greater precision in defining conditions favorable for leaf spot. The less suppression of leaf spot late in the season using the JB model has exposed this defect (16). This study further found that using the JB model could not provide adequate control of early leaf spot even in the early-season and mid-season in Oklahoma because of its failure to schedule sprays in 1992 and only one spray in 1993 along with yield losses on Spanco. Oklahoma has a typical sub-humid continental climate (23) differing largely in day and night temperatures. Long hours of relative humidity above 95% due to rainfall is often accompanied by low night temperatures (below 70°F) which may result in lower infection indices that do not exceed the threshold and hence not trigger spray. This phenomenon becomes apparent late in the season in Oklahoma when night temperatures often fall in the range of 45-67°F from mid-September through October.

The Jensen and Boyle model and the Virginia model differ in accumulating favorable weather conditions for infection. The JB model does not accumulate near favorable condition longer than two days while the Virginia model accumulates infection hours ($RH \geq 95\%$ and $16°C \leq T \leq 30°C$) until reaching the threshold to trigger spray. In 1991, both the JB model and the VA 36 program scheduled three sprays. However, leaf spot incidence (56%), defoliation (24%), and AUDPC (1232) for the JB model were higher than these measures (18%, 3%, and 705) of the VA 36 program. This implied that it was the timing of sprays rather than the number of sprays that determined the effectiveness of sprays to control early leaf spot.

The AU-Pnut model was only tested one year but performed well. Leaf spot control was equivalent to the VA 36 program on all cultivars and with only four sprays in the season. Three of the four sprays coincided with the VA 36 program which suggested that rainfall eventually triggered the VA 36 program. However, AU-Pnut model needs further validation in Oklahoma to demonstrate its utility. Growers may be more willing to use this model by themselves because it requires only a rain gauge to implement.

Commercial peanut cultivars have only partial resistance to early leaf spot (14). Incorporation of partial resistance into leaf spot control program could promote a full utility of both the partial resistance and the leaf spot models used. However, such research was limited and was only done on an empirical basis to extend threshold (9, 13). Results of our dew chamber experiments found that the minimal infection requirements of exposure period to RH≥95% were 24, 36, and 48 hours within the temperature range of 18-30°C for Spanco, Florunner, and Okrun, respectively. The difference in infection requirements results from varying susceptibility to leaf spot among these cultivars and may be an indirect expression of the infection components for these cultivars. Out field study and dew chamber study support each other in that infection thresholds were similar.

In this study, the performance of the leaf spot models were evaluated using the protective fungicide chlorothalonil. Systemic fungicides propiconazole and tebuconazole, both sterol biosynthesis inhibitors (SBI's), have been demonstrated more effective in leaf spot management than chlorothalonil (4). The better effects of these fungicides were likely attributed to the systemic nature and post infection activity (4). It is possible, pending registration of propiconazole and tebuconazole for use on peanut, to improve the level of leaf spot control with leaf spot models.

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Table 1. Comparison of Spray schedules of Chlorothalonil (1.26 kg/ha) on leaf spot incidence, defoliation, and area under the disease progress curve for control of early leaf spot on the peanut cv. Spanco in 1991, 1992, and 1993.

Spray	Leaf spot incidence (%)[2]			Defoliation (%)[2]			AUDPC[3]		
Schedule[1]	1991	1992	1993	1991	1992	1993	1991	1992	1993
Jensen and Boyle	56	100	86	24	91	63	1232	4655	3320
0.85*JB	--	100	96	--	90	69	--	4456	3702
0.70*JB	--	100	--	--	93	--	--	4741	--
AU-Pnut	--	--	42	--	--	25	--	--	1638
VA 36	18	24	41	3	10	24	705	994	1336
VA 48	48	29	57	23	11	43	1381	976	1915
VA 60	--	47	75	--	27	53	--	1475	2400
VA 72	70	89	77	29	67	67	1464	3585	2820
VA 96	60	88	81	22	66	69	1327	3496	2606
14-Day	2	12	13	0	5	4	257	269	457
Untreated Control	66	100	97	29	90	76	1510	4582	4001
$LSD_{P=0.05}$	13	6	9	11	8	6	267	629	388

[1] Modified Jensen and Boyle advisory, 0.85*JB = modified Jensen & Boyle advisory for partially resistant cultivars, AU-Pnut = modified Auburn Peanut Advisory, VA 36-96 = the Virginia advisory with different thresholds of cumulative TDVs of 36-96 hours, 14-Day = conventional full-season schedule.

[2] Final estimations of the percentage of infected leaflets and defoliated leaflets.

[3] The area under the disease progress curve.

Table 2. Comparison of Spray schedules of Chlorothalonil (1.26 kg/ha) on leaf spot incidence, defoliation, and area under the disease progress curve for control of early leaf spot on the peanut cv. Florunner in 1991, 1992, and 1993.

Spray	Leaf spot incidence (%)[2]			Defoliation (%)[2]			AUDPC[3]		
Schedule[1]	1991	1992	1993	1991	1992	1993	1991	1992	1993
Jensen and Boyle	14	76	76	3	14	13	326	2018	2976
0.85*JB	--	82	82	--	17	15	--	2201	3390
0.70*JB	--	78	--	--	15	--	--	1937	--
AU-Pnut	--	--	14	--	--	3	--	--	633
VA 36	2	2	15	0	0	3	77	85	543
VA 48	16	3	19	3	0	5	301	101	677
VA 60	--	17	33	--	3	7	--	576	1391
VA 72	13	21	49	1	3	9	275	686	2116
VA 96	13	61	67	2	8	11	255	1226	2427
14-Day	1	1	6	0	0	1	34	62	221
Untreated Control	56	80	83	14	18	16	790	2016	3595
LSD $_{P=0.05}$	13	11	20	6	7	5	228	451	712

[1] Modified Jensen and Boyle advisory, 0.85*JB = modified Jensen & Boyle advisory for partially resistant cultivars, AU-Pnut = modified Auburn Peanut Advisory, VA 36-96 = the Virginia advisory with different thresholds of cumulative TDVs of 36-96 hours, 14-Day = conventional full-season schedule.

[2] Final estimations of the percentage of infected leaflets and defoliated leaflets.

[3] The area under the disease progress curve.

Table 3. Comparison of Spray schedules of Chlorothalonil (1.26 kg/ha) on leaf spot incidence, defoliation, and area under the disease progress curve for control of early leaf spot on the peanut cv. Okrun in 1992 and 1993.

Spray	Leaf spot incidence (%)[2]		Defoliation (%)[2]		AUDPC[3]	
Schedule[1]	1992	1993	1992	1993	1992	1993
Jensen and Boyle	82	69	19	12	2284	2907
0.85*JB	85	71	21	16	2583	3297
0.70*JB	85	--	19	--	2447	--
AU-Pnut	--	11	--	2	--	362
VA 36	3	7	0	2	151	374
VA 48	4	12	2	5	187	402
VA 60	27	15	6	7	1364	540
VA 72	19	46	5	7	1050	1633
VA 96	73	50	9	12	1568	1592
14-Day	1	2	0	1	44	133
Untreated Control	84	73	21	15	2514	3288
LSD $_{P=0.05}$	8	20	5	4	447	474

[1] Modified Jensen and Boyle advisory, 0.85*JB = modified Jensen & Boyle advisory for partially resistant cultivars, AU-Pnut = modified Auburn Peanut Advisory, VA 36-96 = the Virginia advisory with different thresholds of cumulative TDVs of 36-96 hours, 14-Day = conventional full-season schedule.

[2] Final estimations of the percentage of infected leaflets and defoliated leaflets.

[3] The area under the disease progress curve.

Table 4. Comparison of Spray Schedules of Chlorothalonil (1.26 kg/ha) on number of sprays and pod yields for control of early leaf spot on the peanut cultivars Spanco, Florunner, and Okrun in 1991, 1992, and 1993.

	Number of Sprays[2]			Yield (kg/ha)							
Spray	Spanco (Florunner & Okrun)			Spanco			Florunner			Okrun[3]	
Schedule[1]	1991	1992	1993	1991	1992	1993	1991	1992	1993	1992	1993
Jensen and Boyle	3 (3)	0 (0)	1 (1)	4129	3315	3955	4780	4052	4028	3615	3361
0.85*JB	--	0 (0)	0 (0)	--	3359	3727	--	4143	3849	3665	3523
0.70*JB	--	0 (0)	--	--	3258	--	--	4133	--	3787	--
AU-Pnut	--	--	4 (4)	--	--	4598	--	--	4231	--	3418
VA 36	3 (4)	4 (4)	3 (3)	4272	4540	4557	4740	4480	4337	3410	3808
VA 48	2 (3)	3 (3)	2 (3)	4556	4500	4329	4598	4357	4069	3603	3540
VA 60	--	3 (2)	2 (2)	--	4642	4084	--	4225	3906	3787	3678
VA 72	2 (2)	3 (2)	2 (1)	4476	3583	3654	4516	4195	4183	3288	3222
VA 96	2 (2)	2 (2)	1 (1)	4536	3868	3890	4740	4265	3922	3645	3995
14-Day	7 (7)	7 (7)	7 (7)	4678	4989	4598	4700	4377	3662	3207	3165
Untreated Control	0 (0)	0 (0)	0 (0)	4536	3360	3564	4434	4195	3922	3553	3052
$LSD_{P=0.05}$				835	639	734	437	220	428	477	938

[1] Modified Jensen and Boyle advisory, 0.85*JB = modified Jensen & Boyle advisory for partially resistant cultivars, AU-Pnut = modified Auburn Peanut Advisory, VA 36-96 = the Virginia advisory with different thresholds of cumulative TDVs of 36-96 hours, 14-Day = conventional full-season schedule.

[2] Numbers in parenthesis are spray numbers for Florunner and Okrun.

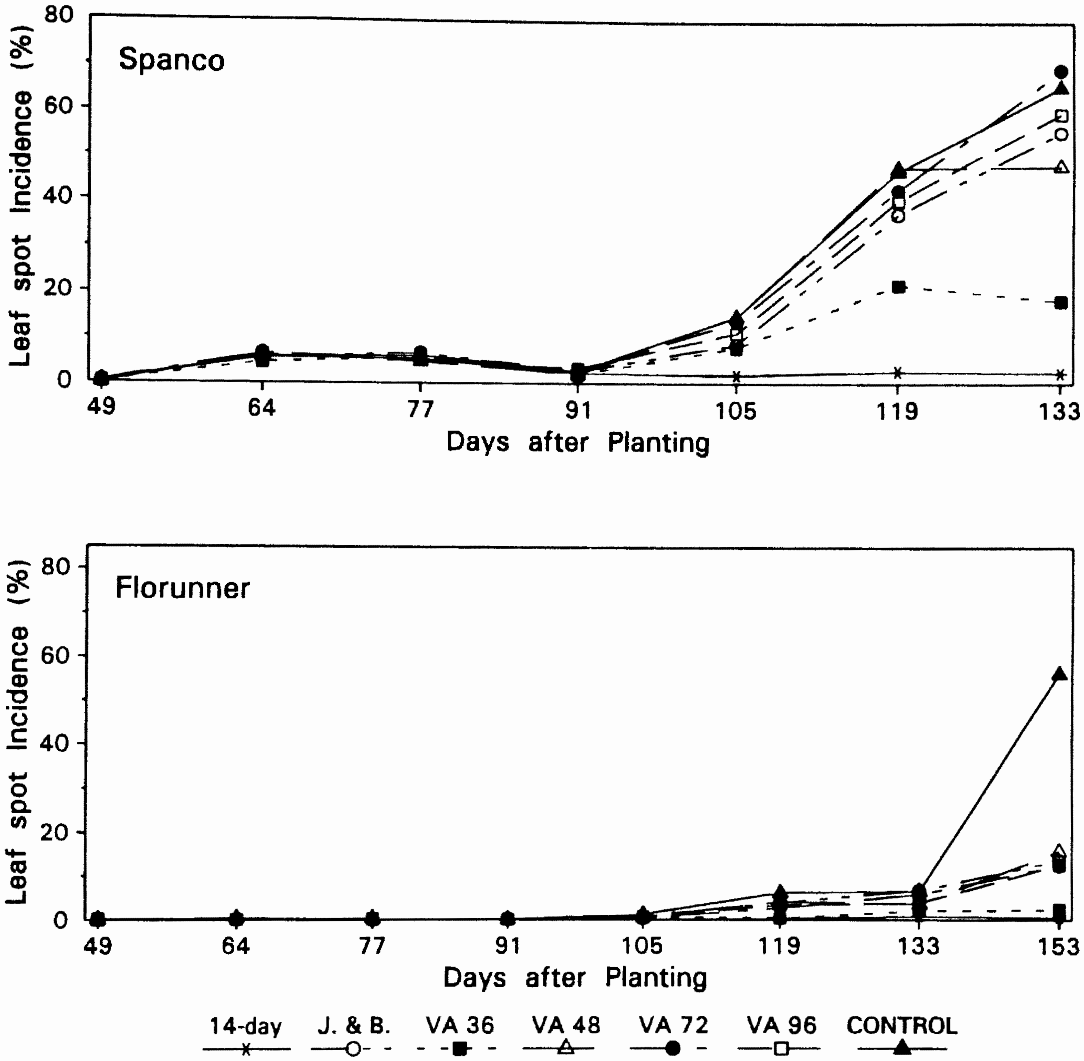


Figure 1. Influence of spray schedule with chlorothalonil (1.26 kg/ha) on progress of early leaf spot in 1991. Data points represent mean leaf spot incidence from four plots per treatment with six subsamples per plot.

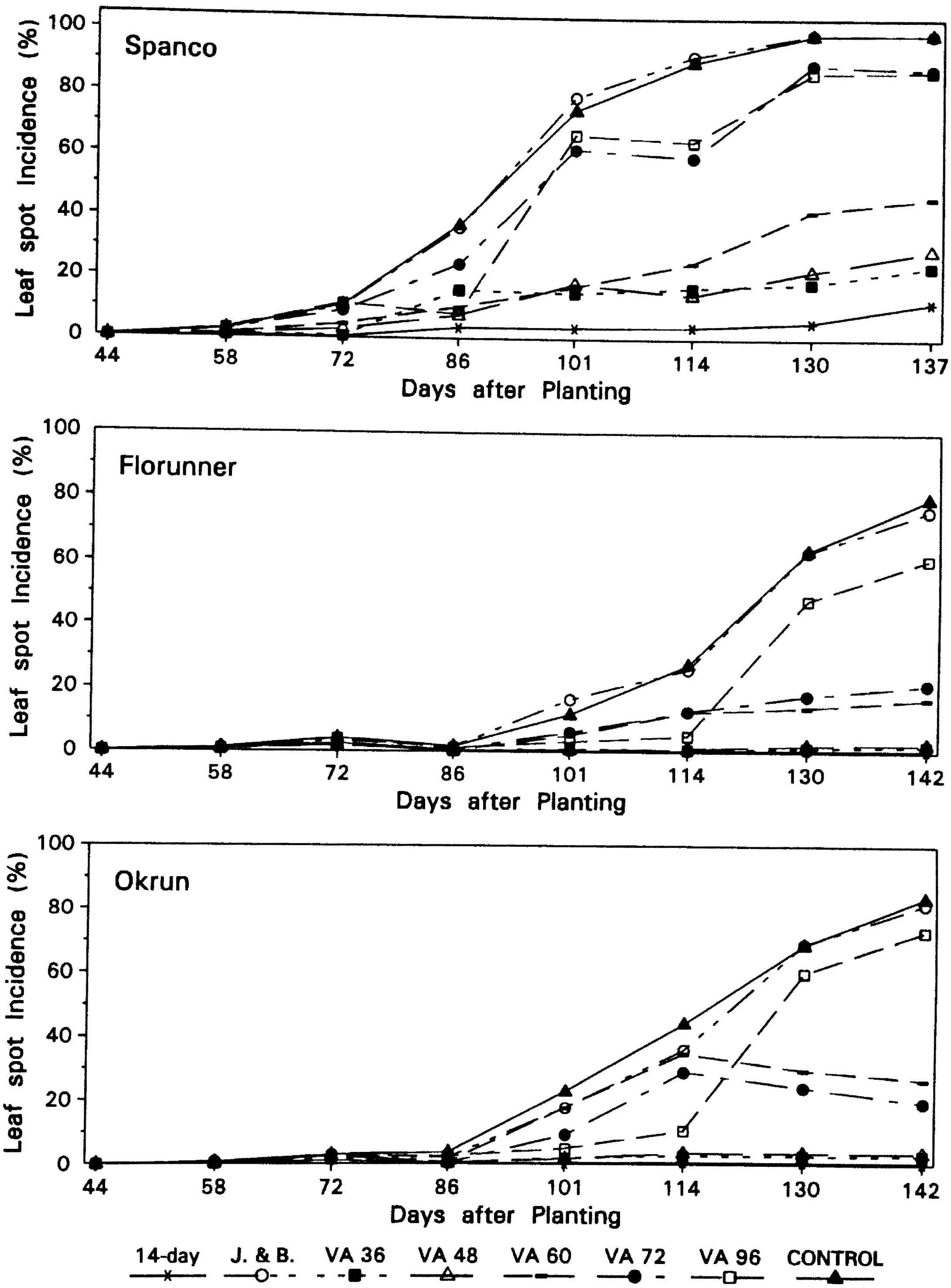


Figure 2. Influence of spray schedule with chlorothalonil (1.26 kg/ha) on progress of early leaf spot in 1992. Data points represent mean leaf spot incidence from four plots per treatment with six subsamples per plot.

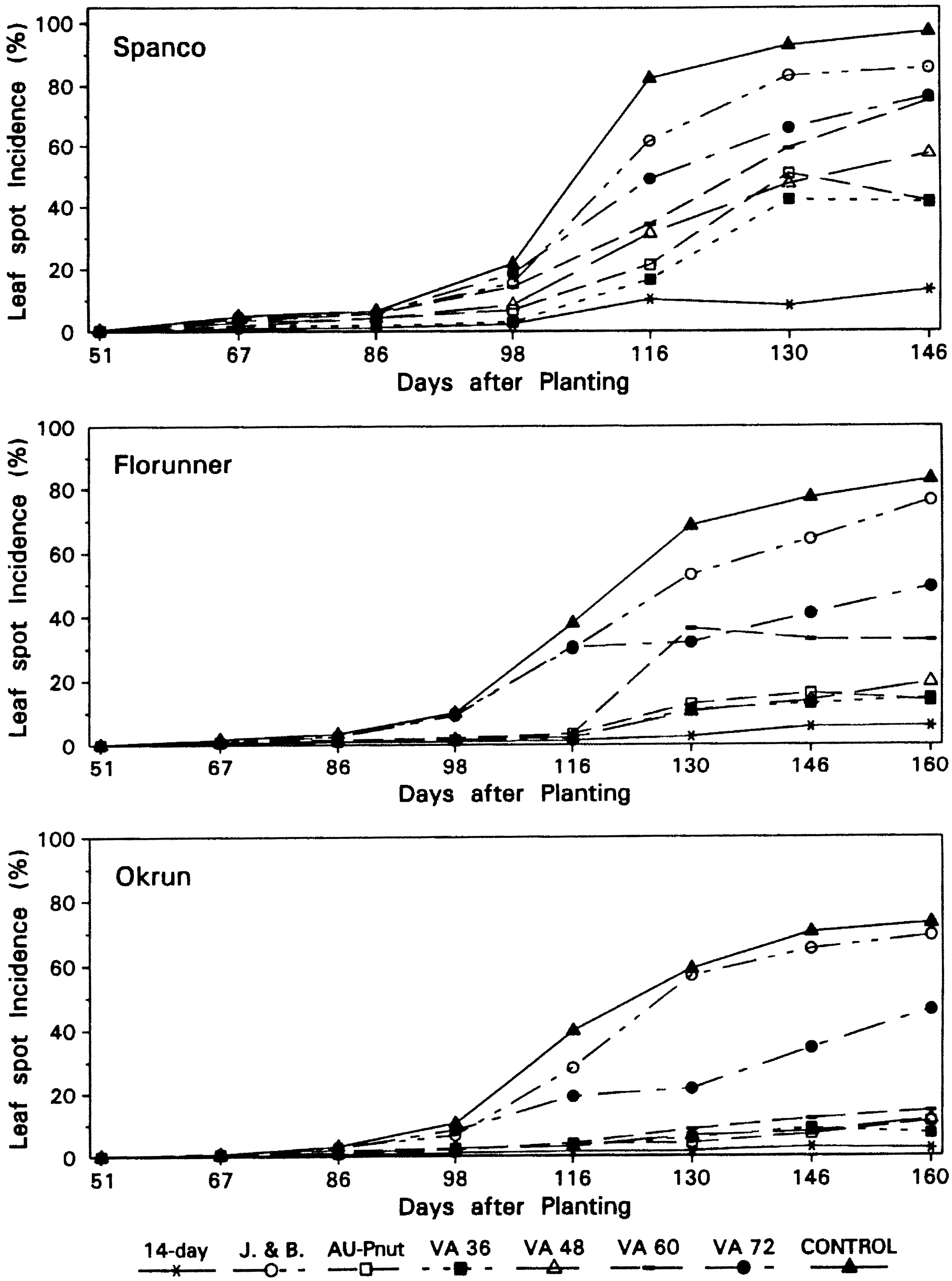
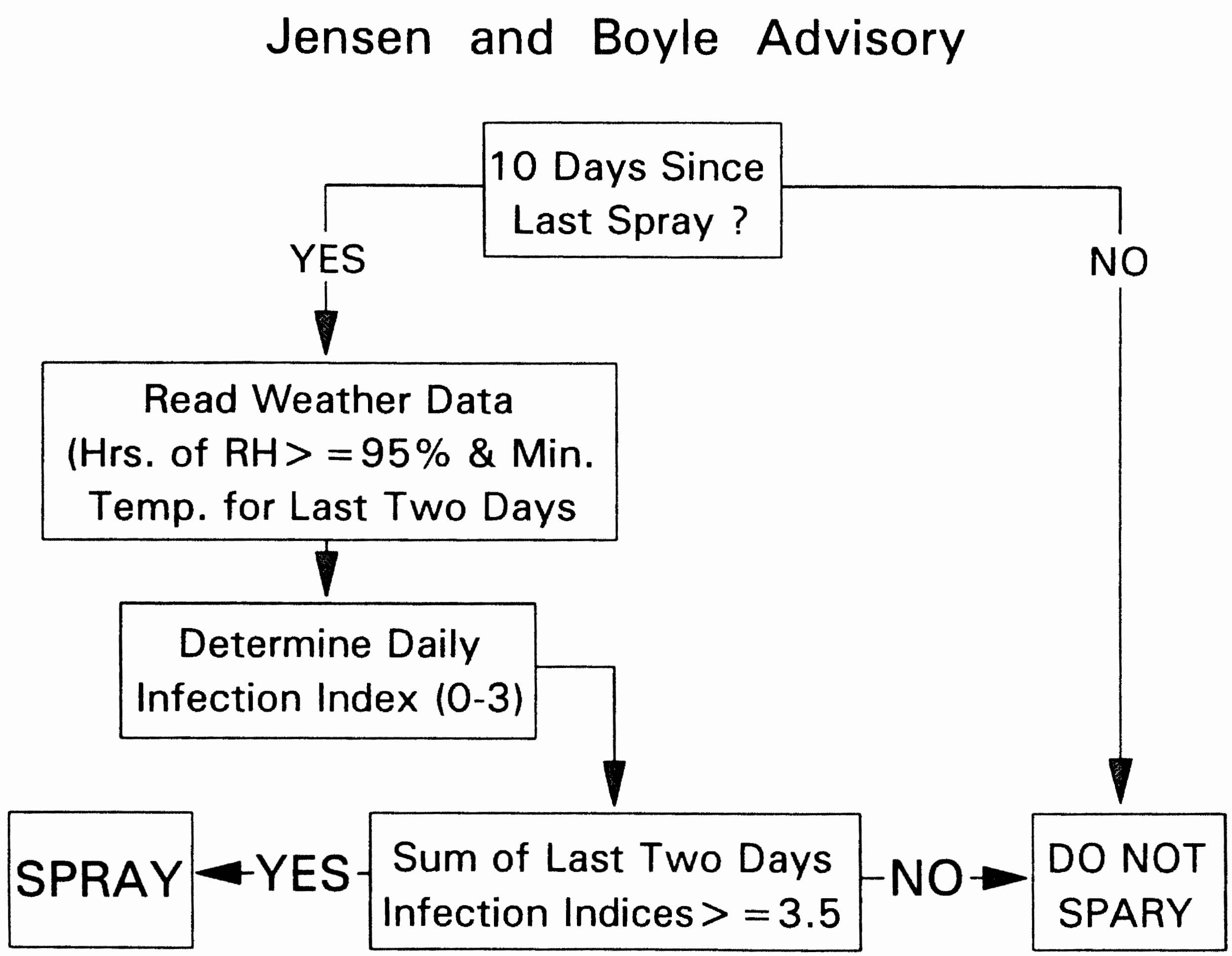


Figure 3. Influence of spray schedule with chlorothalonil (1.26 kg/ha) on progress of early leaf spot in 1993. Data points represent mean leaf spot incidence from four plots per treatment with six subsamples per plot.

APPENDIXES

APPENDIX A. JENSEN AND BOYLE ADVISORY FLOW CHART



APPENDIX B

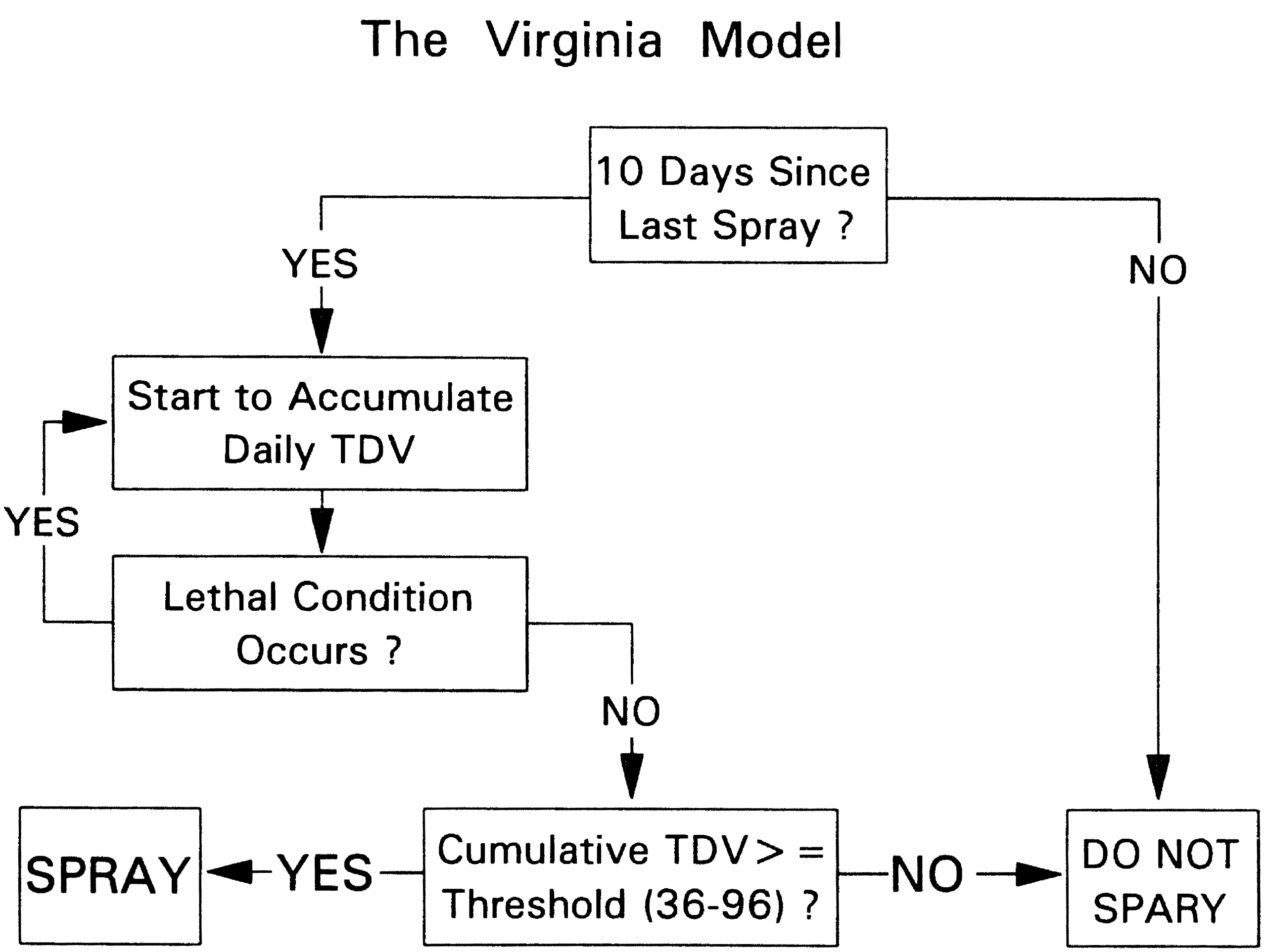
JENSEN AND BOYLE ADVISORY

INFECTION INDEX CHART

LEAFSPOT ADVISORY - CHART TO DETERMINE DAILY INFECTION INDEX

HOURS RELATIVE HUMIDITY > 95%	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
20	0	0	0	1	1.5	2	2.5	3	3	3	3	3	3	3	3	3	3	3	3	3	3
19	0	0	0	1	1.5	2	2	2.5	3	3	3	3	3	3	3	3	3	3	3	3	3
18	0	0	0	1	1	1.5	2	2.5	3	3	3	3	3	3	3	3	3	3	3	3	3
17	0	0	0	0	1	1.5	2	2.5	3	3	3	3	3	3	3	3	3	3	3	3	3
16	0	0	0	0	1	1.5	2	2	3	3	3	3	3	3	3	3	3	3	3	3	3
15	0	0	0	0	1	1	1.5	2	2.5	3	3	3	3	3	3	3	3	3	3	3	3
14	0	0	0	0	0	1	1.5	2	2.5	3	3	3	3	3	3	3	3	3	3	3	3
13	0	0	0	0	0	1	1	1.5	2	2.5	3	3	3	3	3	3	3	3	3	3	3
12	0	0	0	0	0	0	1	1.5	2	2.5	3	3	3	3	3	3	3	3	3	3	3
11	0	0	0	0	0	0	1	1	1.5	2	2.5	3	3	3	3	3	3	3	3	3	3
10	0	0	0	0	0	0	0	1	1	1.5	2	2.5	3	3	3	3	3	3	3	3	3
9	0	0	0	0	0	0	0	0	1	1.5	1.5	2	2.5	3	3	3	3	3	3	3	3
8	0	0	0	0	0	0	0	0	1	1	1.5	1.5	2	2.5	3	3	3	3	3	3	3
7	0	0	0	0	0	0	0	0	0	1	1	1.5	1.5	2	2	2.5	3	3	3	3	3
6	0	0	0	0	0	0	0	0	0	0	0	1	1	1.5	2	2	2	2.5	2.5	2.5	3
5	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1.5	1.5	1.5	2	2	2	2
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1.5	1.5	1.5	1.5
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

MINIMUM TEMERATURE (F)


The Virginia Model
10 Days Since Last Spray ?
YES
NO
Start to Accumulate Daily TDV
YES
Lethal Condition Occurs ?
NO
SPRAY
YES
Cumulative TDV>= Threshold (36-96) ?
NO
DO NOT SPARY

APPENDIX D

MODIFIED AU-PNUT ADVISORY RULES

Timing for the first spray of the season:

Immediately after six or more rain or irrigation events.

Immediately after leaf spot symptoms start being seen.

Timing for subsequent sprays:

Immediately after three rain or irrigation events but not within ten days apart from previous spray.

APPENDIX E

ANALYSIS OF VARIANCE TABLE FOR FIELD STUDY IN 1991

			Mean Square			
Cultivar	Source[a]	df	Leafspot Inci.(%)[b]	Defoliation Inci.(%)[b]	AUDPC[c]	Yield (kg/ha)
Spanco	TRT	8	2395*	640*	8.69×10^5*	2.06×10^5
	BLK	3	218	186*	2.86×10^5*	2.21×10^5
	ERROR	24	85	57	3.35×10^4	3.27×10^5
Florunner	TRT	8	1182*	81*	2.24×10^5*	8.82×10^4
	BLK	3	211	29	6.43×10^4	7.70×10^5*
	ERROR	24	78	15	2.44×10^4	8.97×10^4

* Significant at $P=0.05$.
[a] TRT = leaf spot treatment, BLK = block.
[b] Final estimates at harvest.
[c] The area under the disease progress curve.

APPENDIX F

ANALYSIS OF VARIANCE TABLE FOR FIELD STUDY IN 1992

			Mean		Square	
Cultivar	Source[a]	df	Leafspot Inci.(%)[b]	Defoliation Inci.(%)[b]	AUDPC[c]	Yield (kg/ha)
Spanco	TRT	9	5307*	5651*	1.28×10^{7}*	1.74×10^{6}*
	BLK	3	41	8	1.06×10^{5}	1.32×10^{5}
	ERROR	27	17	29	1.88×10^{5}	1.94×10^{5}
Florunner	TRT	9	5243*	223*	3.18×10^{6}*	6.71×10^{4}*
	BLK	3	65	1	7.21×10^{4}	9.09×10^{4}*
	ERROR	27	52	23	9.66×10^{4}	2.30×10^{4}
Okrun	TRT	9	5884*	317*	4.24×10^{6}*	1.54×10^{5}
	BLK	3	60	31	1.12×10^{6}*	9.53×10^{5}*
	ERROR	27	30	14	9.50×10^{4}	1.08×10^{5}

* Significant at $P=0.05$.
[a] TRT = leaf spot treatment, BLK = block.
[b] Final estimates at harvest.
[c] The area under the disease progress curve.

APPENDIX G

ANALYSIS OF VARIANCE TABLE FOR FIELD STUDY IN 1993

			Mean		Square	
Cultivar	Source[a]	df	Leafspot Inci.(%)[b]	Defoliation Inci.(%)[b]	AUDPC[c]	Yield (kg/ha)
Spanco	TRT	9	2819*	2361*	1.92×10^6*	6.03×10^5*
	BLK	3	4	48*	5.27×10^4	6.34×10^4
	ERROR	27	37	16	2.22×10^4	7.34×10^4
Florunner	TRT	9	3326*	117*	6.64×10^6*	1.25×10^5
	BLK	3	101	3	9.90×10^4	1.39×10^6*
	ERROR	27	42	1	4.59×10^4	6.81×10^4
Okrun	TRT	9	3491*	122*	6.90×10^6*	3.11×10^5*
	BLK	3	56	2	1.36×10^5*	1.97×10^5
	ERROR	27	41	1	3.29×10^4	1.06×10^5

* Significant at $P=0.05$.
[a] TRT = leaf spot treatment, BLK = block.
[b] Final estimates at harvest.
[c] The area under the disease progress curve.

APPENDIX H

Linear regression analysis for the time duration values (TDVs) of the Virginia model vs. leaf spot incidence, defoliation percentage, and area under the disease progress curve (AUDPC).

	Dependent	1991			1992			1993		
	Variable [a]	R^2 [b]	Intercept [c]	Slope [d]	R^2 [b]	Intercept [c]	Slope [d]	R^2 [b]	Intercept [c]	Slope [d]
Spanco	Leaf Spot	0.50	7.56±11.73	0.66±0.17	0.81	-22.07±9.31	1.24±0.14	0.62	27.33±7.87	0.65±0.12
	Defoliation	0.27	3.43±7.50	0.25±0.11	0.78	-33.75±9.29	1.12±0.14	0.80	4.41±5.85	0.75±0.09
	AUDPC	0.25	708.46±248.59	8.11±3.71	0.70	-1058.72±512.82	50.70±7.8	0.60	894.64±295.82	23.19±4.50
Florunner	Leaf Spot	0.08	3.83±6.55	0.11±0.10	0.79	-41.56±7.84	0.99±0.12	0.84	-14.50±5.62	0.83±0.08
	Defoliation	0.01	0.90±1.78	0.01±0.03	0.73	-4.99±1.19	0.13±0.02	0.82	-1.48±0.97	0.14±0.01
	AUDPC	0.09	99.57±118.49	2.02±1.77	0.74	-714.44±183.95	20.02±2.80	0.83	-623.61±233.57	32.91±3.55
Okrun	Leaf Spot				0.80	-46.65±8.82	1.15±0.13	0.76	-24.48±7.31	0.84±0.11
	Defoliation				0.56	-4.10±1.83	0.13±0.03	0.95	-3.72±0.60	0.17±0.01
	AUDPC				0.52	-682.08±369.88	24.78±5.63	0.74	-563.49±227.55	24.74±3.46

[a] Dependent variables are leaf spot incidence and defoliation percentage at harvest and AUDPC.
[b] Coefficient of determination.
[c] Intercept and its standard error for linear regression equation.
[d] Slope and its standard error for linear regression equation.

VITA

Li-Jun Wu

Candidate for the Degree of

Master of Science

Thesis: DEVELOPMENT OF A WEATHER-BASED ADVISORY FOR SCHEDULING FUNGICIDE APPLICATIONS TO MANAGE CERCOSPORA LEAF SPOT OF PEANUT IN OKLAHOMA

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