An Algorithm for Predicting Outbreaks of Sclerotinia Blight of Peanut and Improving the Timing of Fungicide Sprays

D. B. Langston, Jr., Former Graduate Student and currently Assistant Professor, University of Georgia, Coastal Plain Experiment Station, Tifton 31793; **P. M. Phipps**, Professor, Tidewater Agricultural Research and Extension Center, Suffolk, VA 23437; and **R. J. Stipes**, Professor, Department of Plant Pathology, Physiology and Weed Science, Virginia Polytechnic Institute and State University, Blacksburg 24061

ABSTRACT

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Algorithms were evaluated for computing disease risk and improving the timing of fungicide applications for control of Sclerotinia blight of peanut. Disease risk was calculated by multiplying indices of moisture, soil temperature, vine growth, and canopy density each day, and summing values for the previous 5 days to obtain a 5-day risk index (FDI). After fungicide application, the FDI was reset to zero for 3 weeks. Fluazinam at 0.58 kg a.i./ha applied at FDI 24 or 32 in 1994 and 1995 suppressed disease and increased yield as much as or more than programs of weekly scouting and applying fungicide at the initial onset of disease with additional sprays at 3- to 4-week intervals. The FDI algorithm was also more efficient than calendar sprays at 60, 90, and 120 days after planting (DAP). Environmental and host parameters were expanded in 1996 and 1997 by adding new temperature and new vine growth indices. These parameters along with DAP-dependent thresholds consistently improved the timing of fungicide sprays and disease management when using the FDI algorithm in comparison to weekly scouting or calendar sprays at 60, 90, and 120 DAP.

Sclerotinia blight (SB) of peanut (*Arachis hypogaea* L.), caused by *Sclerotinia minor* Jagger, is the most destructive disease of peanut in Virginia, northeastern North Carolina, Oklahoma, and Texas (15,16,22,24,25). According to replicated field trials over 4 years, losses to this disease averaged 33% or 1,598 kg/ha of potential yield in naturally infested fields not receiving fungicide treatment (21). Iprodione, the only registered fungicide for control of this disease, provided only 31% suppression of disease incidence, while similar applications of fluazinam resulted in 69% suppression of disease incidence. Fluazinam was approved in 2000 and 2001 for control of SB of peanut in the above states pursuant to section 18 of the Federal Insecticide, Fungicide and Rodenticide Act. Section 3 registration of fluazinam for disease management in peanut is expected in the fall of 2001 or before spring of 2002.

Moisture, soil temperature, vine growth, and foliar canopy have been implicated in

the onset and progress of SB (1,6-8,11,17). Disease onset usually occurs once lateral limbs are within 15 cm of touching between rows or after vines have overlapped between rows (11). This produces a canopy of dense foliage that restricts air movement and shades the soil surface from direct sunlight. Once these plant growth conditions are met, temperature and the availability of moisture are believed to be the primary determinants of disease onset and progress. A recent study showed that rainfall usually preceded disease onset by 6 to 15 days in nonirrigated fields (11). Maximum and minimum air temperatures over the 15 days prior to disease onset fluctuated between 32 and 20°C, while maximum and minimum soil temperatures were between 30 and 25°C, respectively. Optimum sclerotial germination and infection of peanut by *S. minor* have been reported to be between 20 and 25°C (6). In Texas, *S. minor* was reported to be inactive in peanut fields when soil temperatures exceed 28°C at the 5-cm depth (8). Knowledge of the environmental and host conditions that trigger outbreaks of SB has provided the fundamental building blocks for the development of algorithms to assess disease risk and predict the time of disease onset. Experimental models for predicting the onset of SB have been investigated through cooperative studies in Virginia, North Carolina, Oklahoma, and Texas (2). Fungicide applications based on these models performed as well as or better than the stan-

dard scouting program and showed good potential for improved timing of fungicide applications. The scouting or "demand program" requires that the first fungicide application be made when the symptoms or signs of disease are first detected, with subsequent sprays applied on a 3- to 4-week schedule (12). Until prototypes of the algorithms described herein were released in 1996 (13), weekly scouting and the application of fungicide at the first symptoms or signs of disease were a standard practice.

The objectives of this study were: (i) to evaluate algorithms for assessing risk for outbreaks of SB, and (ii) to increase the efficiency of fungicides through improved timing of applications. Field trials were designed to evaluate the efficacy of fungicides applied according to disease risk as determined by host and environmental parameters.

MATERIALS AND METHODS

Model development. Based on the results of field trials in 1992 (2) and assessments of SB development over a 16-year period (11), an algorithm was developed in 1994 to warn growers of periods of high disease risk and the need for a fungicide application. This warning system used environmental factors and the condition of the host plant for assessing levels of risk for disease (10). Host indices were determined by measuring vine growth and estimating the percentage of the soil shaded by foliar canopy development (Table 1). Growth indices of one or two were assigned when vines were >15 cm or ≤15 cm from touching between rows, respectively. A growth index of three was assigned after vines were overlapping between rows. Plant canopy indices were derived from weekly estimates of the percentage of the soil surface shaded. Foliar canopy indices of one, two, or three were given when <75, ≥75, or ≥95% of the soil surface was shaded, respectively. Environmental indices included rainfall, relative humidity, and soil temperature at the 10-cm depth. A moisture index of one was assigned if accumulated rainfall was ≥1.27 cm in the previous 5 days, ≥2.54 cm in the previous 10 days, or a period of relative humidity (RH) ≥ 95% had occurred for ≥8 h the previous day. Soil temperature indices were three, two, or one when the daily

Corresponding author: D. B. Langston, Jr.
E-mail: dlangsto@arches.uga.edu

Current address: Department of Plant Pathology,
University of Georgia Rural Development Center,
P.O. Box 1209, Tifton 31793

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temperature averaged ≤ 22 , ≤ 25 , or $\leq 28^{\circ}\text{C}$, respectively, at the 10-cm depth. Soil temperature, air temperature, and RH were measured at 15-min intervals using equipment to be described later in this section. Environmental conditions not within these parameters were assigned an index of zero. A 5-day index (FDI) was developed by multiplying the host and environmental indices for a given day, then summing daily indices of the preceding 5 days. After a fungicide application, the indices were set to zero for a 3-week period to reflect the protection interval of the fungicide. This algorithm will hereafter be referred to as the "original algorithm." FDI levels of 16, 24, 32, 40, and 48 were tested as thresholds for initiating fungicide treatments in 1994 and 1995. Reference standards included spray applications at 60, 90, and 120 days after planting, and applications according to the recommended practice of scouting for disease in fields. The later approach is often called the "demand program," because the first fungicide spray is applied at the initial onset of disease.

Using 1995 plant growth data, simulations of new vine indices were evaluated for increasing the role of plant growth as a parameter in determining disease onset. The new vine index used growth indices of one or two when vines were >30 or ≤ 30 cm from touching between rows, respectively, and values of three or four were assigned when vines were ≤ 15 cm from touching or when vines were overlapping between rows, respectively (Table 1). The algorithm with new vine growth indices was evaluated in 1996 and 1997, and hereafter is referred to as the "modified vine algorithm." New environmental parameters in 1996 and 1997 used air temperature along with soil temperature in determinations of disease risk. This algorithm, hereafter called the "modified air-soil temperature algorithm," used either soil or air temperature, according to the parameter which resulted in the highest index. Also tested in 1996 and 1997 was an algorithm that combined vine and temperature parameters to make a "mod. vine/air-soil temp. algorithm." Additional versions of these algorithms used DAP (days after planting)-dependent thresholds. Thresholds included FDI = 16 at ≤ 90 DAP, FDI = 32 at 91 to 120 DAP, and FDI = 64 at >120 DAP to reflect a decrease in susceptibility of peanut tissue with age. In addition to DAP-dependent thresholds, the algorithms were tested with an FDI threshold of 32.

Input data. Environmental data were collected by Envirocaster weather stations (Neogen Corp., Lansing, MI) at each location with the exception of location A, which utilized a Virginia Tech/USDA agro-environmental monitor in 1994 (18). Each weather station monitored daily rainfall and recorded hourly averages of air temperature, soil temperature, dew point, and RH. The status of vine growth and the

foliar canopy was recorded weekly for input into each algorithm.

Weather data were obtained through the Peanut/Cotton InfoNet, which is a web site for extension agents and growers to obtain timely disease advisories and weather data in southeastern Virginia (5,13). Microsoft Excel was used to manage data records, run each algorithm, and determine the need for fungicide application at a given location. Planting dates were recorded and used to determine the timing of fungicide sprays according to a DAP schedule and algorithms with DAP-dependent thresholds.

Field procedures and data analysis. Field trials were planted in soils suited to peanut production in southeastern Virginia and managed according to recommended practices (20,23). Tests were conducted at two sites in 1994 and 1995 and at three sites in 1996 and 1997. Sites used either a peanut-corn or peanut-cotton rotation. All test sites had a history of yield losses to SB. Chlorothalonil at 1.26 kg a.i./ha was applied for control of early leaf spot according to the Virginia leaf spot advisory program (4,13). Locations in 1994 and 1995 were the Tidewater Agricultural Research and Education Center (TAREC) located in Suffolk, VA (location A), and the TAREC research farm (location B). Locations in 1996 were TAREC and the TAREC research farm (locations A and B, respectively) and a commercial farm in Elberon, Surry Co., VA (location C). Locations in 1997 were the Duke farm, which is adjacent to TAREC (location A), a commercial farm in Courtland, Southampton Co., VA (location B), and a commercial

farm in Statesville, Southampton Co., VA (location C). Research methods for field evaluation of fungicides were followed in all trials and consisted of a randomized complete block design with four replications (14). Plots consisted of four rows and were either 10.3 or 10.7 m in length. Fungicide sprays were applied to the two center rows of each plot. All tests used fluazinam at 0.58 kg a.i./ha and iprodione at 1.12 kg a.i./ha. Fungicide applications were made with one 8010LP nozzle centered over each row at a level to provide complete coverage of plants. The sprayer was calibrated to deliver 374 liters/ha at 172 kPa and a ground speed of 6.28 km/h. Adjacent outside rows served as buffer rows. Rows were spaced 0.91 m apart, and seed rates were ca. 123 kg/ha each year. In 1994, location B received 3.8 cm of irrigation on 14 July. The trial at location B in 1995 received 3.8 cm of irrigation on 4 and 25 August. Location A received 2.9 cm of irrigation on 8 September 1997. Irrigation was not required in 1996 due to above-normal rainfall.

Field plots were scouted weekly beginning in mid-June for early detection of disease. Upon detection, disease incidence was recorded as the number of infection foci in the two center rows of each plot. Infection foci exhibited symptoms and/or signs (16) of the disease and included 30.5 cm of row length. Records of disease incidence were used to compute area under the disease progress curve (AUDPC) according to the procedures described by Shaner and Finney (19). Peanuts were dug and harvested from the two center rows of each

Table 1. Environmental and host parameters with corresponding multiplier values used to calculate the risk of Sclerotinia blight of peanut

	Risk index	
	Original algorithm	Modified algorithm
Host parameters ^y		
Vine growth		
Vines >30 cm from touching	1	1
Vines >15 cm from touching	1	2
Vines ≤ 15 cm from touching	2	3
Vines overlapping between rows	3	4
Plant canopy density		
$<75\%$ of soil surface shaded	1	1
$\geq 75\%$ of soil surface shaded	2	2
$\geq 95\%$ of soil surface shaded	3	3
Environmental parameters		
Available moisture		
Rainfall ≥ 1.27 cm over previous 5 days	1	1
Rainfall ≥ 2.54 cm over previous 10 days	1	1
RH $\geq 95\%$ for ≥ 8 h per day	1	1
Conditions otherwise	0	0
Air and soil temperature ^z		
$\leq 22^{\circ}\text{C}$	3	3
$\leq 25^{\circ}\text{C}$	2	2
$\leq 28^{\circ}\text{C}$	1	1
$>28^{\circ}\text{C}$	0	0

^y Determined by weekly assessments.

^z Indices for both air and soil temperature are daily averages from 15-min readings. Soil readings were from probes buried 10 cm under managed turf adjacent to field sites. Soil temperature parameters were part of the original algorithm, while air and soil temperature were included in the modified algorithm.

plot with commercial equipment modified to collect yield data from each plot. Yield weights were adjusted to a moisture content of 7% (wt/wt). The analysis of disease incidence at harvest (DIH), AUDPC, and yield utilized the Waller-Duncan *k*-ratio *t* test at *k* = 100 (*P* ≤ 0.05) using general linear models (PROC GLM) of SAS (SAS Institute, Cary, NC).

RESULTS

1994 Field tests. The 1994 growing season provided near-optimum conditions for peanut production, with state average yields approaching the record level of 3,587 kg/ha. Rainfall was only 60% of normal (60.7 cm) for the entire growing season (May–September), but levels in July were 5.1 and 7.5 cm above normal at locations A and B, respectively. The initial outbreak of SB was detected on 29 July (91 and 88 DAP for locations A and B, respectively) at both locations after vines had overlapped between rows. This outbreak followed ca. 15 cm of rainfall that occurred between 17 and 27 July at both locations. Mycelium of the causal fungus was visible beneath the dense plant canopy at both locations with only a few peanut

limbs showing initial symptoms. Disease outbreaks in 1994 occurred close to the reported mean of 28 July and median of 25 July for the period from 1978 to 1993 (11). Disease progress increased to yield-damaging levels by the time of harvest at both locations. Graphs depicting seasonal FDI levels and disease incidence in nontreated plots at both locations in 1994 illustrated the manner in which the original algorithm may serve as a warning system for disease (Fig. 1). Irrigation at location B on 14 July (73 DAP) enhanced plant growth and allowed row closure 6 days earlier than at location A. Higher FDI levels at location B in August and September were the result of lower soil temperatures, which were thought to favor a more rapid rate of disease development compared with location A.

Data across years and locations could not be combined for any year due to significant interactions. Therefore, all data from each location within each year are presented separately. At location A in 1994, the application of fungicide at FDI thresholds of 16, 24, and 32 had to be delayed until 93 DAP due to rainfall and saturated soil conditions. The first spray at FDI

thresholds of 40 and 48 was applied on 94 and 100 DAP, respectively. The demand program resulted in the first spray being applied on 96 DAP when disease symptoms were beginning to show from above the plant canopy. Higher FDI levels at location B resulted in the initial spray of fungicide at FDI 16 and 24 being applied on 80 and 83 DAP, respectively, which was prior to any visible signs of disease (Fig. 1). Sprays applied according to FDI thresholds of 32 and 40 were applied on 87 and 91 DAP at location B, respectively. Sprays at the FDI 48 threshold and the first appearance of symptoms were applied on 97 DAP. The first spray of the 60, 90, 120 DAP program was applied at 31 and 30 days prior to initial symptoms and signs of disease at locations A and B, respectively. Three sprays were applied according to the 60, 90, 120 DAP program at both locations and according to the FDI 16 and 24 thresholds at location B. All of the other programs at both locations required only two sprays.

The 60, 90, 120 DAP program and the original algorithm with thresholds ranging from 16 to 40 performed as well as or better than the conventional demand program and resulted in significant suppression of DIH and AUDPC, while significantly increasing yield at both locations in 1994 (Table 2). The FDI 32 threshold resulted in sprays being applied on or about the time of disease onset at both locations, and the number of applications was one less than with FDI thresholds of 16 and 24 at location B only. Based on these results, the FDI 32 threshold was believed to offer the most efficient use of fungicide for disease control and yield improvement in 1994.

1995 Field tests. Overall, the 1995 growing season was hot and dry compared with previous years in southeastern Virginia. Locations A and B had rainfall deficits of 12.1 and 20.2 cm, respectively, below the 63-year mean (60.5 cm) for the period from May through September. SB was detected on 56 DAP at location A. Until this time, the original algorithm had reached an FDI of 10; an FDI ≥ 32 was not reached until 67 DAP (Fig. 2A). From 57 DAP to 69 DAP, disease incidence increased and then showed almost no change through 130 DAP. Thereafter, levels of FDI ≥ 32 occurred consecutively for 14 days prior to harvest on 143 DAP. Disease onset was not detected until 120 DAP at location B. Following the first irrigation, disease risk reached the FDI of 32 on 99 DAP, but returned to zero on 104 DAP. Disease risk reached the FDI 32 threshold again following the second irrigation and maintained a high level through much of the period before harvest. Disease did not reach damaging levels at location B in 1995, which may have been a result of reduced vine growth and possibly lower soil inoculum in comparison to location A.

All spray programs at location A in 1995 required three fungicide applications (Ta-

Fig. 1. Relationship of the 5-day index (FDI) to the onset and development of Sclerotinia blight of peanut at locations A and B in 1994. Bars represent the 5-day risk index, while the dotted lines and markers represent disease progress.

ble 2). The 60 DAP spray was applied 2 days after disease onset, while plots sprayed according to a demand program were treated on the same day as disease onset. Sprays according to FDI thresholds of 16, 24, and 32 were applied 13 days (71 DAP) subsequent to disease onset. The FDI thresholds of 40 and 48 were not sprayed until 35 days (91 DAP) after disease onset. At location B, the FDI 16 threshold required a total of three fungicide applications. The first fungicide spray was applied on 76 DAP or 43 days before any symptoms or signs of disease. At FDI thresholds of 24 and greater, two fungicide applications were made in 1995. The initial application using thresholds of FDI 24 and 32 was made on 100 DAP or 20 days prior to disease onset. FDI thresholds of 40 and 48 triggered the first spray on 101 DAP. The 60 and 90 DAP applications were applied prior to disease onset, and the 120 DAP application was applied when disease was first detected as small lesions on stems at the soil surface. The first and only application according to the demand program was applied on 142 DAP, when disease symptoms were visible in the upper plant canopy.

Treatments according to the 60, 90, 120 DAP and demand programs in 1995 resulted in significant suppression of DIH, AUDPC, and a corresponding increase of yield at location A compared with the nontreated check (Table 2). Applications according to the original algorithm at thresholds ranging from 16 to 48 also gave significant disease suppression and a significant increase of yield. However, sprays according to the FDI 48 threshold yielded significantly lower than treatments applied according to other FDI thresholds and the 60, 90, 120 DAP program. Disease incidence was low throughout the growing season at location B, and differences were not significant in comparisons of fungicide-treated and nontreated plots.

Simulations of algorithms with modified vine indices and the addition of air temperature parameters were evaluated to identify changes that might improve the performance of algorithms. The results indicated that these factors and the addition of DAP-dependent thresholds for fungicide treatment would improve the sensitivity of the model to favorable conditions for disease (Fig. 2). The air temperature parameter increased disease risk at times when cooler air temperatures may have an overriding effect on soil temperature (Fig. 2B). Modified vine indices increased the algorithm's sensitivity to the progression of vine growth through the season. When these changes were combined, the simulations indicated that a modified vine/air-soil temperature algorithm would offer a superior warning of disease risk to the original algorithm. Using this algorithm, the FDI 32 threshold would have been reached on 3 July or the day before disease onset.

1996 Field tests. Cool and wet conditions were experienced during the 1996 growing season, with rainfall totals of 5.8, 16.3, and 4.0 cm above normal (60.7 cm) for locations A, B, and C, respectively. Vine growth was excessive at locations A and B, while location C showed considerably less growth due to a 2.2-cm deficit of rainfall in June compared with 0.1 and 0.5 cm above normal (10.9 cm) at locations A and B. Disease onset was initially detected at locations A and B on 64 and 67 DAP, respectively, following heavy precipitation from Hurricane Bertha. Disease onset was delayed at location C until 82 DAP, which may be attributed to reduced vine growth.

Disease risk surpassed the FDI 32 threshold of the original algorithm on 70 and 74 DAP at locations A and B, respectively. Thereafter, disease risk remained high through the remainder of the growth season. Location C did not encounter these high levels of disease risk until the end of July when vine growth began to cover the

soil surface. Thereafter, conditions at location C were favorable for SB as illustrated by disease progress in August and September (Fig. 3). Field tests in 1996 included the original model and the modified vine and air-soil temperature algorithms as simulated after the 1995 season.

All programs called for three fungicide applications at locations A and B (Table 3). DAP-dependent thresholds for the air-soil temperature, modified vine, and modified vine/air-soil temperature algorithms called for three sprays at location C. Other fungicide programs called for just two sprays at location C. The original FDI 32 and the air-soil temperature algorithms triggered the initial fungicide applications 9 and 7 days subsequent to disease onset at location A, and 8 and 6 days subsequent to disease onset at location B, respectively. All other algorithms called for the initial fungicide application 1 day prior to disease onset at locations A and B. The 60 DAP treatment in the calendar program was

Table 2. Sclerotinia blight disease and yield data from treatments using a 5-day index (FDI) algorithm with different thresholds, a days after planting (DAP) calendar-based program, and a scouting-based demand program for timing sprays of fluazinam in 1994 and 1995

Year, location, spray program	Spray DAP	DIH ^a	AUDPC ^w	Yield(kg/ha) ^x
1994, TAREC				
FDI 16	93 ^y , 118	15.3 b ^z	659 c	2,916 b
FDI 24	93, 118	12.3 bc	503 cd	3,343 ab
FDI 32	93, 118	11.5 bc	511 cd	3,446 ab
FDI 40	94, 122	14.3 b	706 c	2,872 b
FDI 48	100, 130	26.5 a	1,312 b	2,047 cd
Calendar (ca. 60, 90, 120 DAP)	60, 90, 114	7.3 c	228 d	3,991 a
Demand + 4 wk + 4 wk	96, 130	15.8 b	661 c	2,768 bc
Nontreated check	—	31.3 a	1,698 a	1,517 d
1994, TAREC research farm				
FDI 16	80, 107, 133	19.3 d	592 d	4,841 ab
FDI 24	83, 107, 133	18.8 d	583 d	5,468 a
FDI 32	87, 115	23.8 cd	827 cd	5,240 a
FDI 40	91, 115	15.5 d	527 d	5,283 a
FDI 48	97, 126	31.8 bc	1,114 bc	4,784 ab
Calendar (ca. 60, 90, 120 DAP)	59, 91, 121	25.3 cd	723 cd	5,311 a
Demand + 4 wk + 4 wk	97, 126	36.0 ab	1,327 b	4,528 b
Nontreated check	—	45.5 a	1,815 a	3,090 c
1995, TAREC				
FDI 16	70, 92, 111	5.3 c	700 c	4,496 a
FDI 24	70, 92, 111	9.0 bc	1,074 bc	4,669 a
FDI 32	70, 92, 111	9.8 bc	1,024 bc	4,525 a
FDI 40	92, 112, 134	10.3 bc	919 bc	4,554 a
FDI 48	92, 114, 134	14.0 b	1,132 b	3,804 b
Calendar (ca. 60, 90, 120 DAP)	59, 92, 122	9.8 bc	859 bc	4,611 a
Demand + 3 wk + 3 wk	57, 78, 99	11.5 bc	750 bc	4,179 ab
Nontreated check	—	34.8 a	1,722 a	2,695 c
1995, TAREC research farm				
FDI 16	77, 100, 120	2.3 a	58 a	5,500 a
FDI 24	100, 119	1.5 a	25 a	4,917 a
FDI 32	100, 119	2.0 a	59 a	5,292 a
FDI 40	101, 120	3.0 a	108 a	5,458 a
FDI 48	101, 127	2.3 a	39 a	5,306 a
Calendar (ca. 60, 90, 120 DAP)	60, 91, 120	3.3 a	62 a	5,056 a
Demand + 3 wk + 3 wk	142	9.0 a	216 a	4,847 a
Nontreated check	—	10.0 a	215 a	4,667 a

^a Disease incidence at harvest (DIH) = counts of disease foci in the two center rows of each plot.

^w Area under the disease progress curve (AUDPC).

^x Yields are based on weight of peanuts with 7% moisture (wt/wt).

^y FDI thresholds of 16, 24, and 32 had to be delayed until 93 DAP due to rainfall and saturated soil conditions.

^z Means in a column with letter(s) in common and within the same year are not significantly different according to the Waller-Duncan *k*-ratio *t* test at *k* = 100 (*P* ≤ 0.05).

Fig. 2. Relationship of the 5-day index (FDI) to the onset and development of *Sclerotinia* blight of peanut as determined by the A, original, B, air-soil temp., C, modified vine, and D, modified vine/air-soil temp. FDI algorithms at location A in 1995. Bars represent the 5-day risk index, while the dotted lines and markers represent disease progress.

applied 4 days prior to disease onset at location A, while the initial treatment according to the demand program was applied 3 days after disease onset at locations A and B.

At location C, the air-soil temperature and modified vine/air-soil temperature algorithms showed the highest sensitivity to disease risk and resulted in fungicide treatment 7 days ahead of disease onset (Fig. 3). Sprays according to the DAP-dependent version of the modified vine and the modified vine/air-soil temperature algorithms were applied 6 days prior to disease onset at location C. The modified vine/air-soil temperature algorithm with an FDI 32 threshold was also treated 6 days prior to disease onset at location C. The first fungicide application for all other algorithms was made 7 days subsequent to disease onset. The initial treatment according to the demand program was applied 15 days after the first occurrence of wilt symptoms. The decision to delay treatment was made on the basis of only a few small lesions on stems at the soil surface and the unlikelihood of detection by scouts until the terminals of one or more branches exhibited the first symptoms of wilt. The approach has been a common practice with scouting programs because of the absence of wilt symptoms and because little or no mycelial growth is visible under the plant canopy.

All fungicide programs significantly suppressed DIH and AUDPC at locations A and B compared with nontreated plots (Table 3). Sprays according to the air-soil temperature, modified vine, and modified vine/air-soil temperature algorithms with DAP-dependent thresholds resulted in significant suppression of DIH and AUDPC at location C when compared with the demand program and the nontreated check. No significant yield differences were detected at location A. All spray programs significantly improved yield compared with the nontreated check at locations B and C.

1997 Field tests. Cool and extremely dry conditions prevailed in the 1997 growing season. Locations A and B experienced below-normal precipitation in May, June, August, and September, while July was 12.2 and 2.5 cm above normal (60.5 cm), respectively, for both locations. Below-normal rainfall was also experienced in May (9.6 cm), June (10.8 cm), and August (14.6 cm) at location C, while July and September were 3.3 and 0.5 cm above normal (15.0 and 10.4 cm, respectively). Disease onset was detected on 4 August (90 DAP at location A and 86 DAP at locations B and C) across all locations within 13 days of rain accumulations of 7.8, 11.9, and 16.4 cm at locations A, B, and C, respectively.

Variability in precipitation between test locations probably accounted for differ-

ences in disease risk at each location. Disease progress was rapid at all locations due to the occurrence of conditions favorable for disease development in mid- to late-August. Conditions remained favorable for disease at location B throughout the rest of the season, while locations A and C experienced a period of unfavorable conditions in early September. The modified algorithms reached threshold levels for fungicide application just prior to the detection of disease onset, whereas the original algorithm did not reach threshold levels until 2 days after disease onset at location B (Fig. 4).

With the exception of the original FDI 32 algorithm, which triggered only two sprays, all models called for three sprays at locations A and B (Table 4). At location C, the original FDI 32, the air-soil temperature, and the modified vine algorithms with DAP-dependent thresholds called for only one spray at location C, while the mod. vine/air-soil temperature algorithm with DAP-dependent thresholds resulted in three sprays. The original FDI 32 algorithm using DAP-dependent thresholds called for no fungicide applications at location C. Three sprays were applied according to the demand program and the 60, 90, 120 DAP program at all locations. Algorithms using DAP-dependent thresholds consistently triggered fungicide applications earlier than algorithms using an FDI 32 threshold in 1997.

At location A, sprays applied according to each algorithm reduced disease as effectively as the 60, 90, 120 DAP and demand programs (Table 4). At location B, treatments applied according to algorithms using DAP-dependent thresholds reduced disease similarly to the demand program and reduced AUDPC significantly below that of the 60, 90, 120 DAP program and the original FDI 32 algorithm. The most significant reductions in DIH at location C were observed when sprays were applied according to the mod. vine/air-soil algorithm with DAP-dependent thresholds, the 60, 90, 120 DAP calendar program, and the demand program. No significant differences were detected in AUDPC. All fungicide treatments increased yield significantly at location A compared with the nontreated plots. Except for the 60, 90, 120 DAP program, all fungicide treatments at location B gave significantly greater yield than the nontreated check. The air-soil temperature algorithm and the modified vine/air-soil temperature algorithm with DAP-dependent thresholds significantly improved yield at location C. Yields were also improved significantly by the 60, 90, 120 DAP program and the demand program at location C.

DISCUSSION

The FDI algorithm uses environmental factors, vine growth, and plant canopy

Fig. 3. Relationship of the 5-day index (FDI) to the onset and development of Sclerotinia blight of peanut as determined by the A, original, B, air-soil temp., C, modified vine, and D, modified vine/air-soil temp. FDI algorithms at location C in 1996. Bars represent the 5-day risk index, while the dotted lines and markers represent disease progress.

indices to assess risk for SB. Like environmental factors (6,8,11), vine growth and canopy density have been demonstrated to have an important role in disease development (1,7,11). Fungicides for control of SB have been shown to be more effective when applied in a preventive manner (3,26). While the original FDI 32 algorithm improved the timing of fungicide sprays and enhanced the efficiency of scouting for disease, it often failed to trigger applications prior to disease onset or at the initial onset of disease. While scouting has augmented the utility of the FDI 32 algorithm, it may not indicate a fungicide application during the initial period of risk, and significant losses in yield may still occur. As a result, the first application of fungicide has frequently been applied at disease onset or later when crop damage has already occurred. Prior to introduction of the FDI 32 algorithm, the demand program, as the scouting program is called, recommended sprays be repeated at 21- to 28-day intervals. Like the 60, 90, 120 DAP program, this approach created the potential for needless applications during times

unfavorable for disease development. Results from the 1994 field trials indicated that the original FDI 32 algorithm offered the opportunity for minimizing fungicide input while maintaining high yield by controlling disease as well as or better than a 60, 90, 120 DAP program or the demand program.

Disease onset in 1995 occurred 13 days prior to the 16, 24, and 32 thresholds of the original FDI algorithm at location A. In spite of this delay, disease control was not compromised as all algorithms performed similarly to the demand program, which received the initial fungicide application on the day of disease onset. This was due, in part, to the lack of favorable environmental conditions for disease progress from 1 August until 16 September. Also, algorithm thresholds triggered sprays in August and September which provided fungicide protection only during periods of high risk, thus providing more efficient fungicide use. Sprays applied according to the 60, 90, and 120 DAP schedule performed well due to the serendipitous placement of fungicide applications. In contrast to location

A, disease pressure was low at location B in 1995 and fungicide applications failed to provide significant disease suppression or increases of yield.

The 1996 growing season provided ideal environmental conditions for testing fungicide spray programs for control of SB. This was the first year of testing modified FDI algorithms with air temperature parameters, expanded vine indices, and DAP-dependent thresholds. All test locations averaged above normal rainfall for the peanut growing season, and correspondingly high levels of disease risk and SB were observed. All of the modified FDI algorithms with air temperature parameters, expanded vine indices, and/or DAP-dependent thresholds resulted in initial fungicide applications being applied prior to or on the same day of disease onset. At location C, algorithms with DAP-dependent thresholds increased yield an average of 1,098 kg/ha compared with the original FDI 32 algorithm. This was likely the result of the increased number of fungicide applications and greater precision in timing

Table 3. Sclerotinia blight disease and yield data from treatments using a 5-day index (FDI) algorithm with different disease risk parameters and thresholds, a days after planting (DAP) calendar-based program, and a scouting-based demand program for timing sprays of fluzinam in 1996

Location and spray program	Spray DAP	DIH ^y	AUDPC ^w	Yield (kg/ha) ^x
Location A – TAREC (nonirrigated)				
Original FDI 32	73, 100, 126	18.8 b ^y	735 bc	2,100 a
Original w/DAP-dependent threshold ^z	63, 86, 113	11.5 bc	339 d	2,625 a
Air-soil temp. FDI 32	71, 94, 119	12.8 bc	882 b	2,284 a
Air-soil temp. w/DAP-dependent threshold	63, 85, 113	10.8 c	473 cd	2,157 a
Mod. vine FDI 32	63, 86, 113	11.8 bc	437 cd	2,015 a
Mod. vine w/DAP-dependent threshold	63, 86, 113	16.3 bc	494 cd	2,100 a
Mod. vine/air-soil temp. FDI 32	63, 86, 113	15.5 bc	604 b-d	2,398 a
Mod. vine/air-soil temp. w/DAP-dependent threshold	63, 86, 113	16.3 bc	550 cd	2,526 a
Calendar (ca. 60, 90, 120 DAP)	60, 91, 121	18.5 bc	865 b	1,987 a
Demand + 3 wk + 3 wk	67, 119, 137	11.5 bc	506 cd	2,256 a
Nontreated check	–	33.8 a	1,830 a	1,831 a
Location B – TAREC research farm (nonirrigated)				
Original FDI 32	75, 98, 125	27.8 bc	1,591 b	4,705 a
Original w/DAP-dependent threshold	84, 90, 116	23.8 bc	1,217 bc	5,003 a
Air-soil temp. FDI 32	73, 96, 122	20.3 c	1,022 c	4,833 a
Air-soil temp. w/DAP-dependent threshold	84, 89, 116	29.0 bc	1,419 bc	4,280 ab
Mod. vine FDI 32	84, 89, 116	30.3 b	1,302 bc	4,663 a
Mod. vine w/DAP-dependent threshold	84, 90, 116	21.5 bc	996 c	4,677 a
Mod. vine/air-soil temp. FDI 32	84, 89, 116	27.3 bc	1,405 bc	4,592 ab
Mod. vine/air-soil temp. w/DAP-dependent threshold	84, 89, 116	29.3 bc	1,409 bc	4,606 ab
Demand + 3 wk + 3 wk	88, 89, 110	24.0 bc	1,103 bc	3,699 b
Nontreated check	–	49.8 a	3,007 a	2,367 c
Location C – Elberon, Surry Co., VA (nonirrigated)				
Original FDI 32	88, 118	28.5 bc	1,378 a-c	4,912 bc
Original w/DAP-dependent threshold	88, 116	22.0 b-d	1,044 b-d	5,265 a-c
Air-soil temp. FDI 32	88, 116	34.0 ab	1,688 ab	4,521 c
Air-soil temp. w/DAP-dependent threshold	75, 97, 123	14.8 cd	672 cd	6,028 ab
Mod. vine FDI 32	88, 118	33.7 ab	1,700 ab	4,410 c
Mod. vine w/DAP-dependent threshold	76, 102, 126	9.3 d	451 d	6,159 ab
Mod. vine/air-soil temp. FDI 32	76, 98, 126	14.0 cd	655 cd	5,600 a-c
Mod. vine/air-soil temp. w/DAP-dependent threshold	75, 97, 123	6.7 d	400 d	6,382 a
Demand + 3 wk + 3 wk	97, 116	30.3 ab	1,635 ab	4,968 bc
Nontreated check	–	45.3 a	2,126 a	2,135 d

^y Disease incidence at harvest (DIH) = counts of disease foci in the two center rows of each plot.

^w Area under the disease progress curve (AUDPC).

^x Yields are based on weight of peanuts with 7% moisture (wt/wt).

^y Means in a column with letter(s) in common and within the same year are not significantly different according to the Waller-Duncan *k*-ratio *t* test at *k* = 100 (*P* ≤ 0.05).

^z DAP-dependent thresholds are FDI = 16 ≤ 90 DAP, FDI = 32 ≤ 120 DAP, and FDI = 64 > 120 DAP.

sprays during periods favorable for disease development.

Cool and dry conditions in 1997 did not allow for a continuation of high risk after disease onset. As demonstrated in 1996, the DAP-dependent algorithms resulted in sprays being applied earlier than those of the original FDI 32 algorithm and demonstrated a trend toward improved disease control and yield. At location C, reduced vine growth delayed the development of SB and resulted in a low disease risk until late in July. Compared with other locations, the number of fungicide sprays at location C was reduced by all algorithms with the exception of the modified vine/air-soil temperature algorithm with DAP-dependent thresholds. This algorithm was the most sensitive to changes in host and environmental conditions. The original FDI algorithm with DAP-dependent thresholds did not trigger a fungicide application due to its reduced sensitivity to environmental and host parameters and due to the high FDI threshold imposed at >120 DAP. Spray programs calling for fungicide applications on or prior to 25 August performed similarly at location C in 1997.

A program similar to the Virginia Leaf Spot Advisory (4) is needed to provide an early warning system to growers in advance of outbreaks of SB of peanut. This would be a valuable addition to programs that provide prescription strategies for disease management in peanuts (9). Results from 1994 and 1995 suggested that the original FDI 32 algorithm with thresholds of 16, 24, and 32 can perform as well as or better than the currently used demand program. Disease warnings based on these thresholds would have triggered sprays prior to or near the time of demand treatments and would have allowed growers to time fungicide sprays more efficiently without intensive scouting. Data from 1996 and 1997 consistently indicated that algorithms with modified vine and air-soil temperature parameters coupled with DAP-dependent thresholds also allow for timing of fungicide sprays before disease onset. However, scouting is still an important factor in determining if these programs are necessary. These variable FDI threshold algorithms with expanded temperature, moisture, and vine growth parameters show the greatest potential for optimizing fungicide efficiency for control of SB of peanut. The "mod. vine/air-soil temperature algorithm" is currently available to growers in southeastern Virginia via the Peanut-Cotton InfoNet web site.

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Fig. 4. Relationship of the 5-day index (FDI) to the onset and development of Sclerotinia blight of peanut as determined by the A, original, B, air-soil temp., C, modified vine, and D, modified vine/air-soil temp. FDI algorithms at location B in 1997. Bars represent the 5-day risk index, while the dotted lines and markers represent disease progress.

Table 4. Sclerotinia blight disease and yield data from treatments using a 5-day index (FDI) algorithm with different disease risk parameters and thresholds, a days after planting (DAP) calendar-based program, and a scouting-based demand program for timing sprays of fluazinam in 1997

Location and spray program	Spray DAP	DIH ^v	AUDPC ^w	Yield (kg/ha) ^x
Location A – TAREC Duke research farm (irrigated)				
Original FDI 32	111, 136	25.5 ab ^y	1,274 a	4,637 a
Original w/DAP-dependent threshold ^z	87, 111, 139	17.8 c	937 a	5,021 a
Air-soil temp. FDI 32	91, 115, 140	15.5 c	866 a	4,779 a
Air-soil temp. w/DAP-dependent threshold	86, 111, 139	20.3 a-c	716 a	4,594 a
Mod. vine FDI 32	91, 118, 143	19.3 bc	1,051 a	4,879 a
Mod. vine w/DAP-dependent threshold	86, 111, 139	16.5 c	830 a	4,978 a
Mod. vine/air-soil temp. FDI 32	87, 111, 135	18.5 c	1,020 a	4,879 a
Mod. vine/air-soil temp. w/DAP-dependent threshold	86, 111, 136	15.8 c	854 a	4,751 a
Calendar (ca. 60, 90, 120 DAP)	63, 91, 120	20.5 ab	1,118 a	4,921 a
Demand + 3 wk + 3 wk	91, 111, 132	20.3 a-c	1,144 a	4,879 a
Nontreated check	–	26.8 a	1,217 a	3,755 b
Location B – Courtland, Southampton Co., VA (nonirrigated)				
Original FDI 32	93, 118	36.0 a-c	2,366 ab	2,891 bc
Original w/DAP-dependent threshold	83, 107, 135	33.5 bc	1,947 c	2,905 bc
Air-soil temp. w/DAP-dependent threshold	82, 107, 131	29.3 c	1,847 c	3,486 a
Mod. vine w/DAP-dependent threshold	82, 107, 131	31.5 bc	1,916 c	2,993 a-c
Mod. vine/air-soil temp. w/DAP-dependent threshold	81, 107, 131	30.8 bc	1,549 d	3,327 ab
Calendar (ca. 60, 90, 120 DAP)	58, 90, 121	37.0 ab	2,245 b	2,615 cd
Demand + 3 wk + 3 wk	86, 107, 128	32.5 bc	2,017 c	2,978 a-c
Nontreated check	–	43.3 a	2,486 a	2,194 d
Location C – Statesville, Southampton Co., VA (nonirrigated)				
Original FDI 32	128	25.8 b-d	1,053 a	3,087 b-d
Original w/DAP-dependent threshold	–	32.8 ab	1,262 a	2,930 cd
Air-soil temp. w/DAP-dependent threshold	107	30.8 ab	1,278 a	3,401 a-c
Mod. vine w/DAP-dependent threshold	109	27.8 a-c	953 a	3,087 b-d
Mod. vine/air-soil temp. w/DAP-dependent threshold	86, 111, 139	22.0 cd	1,080 a	3,987 a
Calendar (ca. 60, 90, 120 DAP)	58, 89, 121	19.3 cd	868 a	3,615 ab
Demand + 3 wk + 3 wk	58, 107, 128	17.3 d	788 a	3,744 a
Nontreated check	–	35.3 a	1,430 a	2,515 d

^v Disease incidence at harvest (DIH) = counts of disease foci in the two center rows of each plot.

^w Area under the disease progress curve (AUDPC).

^x Yields are based on weight of peanuts with 7% moisture (wt/wt).

^y Means in a column with letter(s) in common and within the same year are not significantly different according to the Waller-Duncan *k*-ratio *t* test at *k* = 100 (*P* ≤ 0.05).

^z DAP-dependent thresholds are FDI = 16 ≤ 90 DAP, FDI = 32 ≤ 120 DAP, and FDI = 64 > 120 DAP.

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