CHAPTER 2. ALGORITHMS FOR PREDICTING OUTBREAKS OF SCLEROTINIA BLIGHT OF PEANUT AND IMPROVING THE EFFICIENCY OF FUNGICIDE SPRAYS

ABSTRACT

New algorithms were developed for computing disease risk and optimizing the timing of fungicide sprays for control of Sclerotinia blight of peanut. A 5-day index (FDI) of disease risk was calculated by multiplying indices of moisture, soil temperature, vine growth and canopy density each day, and summing the values for the previous 5 days. After fungicide application, the FDI was reset to zero for 3-wk or the interval of crop protection. FDI thresholds from 16 to 48 were tested for initiating fungicide sprays in 1994 and 1995. Fluazinam at 0.58 kg a.i./ha applied at FDI levels of 24 or 32 suppressed disease and increased yield as much or more than the currently recommended demand program and was more efficient than calendar sprays at 60, 90, 120 DAP (days after planting). Environmental and host parameters were expanded in 1996 and 1997 by adding new air temperature and vine growth indices. Data from 1996 and 1997 indicated that the addition of DAP-dependent variable thresholds with new environmental and host indices consistently performed better than or equal to the "demand" and 60, 90, 120 DAP program. Fungicide protection intervals (PI's) of 7, 14, 21 and 28 days were tested to determine the optimum time for restarting the algorithms after sprays of either iprodione or fluazinam. With both iprodione and fluazinam, PI's of 7 days resulted in the greatest suppression of disease while yield was the highest when a 14 or 21day PI was used with the original FDI 32 algorithm. Further testing of fungicide protection periods is needed to define the most efficient protection interval for use with DAP-dependent threshold algorithms.

INTRODUCTION

Sclerotinia blight 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 (16, 17, 23, 25, 26). According to replicated field trials over 4 yrs, losses to this disease averaged 33% or 1598 kg/ha of potential yield in naturally infested fields not receiving fungicide treatment (22). Iprodione [3-(3,5-dichlorophenyl)-N-(methylethyl)-2,4-dioxo-1-imidazolidine carboximide], the only registered fungicide for control of this disease, provided only 31% suppression of disease incidence while similar applications of the experimental fungicide, fluazinam [3-chloro-N-(3-chloro-5-trifluoromethyl-2-pyridyl)-2,2,2-trifluoro-2,6-dinitro-p-toluidine], resulted in 69% suppression of disease incidence.

Moisture, soil temperature, vine growth and the foliar canopy have been implicated in the onset and progress of Sclerotinia blight of peanut (1, 7, 8, 9, 12, 18). Disease onset usually occurs once lateral limbs are within 15 cm of touching between rows or after vines have overlapped between rows (12). 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 non-irrigated fields (12). Maximum and minimum air temperatures over the 15 days prior to disease onset fluctuated between 32 and 20 C , while the maximum and minimum soil temperatures were between 30 C and 25 C, respectively. Optimum sclerotial germination and infection of peanut by *S. minor* have been reported to be between 20 and 25 C (7). In Texas, *S. minor* is reported to be inactive in peanut fields when soil temperatures exceed 28 C at the 5 cm depth (9). Knowledge of the environmental and host conditions that trigger outbreaks of Sclerotinia blight have 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 Sclerotinia blight of peanut have been investigated through cooperative studies in Texas, Virginia, Oklahoma and North Carolina (2). Fungicide applications based on algorithms performed as well or better than the standard “demand” program, which relies on intensive weekly scouting, and showed good potential for improved timing of fungicide applications. The demand program requires that the first fungicide application be made when the first symptoms or signs of disease are detected with subsequent sprays applied on a 3-4 wk schedule (13).

The objectives of this study were: 1) to evaluate algorithms for assessing risk for outbreaks of Sclerotinia blight, 2) to increase the efficacy of fungicides through improved timing of applications, and 3) to determine the crop protection interval following applications of iprodione and fluazinam. Field trials were designed to evaluate applications of iprodione and fluazinam according to disease risk as determined by algorithms that are based on host and environmental parameters. Reference standards included spray applications at 60, 90, 120 days after planting, and the demand program currently used by growers.

MATERIALS AND METHODS

Model Development. Based on the results of field trials conducted in 1992 (2) and the assessments of disease development over a 16-yr period (12), an algorithm was developed in 1994 to include environmental factors and the condition of the host plant (11). This algorithm was designed to use host parameters which impact on susceptibility to disease and environmental factors which affect growth of the fungus (Table 1). This algorithm was previously described by Phipps et al. (14) and is summarized here because of its use as a standard in this study. Host indices were determined by vine growth and foliar canopy development. 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, visual estimates of the percentage of the soil surface shaded by the canopy. 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, air temperature 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 periods of RH≥95% were ≥8 hr the previous day. Soil temperature indices were three, two or one when the temperature averaged ≤22, 23-25 or 26-28 C, respectively, for the daily average soil temperature at the 10 cm depth. Environmental conditions not within these parameters were assigned an index of zero. A 5-day index (FDI) of risk was developed by multiplying the host and environmental indices for a given day, then summing daily indices of the preceding 5 days. After fungicide application, indices were set to zero for a 3-wk period to reflect the protection period of the fungicide treatment. This algorithm will hereafter be referred to as the "original FDI algorithm". FDI levels of 16, 24, 32, 40 and 48 were tested with this algorithm as thresholds for initiating fungicide treatments in 1994 and 1995.

In 1995, the initial onset of Sclerotinia blight occurred when vines were >15 cm from touching between rows. This prompted the development of new vine indices which would assign higher index values when vines were >15 cm from touching. The new vine index used growth indices of one or two when vines were >30 cm or ≤30 cm from touching between rows, respectively, and index values of three or four when vines were ≤15 cm from touching or when vines were overlapping between rows, respectively (Table 1). Algorithms using these new vine growth indices were tested in 1996 and 1997 and hereafter are referred to as " mod. vine FDI algorithms". In 1996 and 1997, new environmental parameters were tested which used air temperature along with soil temperature indices in determinations of disease risk. This new algorithm, hereafter called the "air-soil temp. FDI algorithm", used either soil or air temperature, according to the parameter which resulted in the highest index. An algorithm which combined parameters from both the mod. vine and the air-soil temp. FDI algorithm was tested in 1996 and 1997 and hereafter is called the "mod. vine/air-soil temp. FDI algorithm. Algorithms using DAP (days after planting)-dependent thresholds were tested in 1996 and 1997. Thresholds included FDI=16 at ≤90 DAP, FDI=32 at 91 to 120 DAP, and FDI=64 at >120 DAP to reflect decreased susceptibility of peanut tissue with age. All algorithms were tested using a fixed FDI threshold of 32 throughout the season as well as DAP-dependent thresholds in 1996 and 1997.

Fungicide protection intervals (PI) were tested for iprodione and fluazinam from 1995

Table 1. Parameters and risk indices used to calculate the risk of Sclerotinia blight of peanut.

	Risk index	
Environmental parameters	Original algorithm	Modified algorithm
Available moisture		
Rainfall ≥1.27 cm over previous 5 days	1	1
Rainfall ≥2.54 cm over previous 10 days	1	1
RH ≥95% for ≥8 hrs per day	1	1
conditions otherwise	0	0
Air and soil temperature[1]		
≤22 C	3	3
23 - 25 C	2	2
26 - 28 C	1	1
>28 C	0	0
Host parameters[2]		
Vine growth		
Vines overlapping between rows	3	4
Vines ≤15 cm from touching	2	3
Vines >15 cm from touching	1	2
Vines >30 cm from touching	–	1
Plant canopy density		
≥95% of soil surface shaded	3	3
≥75% of soil surface shaded	2	2
<75% of soil surface shaded	1	1

[1] 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. Soil temperature parameters were part of the original algorithm, while air and soil temperature were included in the modified algorithm.

[2] Based on weekly assessments recorded at ca. 7 day intervals.

to 1997. All PI treatments were applied according to the original FDI algorithm at the 32 threshold. The PI represented the number of days the crop would be protected against disease by a fungicide spray. At the end of this period, the algorithm was restarted to determine the timing of the next fungicide spray. The 1995 test consisted of two, three, four and six applications of fluazinam at 0.87, 0.58, 0.44, and 0.29 kg a.i./ha, respectively. The number of applications was rate limited such that the total amount of fungicide did not exceed the expected maximum cumulative dose of 1.74 kg a.i./ha. PI treatments in 1996 and 1997 received a maximum of three sprays of fluazinam and iprodione at 0.58 and 1.12 kg a.i./ha for each application, respectively.

Input Data. Environmental data were collected by Envirocaster® weather stations (Neogen Corp., Lansing, MI) at each location with the exception of 1994 location A which utilized a Virginia Tech/USDA agro-environmental monitor (19). 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 station data were obtained through the Peanut/Cotton InfoNet which is a bulletin board system for extension agents and growers to obtain timely weather and crop information in southeastern Virginia (6). Microsoft Excel® was used to maintain data records and perform the necessary calculations to test 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 on a calendar schedule and the 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 (21, 24). 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 which is common rotation syatems in Virginia. All test sites had a history of yield losses to Sclerotinia blight. Chlorothalonil at 1.26 kg a.i./ha was applied for control of early leaf spot according to the Virginia leaf spot advisory program (5). Research methods for field evaluation of fungicides were followed in all trials and consisted of a randomized complete block design with four replications (15). Plots consisted of four rows and ranged from 10.3 to 10.7 m in length depending upon the test. Fungicide sprays were applied to the two center rows of each plot. All fungicide applications in algorithm tests from 1994 to 1997 used fluazinam at 0.58 kg a.i./ha. Iprodione at 1.12 kg a.i/ha was used in the protection interval test with pinolene at 0.16% (v/v). Iprodione and fluazinam were applied with one 8010LP nozzle centered over each row at a level to provide complete coverage of plants. The sprayer was calibrated to deliver 374 L/ha at 172 kPa and a ground speed of 6.28 km/hr. 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. Location A received 2.9 cm irrigation on 8 September in 1997. In 1995, irrigation was applied on 4 and 25 August at 3.8 cm each time at location B. Irrigation was not used for any test in 1996.

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 of the disease and included 30.5 cm of row length. Disease incidence data were used to compute the area under the disease progress curve (AUDPC) according to the procedures described by Shaner and Finney (20). Peanuts were dug and harvested from the two center rows of each plot with commercial equipment modified to collect yield data from each plot. Yield weights were adjusted to reflect a moisture content of 7% (w/w). Statistical analysis of disease incidence at harvest (DIH), AUDPC, and yield utilized the Waller-Duncan *k*-ratio *t* test at $P \leq 0.05$ and SAS procedures (SAS Institute, Inc., 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 3587 kg/ha. Rainfall was only 60% of normal for the entire growing season (May-September), except for July when totals were 5.1 and 7.5 cm above normal at locations A and B, respectively. The initial outbreak of Sclerotinia blight was detected on 29 July 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 visible symptoms of disease at onset. 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. The relationship of FDI levels to disease onset and progress in untreated plots at locations A and B in 1994 illustrates the manner in which the original FDI 32 algorithm may serve as a warning system for disease (Fig. 1A and B). The 3.8 cm irrigation at location B resulted in rapid plant growth which allowed row closure 6 days earlier than 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 development of disease compared to location A.

At location A, initial sprays at FDI thresholds of 16, 24 and 32 were made on 1 August while the FDI 40 and 48 thresholds called for sprays on 2 and 8 August, respectively (Table 2). The initial demand spray was applied on 4 August at location A. The higher FDI levels observed at location B resulted in the initial FDI 16 and 24 applications being applied on 22 and 25 July, respectively, which was prior to any visible signs of disease. Sprays applied according to FDI levels 32 and 40 were initially applied on 29 July and 2 August at location B, while initial applications for the FDI 48 threshold and the demand program were on 8 August. The initial sprays applied at 60, 90, 120 DAP were made 31 and 30 days prior to the initial symptoms and signs of disease at locations A and B respectively. A total of 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. Otherwise, all other programs at both locations received only two sprays. The 60, 90, 120 DAP program and the original FDI algorithm with thresholds ranging from 16 to 40 consistently performed as well or better than

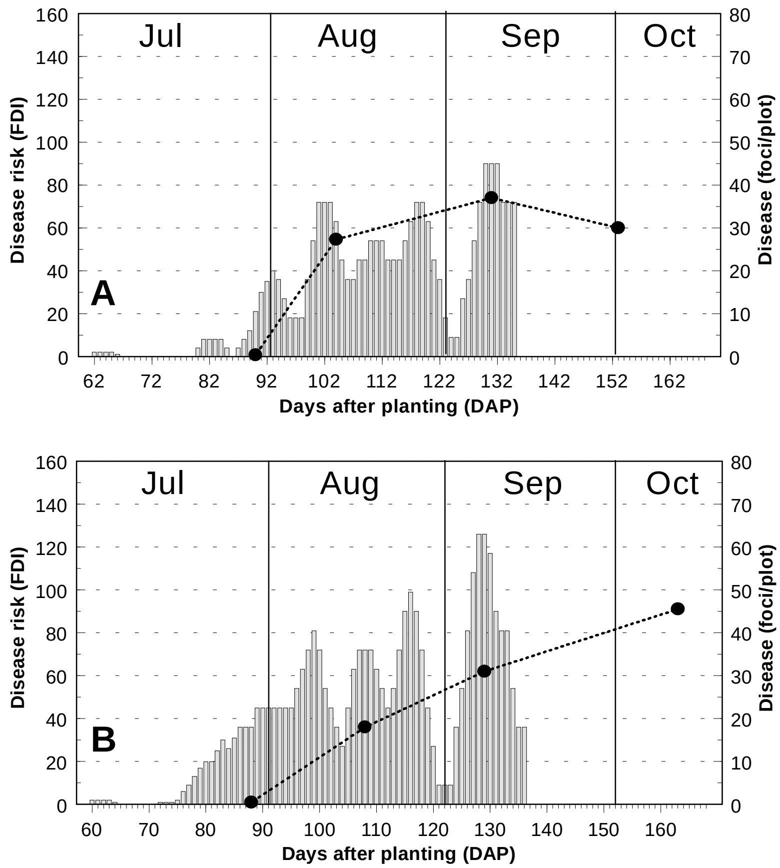


Figure 1. Relationship between disease risk as determined by the original FDI algorithm to the onset and development of Sclerotinia blight of peanut at locations A and B in 1994.

Table 2. Comparison of original FDI algorithm thresholds, DAP, and demand programs for timing sprays with fluazinam at 0.58 kg a.i./ha for control of Sclerotinia blight of peanut in 1994 and 1995.

Year and spray program[1]	DIH[2] Loc A		DIH[2] Loc B		AUDPC[3] Loc A		AUDPC[3] Loc B		Yield(kg/ha)[4] Loc A		Yield(kg/ha)[4] Loc B	
1994												
FDI 16	15.3	b	19.3	d	659	c	592	d	2916	b	4841	ab
FDI 24	12.3	bc	18.8	d	503	cd	583	d	3343	ab	5468	a
FDI 32	11.5	bc	23.8	cd	511	cd	827	cd	3446	ab	5240	a
FDI 40	14.3	b	15.5	d	706	c	527	d	2872	b	5283	a
FDI 48	26.5	a	31.8	bc	1312	b	1114	bc	2047	cd	4784	ab
60, 90, 120 DAP	7.3	c	25.3	cd	228	d	723	cd	3991	a	5311	a
Demand	15.8	b	36.0	ab	661	c	1327	b	2768	bc	4528	b
Untreated check	31.3	a	45.5	a	1698	a	1815	a	1517	d	3090	c
1995												
FDI 16	5.3	c	2.3	a	700	c	58	a	4496	a	5500	a
FDI 24	9.0	bc	1.5	a	1074	bc	25	a	4669	a	4917	a
FDI 32	9.8	bc	2.0	a	1024	bc	59	a	4525	a	5292	a
FDI 40	10.3	bc	3.0	a	919	bc	108	a	4554	a	5458	a
FDI 48	14.0	b	2.3	a	1132	b	39	a	3804	b	5306	a
60, 90, 120 DAP	9.8	bc	3.3	a	859	bc	62	a	4611	a	5056	a
Demand	11.5	bc	9.0	a	750	bc	216	a	4179	ab	4847	a
Untreated check	34.8	a	10.0	a	1722	a	215	a	2695	c	4667	a

[1] FDI (five day index) thresholds were used with the original FDI algorithm. 1994 location A: FDI 16, 24, 32=1 Aug, 26 Aug; FDI 40=2 Aug, 30 Aug; FDI 48=8 Aug, 7 Sep; 60, 90, 120 DAP=29 Jun, 29 Jul, and 22 Aug; demand =4 Aug, 7 Sep. 1994 location B: FDI 16=22 Jul, 18 Aug; 13 Sep; FDI 24=25 Jul, 18 Aug, 13 Sep; FDI 32=29 Jul, 26 Aug; FDI 40=2 Aug, 26 Aug; FDI 48=8 Aug, 6 Sep; 60, 90, 120 DAP=30 Jun, 1 Aug, and 31 Aug; demand=8 Aug, 6 Sep. 1995 location A: FDI 16, 24, 32=18 Jul, 9 Aug, 28 Aug; FDI 40=9 Aug, 29 Aug, 20 Sep; FDI 48=9 Aug, 31 Aug, 20 Sep; 60, 90, 120 DAP=7 Jul, 9 Aug, and 8 Sep; demand=5 Jul, 26 Jul, 16 Aug. 1995 location B: FDI 16=17 Jul, 9 Aug, 29 Aug; FDI 24, 32=9 Aug, 28 Aug; FDI 40=10 Aug, 29 Aug; FDI 48=10 Aug, 5 Sep; 60, 90, 120 DAP=30 Jun, 31Jul, and 29 Aug; demand=20 Sep. Protection intervals for demand treatments were 4 and 3 wk for 1994 and 1995, respectively.

[2] Disease incidence at harvest (DIH) are counts of disease foci in the two centers rows of each plot.

[3] Area under the disease progress curve (AUDPC).

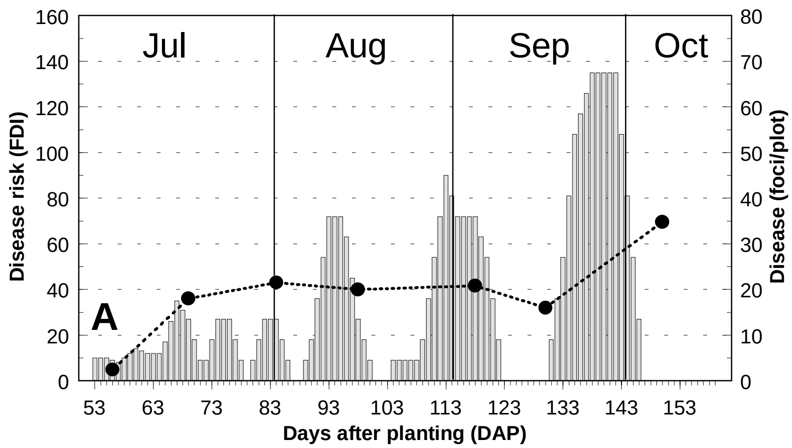
[4] Yields are based on weight of peanuts with 7% moisture (w/w).

Means in a column with letter(s) in common and within the same year are not significantly different ($P \leq 0.05$) according to the Waller-Duncan *k*-ratio *t* test.

the demand program and resulted in significant suppression of DIH and AUDPC, while significantly increasing yield at both locations in 1994 (Table 2). The original algorithm at the fixed FDI threshold of 32 consistently resulted in sprays being applied before disease onset while limiting the number of applications below FDI thresholds 16 and 24 at location B. Therefore, the FDI threshold of 32 was believed to be the most efficient FDI threshold for providing disease control and yield improvement at the lowest fungicide input.

1995 Field Tests. Overall, the 1995 growing season was hot and dry compared to previous years in southeastern Virginia. Locations A and B averaged rainfall deficits of 12.1 and 20.2 cm, respectively. Location B received 3.8 cm of irrigation on 4 and 25 August. Sclerotinia blight was detected on 5 July in location A. Disease progress at location A became static by 1 August due to periods when environmental conditions were extremely unfavorable for growth of *S. minor* which resulted in a zero level of disease risk (Fig. 2A). Disease onset was delayed until 29 August at location B due to the rainfall deficit coupled with reduced vine growth early in the season. However, disease risk reached levels favorable for the development of Sclerotinia blight on 8 August then dropped again to zero on 13 August, but subsequently climbed again due to timely irrigations and maintained a high level of disease risk throughout the remainder of the season (Fig. 2B). However, disease did not progress to damaging levels at location B in 1995 which may have been due to a low level of inoculum.

All spray programs at location A in 1995 received three fungicide applications (Table 2). At location A, calendar sprays at 60 DAP were applied 2 days after disease onset while the demand program called for an application on the same day as disease onset. Sprays according to FDI thresholds 16, 24, and 32, were applied 13 days subsequent to disease onset. The FDI thresholds of 40 and 48 were not sprayed until 9 August which was 35 days after the initial onset of disease. At location B, the original algorithm using a FDI threshold of 16 triggered the initial fungicide application on 16 July which was 43 days before the initial symptoms or signs of disease. The initial fungicide application using FDI thresholds



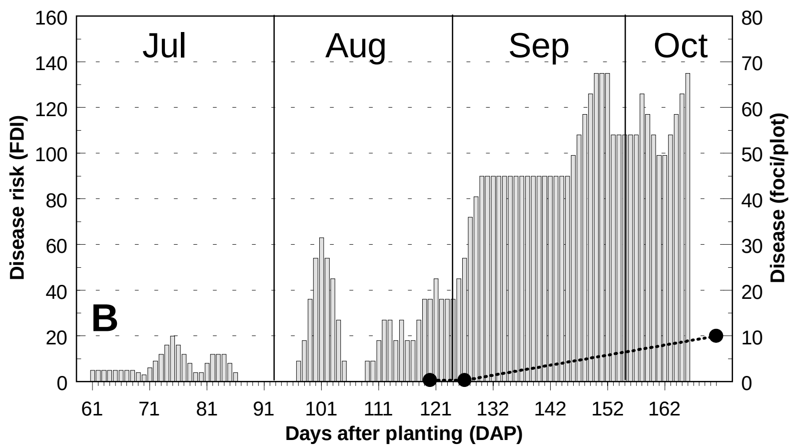


Figure 2. Relationship between disease risk as determined by the original FDI algorithm to the onset and development of Sclerotinia blight of peanut at locations A and B in 1995.

of 24 and 32 was made on 9 August, which was 20 days prior to disease detection. FDI thresholds of 40 and 48 triggered the initial fungicide application on 10 Aug. All three 60, 90, 120 DAP applications were applied prior to disease development, the last spray being applied on 29 August, which was the same day disease was initially detected. The first and only demand application was applied on 20 September, which was the time at which disease levels would most likely have warranted a fungicide treatment.

Treatments according to the 60, 90, 120 DAP and demand programs resulted in significant suppression of DIH, AUDPC and a corresponding increase of yield at location A (Table 2). Applications according to the original FDI algorithm at thresholds ranging from 16 to 48 also gave significant disease suppression and significantly increased 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. The information obtained in 1995 at location A showed the need to develop algorithms more likely to trigger fungicide application just prior to disease onset. Disease incidence was low at location B and significant differences were not detected in comparisons of fungicide-treated and untreated plots. However, the number of fungicide applications was useful in comparing the input requirements of each program. The DAP-dependent calendar program and the FDI 16 threshold called for three fungicide applications each, while FDI 24 through 48 thresholds triggered only two sprays. Only one fungicide application was applied according to the demand program which was the most efficient use of fungicide given the lack of disease pressure at location B.

1996 Field Tests. Cool and wet conditions were experienced during the 1996 growing season with rainfall totals 5.8, 16.3, and 4.0 cm above normal 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 to 0.08 and 0.53 cm above normal at locations A and B. Disease onset was initially detected at locations A and B on 16 July following heavy precipitation from hurricane Bertha. Disease onset was delayed in location C until 31 July due to a lack of vine growth.

Conditions were extremely favorable for the development of Sclerotinia blight in 1996 as illustrated by disease progress in August and September at all three locations (Fig. 3). Disease risk maintained high levels from mid-July to harvest at locations A and B. Location C did not encounter high levels of disease risk until early August when vine growth began to cover the soil surface.

Field tests in 1996 included the mod. vine, air-soil temp., and the mod. vine/ air-soil temp. algorithms with FDI 32 and DAP-dependent thresholds. These new algorithms were developed to be more sensitive to conditions favorable for disease development than the original FDI 32 algorithm and allow fungicide applications to be used in a more preventative manner. All fungicide programs called for three fungicide applications at locations A and B (Table 3). DAP-dependent thresholds for the air-soil temp., mod. vine, and mod. vine/air-soil temp. algorithms called for three sprays at location C. Other fungicide programs called for just two sprays at location C. The original FDI 32 and air-soil temp. FDI 32 algorithms triggered 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 DAP-dependent, calendar program was applied 4 days prior to disease onset at location A while the initial demand treatment was 3 days after disease onset at locations A and B. DAP-dependent threshold versions of the air-soil and mod. vine/air-soil temp. algorithms initiated fungicide treatment 7 days ahead of disease onset while sprays according to the DAP-dependent threshold version of the modified vine algorithm were applied 6 days prior to disease onset at location C. The mod. vine/air-soil temp. 32 algorithm was sprayed 6 days prior to disease onset at location C. The first fungicide application for all other algorithms at location C was made 7 days subsequent to disease onset. The initial demand treatment was delayed 15 days after initial disease symptoms were detected at location C. This is not an uncommon occurrence as demand treatments are often applied after symptoms have already occurred. Also, scouting methods employed in this study are more intensive than those employed by growers.

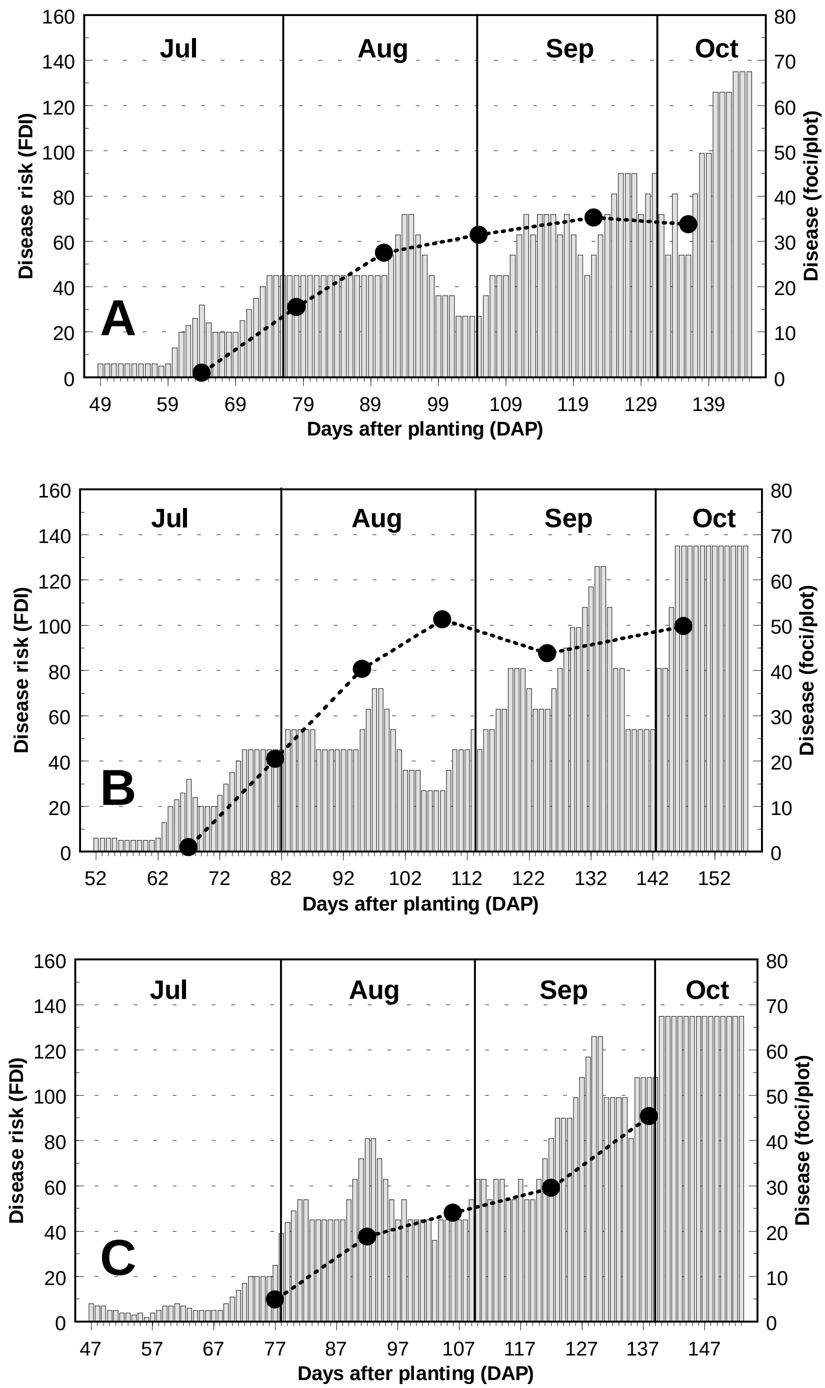


Figure 3. Relationship between disease risk as determined by the original FDI algorithm to the onset and development of Sclerotinia blight of peanut at locations A, B, and C in 1996.

Table 3. A comparison of FDI algorithms for determining the optimum timing of fungicide sprays with fluazinam at 0.58 kg a.i./ha for control of Sclerotinia blight of peanut in 1996.

Location, spray program and timing of application[1]	DIH[2]		AUDPC[3]		Yield (kg/ha)[4]	
Location A (non-irrigated)						
Original FDI 32 (25 Jul, 21 Aug, 16 Sep)	18.8	b	735	bc	2100	a
Original w/DAP-dependent threshold (15 Jul, 7 Aug, 3 Sep)	11.5	bc	339	d	2625	a
Air-soil temp. FDI 32 (23 Jul, 15 Aug, 9 Sep)	12.8	bc	882	b	2284	a
Air-soil temp. w/DAP-dependent threshold (15 Jul, 6 Aug, 3 Sep)	10.8	c	473	cd	2157	a
Mod. vine FDI 32 (15 Jul, 7 Aug, 3 Sep)	11.8	bc	437	cd	2015	a
Mod. vine w/DAP-dependent threshold (15 Jul, 7 Aug, 3 Sep)	16.3	bc	494	cd	2100	a
Mod. vine/air-soil temp. FDI 32 (15 Jul, 7 Aug, 3 Sep)	15.5	bc	604	b-d	2398	a
Mod. vine/air-soil temp. w/DAP-dependent threshold (15 Jul, 7 Aug, 3 Sep)	16.3	bc	550	cd	2526	a
60, 90, 120 DAP (12 Jul, 12 Aug, 12 Sep)	18.5	bc	865	b	1987	a
Demand + 3 wk + 3 wk (19 Jul, 9 Aug, 27 Aug)	11.5	bc	506	cd	2256	a
Untreated check	33.8	a	1830	a	1831	a
Location B (non-irrigated)						
Original FDI 32 (24 Jul, 16 Aug, 12 Sep)	27.8	bc	1591	b	4705	a
Original w/DAP-dependent threshold (15 Jul, 8 Aug, 3 Sep)	23.8	bc	1217	bc	5003	a
Air-soil temp. FDI 32 (22 Jul, 14 Aug, 9 Sep)	20.3	c	1022	c	4833	a
Air-soil temp. w/DAP-dependent threshold (15 Jul, 7 Aug, 3 Sep)	29.0	bc	1419	bc	4280	ab
Mod. vine FDI 32 (15 Jul, 7 Aug, 3 Sep)	30.3	b	1302	bc	4663	a
Mod. vine w/DAP-dependent threshold (15 Jul, 8 Aug, 3 Sep)	21.5	bc	996	c	4677	a
Mod. vine/air-soil temp. FDI 32 (15 Jul, 7 Aug, 3 Sep)	27.3	bc	1405	bc	4592	ab
Mod. vine/air-soil temp. w/DAP-dependent threshold (15 Jul, 7 Aug, 3 Sep)	29.3	bc	1409	bc	4606	ab
Demand + 3 wk + 3 wk (19 Jul, 7 Aug, 28 Aug)	24.0	bc	1103	bc	3699	b
Untreated check	49.8	a	3007	a	2367	c
Location C (non-irrigated)						
Original FDI 32 (6 Aug, 5 Sep)	28.5	bc	1378	a-c	4912	bc
Original w/DAP-dependent threshold (6 Aug, 5 Sep)	22.0	b-d	1044	b-d	5265	a-c
Air-soil temp. FDI 32 (6 Aug, 5 Sep)	34.0	ab	1688	ab	4521	c
Air-soil temp. w/DAP-dependent threshold (24 Jul, 15 Aug, 10 Sep)	14.8	cd	672	cd	6028	ab
Mod. vine FDI 32 (6 Aug, 5 Sep)	33.7	ab	1700	ab	4410	c
Mod. vine w/DAP-dependent threshold (25 Jul, 20 Aug, 13 Sep)	9.3	d	451	d	6159	ab
Mod. vine/air-soil temp. FDI 32 (25 Jul, 16 Aug, 13 Sep)	14.0	cd	655	cd	5600	a-c
Mod. vine/air-soil temp. w/DAP-dependent threshold (24 Jul, 15 Aug, 10 Sep)	6.7	d	400	d	6382	a
Demand + 3 wk + 3 wk (15 Aug, 5 Sep)	30.3	ab	1635	ab	4968	bc
Untreated check	45.3	a	2126	a	2135	d

[1] DAP-dependent thresholds are FDI=16 ≤ 90 DAP, FDI= 32 ≤ 120 DAP, and FDI=64 >120 DAP.
[2] Disease incidence at harvest (DIH) are counts of disease foci in the two centers rows of each plot.
[3] Area under the disease progress curve (AUDPC).
[4] Yields are based on weight of peanuts with 7% moisture (w/w).
Means in a column with letter(s) in common and within the same location are not significantly different ($P \leq 0.05$) according to the Waller-Duncan *k*-ratio *t* test.

All fungicide programs significantly suppressed disease (DIH and AUDPC) at locations A and B (Table 3). Sprays according to air-soil temp., mod. vine, and mod. vine/air-soil temp. algorithm which used DAP-dependent thresholds resulted in significant disease suppression (DIH and AUDPC) at location C when compared to the demand program and the untreated check. No significant yield differences were detected at location A. All spray programs significantly improved yield when compared to the untreated 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, respectively, for both locations. Below normal rainfall was also experienced in May, June, and August at location C, while July and September were 3.3 and 0.53 cm above normal. Disease onset was detected on 4 August 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 accounted for a major part of the differences in disease risk at each location (Fig. 4). Disease progressed rapidly 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 conditions unfavorable for disease in early September. With the exception of the original FDI 32 algorithm, which triggered two sprays, all models called for three sprays at locations A and B (Table 4). The original FDI algorithm, the air-soil temp. and the mod. vine algorithms using DAP-dependent thresholds called for only one spray each at location C, while the mod. vine/air-soil temp. algorithm with DAP-dependent thresholds resulted in three sprays. The original FDI 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.

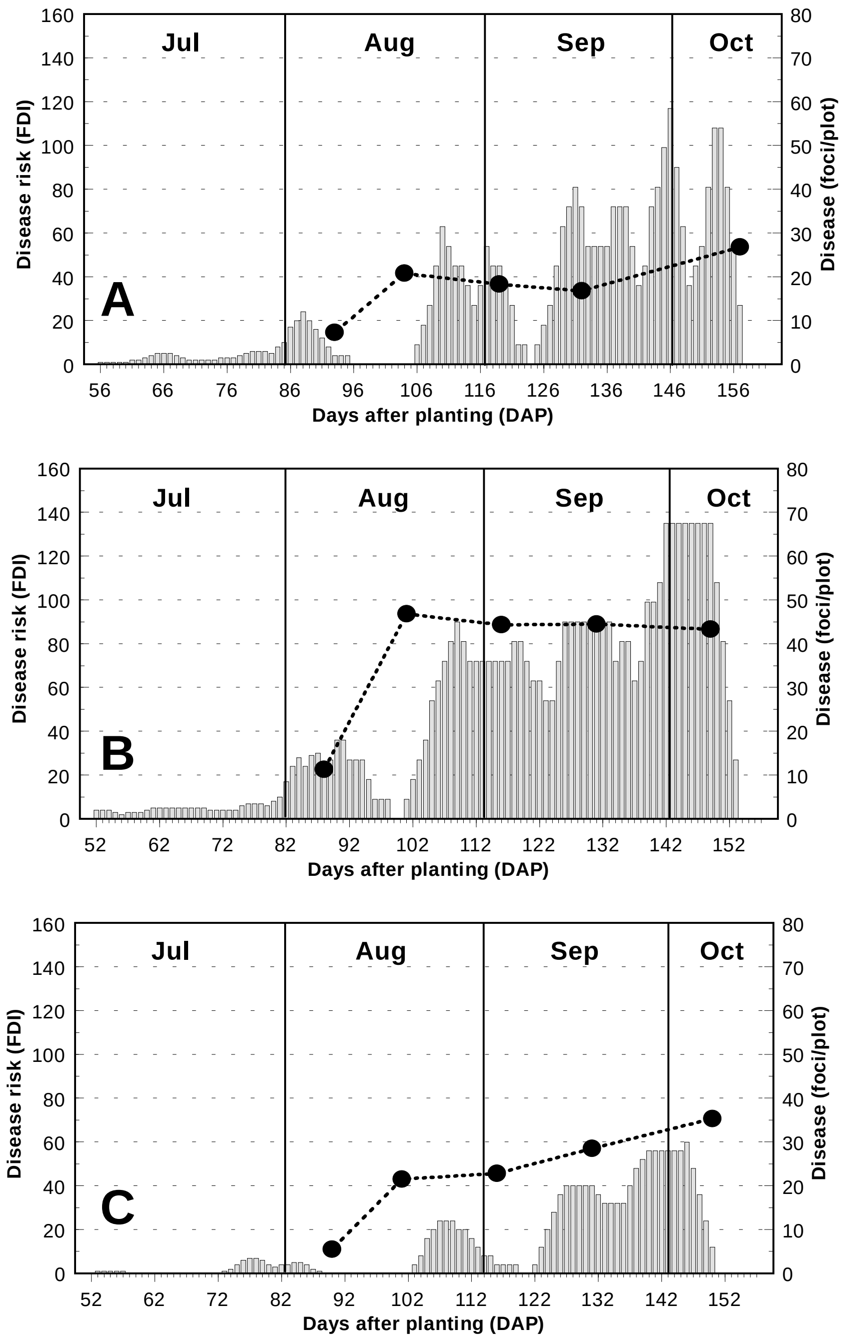


Figure 4. Relationship between disease risk as determined by the original FDI algorithm to the onset and development of Sclerotinia blight of peanut at locations A, B, and C in 1997.

Table 4. A comparison of FDI algorithms for determining the optimum timing of fungicide sprays with fluazinam at 0.58 kg a.i./ha for control of Sclerotinia blight of peanut in 1997.

Location, spray program and timing of application[1]	DIH[2]		AUDPC[3]		Yield (kg/ha)[4]	
Location A (irrigated)						
Original FDI 32 (25 Aug, 19 Sep)	25.5	ab	1274	a	4637	a
Original w/DAP-dependent threshold (1 Aug, 25 Aug, 22 Sep)	17.8	c	937	a	5021	a
Air-soil temp. FDI 32 (4 Aug, 29 Aug, 23 Sep)	15.5	c	866	a	4779	a
Air-soil temp. w/DAP-dependent threshold (31 Jul, 25 Aug, 22 Sep)	20.3	a-c	716	a	4594	a
Mod. vine FDI 32 (4 Aug, 1 Sep, 26 Sep)	19.3	bc	1051	a	4879	a
Mod. vine w/DAP-dependent threshold (31 Jul, 25 Aug, 22 Sep)	16.5	c	830	a	4978	a
Mod. vine/air-soil temp. FDI 32 (1 Aug, 25 Aug, 18 Sep)	18.5	c	1020	a	4879	a
Mod. vine/air-soil temp.w/DAP-dependent threshold (31 Jul, 25 Aug, 19 Sep)	15.8	c	854	a	4751	a
60, 90, 120 DAP (8 Jul, 4 Aug, 3 Sep)	20.5	ab	1118	a	4921	a
Demand + 3 wk + 3 wk (4 Aug, 25 Aug, 15 Sep)	20.3	a-c	1144	a	4879	a
Untreated check	26.8	a	1217	a	3755	b
Location B (non-irrigated)						
Original FDI 32 (11 Aug, 5 Sep)	36.0	a-c	2366	ab	2891	bc
Original w/DAP-dependent threshold (1 Aug, 25 Aug, 22 Sep)	33.5	bc	1947	c	2905	bc
Air-soil temp. w/DAP-dependent threshold (31 Jul, 25 aug, 18 Sep)	29.3	c	1847	c	3486	a
Mod. vine w/DAP-dependent threshold (31 Jul, 25 Aug, 18 Sep)	31.5	bc	1916	c	2993	a-c
Mod. vine/air-soil temp. w/DAP-dependent threshold (30 Jul, 25 Aug, 18 Sep)	30.8	bc	1549	d	3327	ab
60, 90, 120 DAP (7 Jul, 8 Aug, 8 Sep)	37.0	ab	2245	b	2615	cd
Demand + 3 wk + 3 wk (4 Aug, 25 Aug, 15 Sep)	32.5	bc	2017	c	2978	a-c
Untreated check	43.3	a	2486	a	2194	d
Location C (non-irrigated)						
Original FDI 32 (15 Sep)	25.8	b-d	1053	a	3087	b-d
Original w/DAP-dependent threshold (none)	32.8	ab	1262	a	2930	cd
Air-soil temp. w/DAP-dependent threshold (25 Aug)	30.8	ab	1278	a	3401	a-c
Mod. vine w/DAP-dependent threshold (27 Aug)	27.8	a-c	953	a	3087	b-d
Mod. vine/air-soil temp. w/DAP-dependent threshold (4 Aug, 29 Aug, 26 Sep)	22.0	cd	1080	a	3987	a
60, 90, 120 DAP (7 Jul, 7 Aug, 8 Sep)	19.3	cd	868	a	3615	ab
Demand + 3 wk + 3 wk (7 Aug, 25 Aug, 15 Sep)	17.3	d	788	a	3744	a
Untreated check	35.3	a	1430	a	2515	d

[1] DAP-dependent thresholds are 16 $\leq$ 90 DAP, 32 $\leq$ 120 DAP, and 64 >120 DAP.

[2] Disease incidence at harvest (DIH) are counts of disease foci in the two centers rows of each plot.

[3] Area under the disease progress curve (AUDPC).

[4] Yields are based on weight of peanuts with 7% moisture (w/w).

Means in a column with letter(s) in common and within the same location are not significantly different ($P \leq 0.05$) according to the Waller-Duncan *k*-ratio *t* test.

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 similar to the demand program and reduced the 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. Except for the 60, 90, 120 DAP program, all fungicide treatments at location B yielded significantly greater than the untreated check. The air-soil temp. algorithm and the mod. vine/air-soil temp. algorithms using DAP-dependent thresholds as well as the 60, 90, 120 DAP program and the demand program significantly improved yield at location C.

Protection Interval (PI) Tests. The 1995 PI test was located near location B and the data from this test is excluded due to the lack of disease and the lack of a yield response.

All PI treatments received three fungicide applications in 1996 with the exception of the 28 day PI, which was sprayed twice. Disease control based on DIH and AUDPC was greatest for both fluazinam and iprodione where a PI of 7 days was used (Table 5). However, the yield response to both fungicides was consistently highest when the algorithm used 14 and 21 day PIs.

Disease incidence was low and significant differences were not detected in comparisons of protection intervals by each fungicide in 1997. However, all fluazinam-treated plots significantly reduced DIH below the untreated check (Table 5). Fluazinam applied on a 21 day PI was the only treatment which significantly improved yield. PIs of 7 and 14 days received three fungicide applications as compared to two for 21 and 28 day PIs in 1997.

DISCUSSION

The FDI algorithms presented here utilize environmental factors as well as host growth and canopy development in assessing risk for Sclerotinia blight. Like environmental factors

Table 5. Comparison of protection intervals provided by sprays of iprodione and fluazinam for control of Sclerotinia blight of peanut.

Year, treatment, rate a.i./ha and protection interval (PI)[1]	DIH[2]	AUDPC[3]	Yield (kg/ha)[4]
1996			
iprodione at 1.12 kg			
28 day PI (18 Jul, 19 Aug)	44.8 ab	2140 b	2467 de
21 day PI (18 Jul, 12 aug, 9 Sep)	45.8 ab	2129 b	2831 cd
14 day PI (18 Jul, 7 Aug, 31 Aug)	46.8 ab	1982 b	3210 c
7 day PI (8 Jul, 30 Jul, 12 Aug)	38.5 bc	1467 cd	2719 c-e
Demand + 4 wk + 4 wk (18 Jul, 15 Aug, 12 Sep)	40.3 b	1796 bc	3014 cd
fluazinam at 0.58 kg			
28 day PI (18 Jul, 19 Aug)	31.0 cd	1281 de	4093 b
21 day PI (18 Jul, 12 aug, 9 Sep)	18.3 e	907 ef	5172 a
14 day PI (18 Jul, 7 Aug, 31 Aug)	20.0 e	859 ef	5200 a
7 day PI (8 Jul, 30 Jul, 12 Aug)	17.3 e	717 f	4584 b
Demand + 4 wk + 4 wk (18 Jul, 15 Aug, 12 Sep)	25.5 de	1220 de	4163 b
Untreated check	52.8 a	3267 a	2173 e
1997			
iprodione at 1.12 kg			
28 day PI (12 Aug, 12 Sep)	18.5 bc	743 a	4603 ab
21 day PI (12 Aug, 5 Sep)	22.0 ab	828 a	4575 ab
14 day PI (12 Aug, 1 Sep, 18 Sep)	21.3 ab	929 a	4532 ab
7 day PI (12 Aug, 25 Aug, 5 Sep)	18.8 bc	895 a	4817 ab
fluazinam at 0.58 kg			
28 day PI (12 Aug, 12 Sep)	13.0 cd	685 a	4646 ab
21 day PI (12 Aug, 5 Sep)	14.5 b-d	800 a	4944 a
14 day PI (12 Aug, 1 Sep, 18 Sep)	12.0 cd	648 a	4817 ab
7 day PI (12 Aug, 25 Aug, 5 Sep)	9.3 d	565 a	4632 ab
Untreated check	28.3 a	929 a	4262 b

1 All treatments, except the demand + 4 wk + 4 wk in 1996, were applied according to the original FDI 32 algorithm.

2 Disease incidence at harvest (DIH) are counts of disease foci in the two center rows of each plot.

3 Area under the disease progress curve (AUDPC).

4 Yields are based on weight of peanuts with 7% moisture (w/w).

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

(7, 9, 12), plant growth and canopy density have been demonstrated to have an important role in disease development (1, 8, 12). Fungicides for control of Sclerotinia blight have been shown to be more effective when applied in a preventive manner (4, 27). Applying fungicides preventively to control this disease has been a major difficulty with the currently recommended demand program, because growers must detect the disease in the field prior to the first fungicide application. Many times the demand application is applied long after the disease has been present and damage has already occurred. The demand program also relies on a set spray schedule after the initial application, thus creating the potential for needless applications during times unfavorable for disease development. The timing of fungicide sprays can be even less efficient when using a calendar spray schedule based on DAP. Results from the 1994 field trials indicated that the original FDI algorithm using the FDI 32 threshold offered the greatest potential 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 a continuously favorable environment which did not allow disease to 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 for more efficient fungicide use. Sprays applied according to the 60, 90, 120 DAP schedule performed well due to the serendipitous placement of fungicide applications. There was no benefit of any of the spray programs tested at location B since there was no significant difference in disease suppression or yield between the untreated check and any of the spray programs in 1995. The ineffectiveness of fungicide sprays at location B underscores the need to augment the advisory with weekly scouting.

The 1996 growing season provided ideal environmental conditions for testing fungicide spray programs for control of Sclerotinia blight. All test locations averaged above normal rainfall for the peanut growing season and correspondingly high levels of disease risk and Sclerotinia blight were observed. The algorithms using DAP-dependent thresholds resulted in fungicide applications consistently being applied prior to or on the same day disease onset was detected. At location C, algorithms with DAP-dependent thresholds increased yield an average of 1098 kg/ha when compared to the fixed FDI 32 threshold algorithms. This was likely the result of the increased number of fungicide applications and greater precision in timing sprays during periods favorable for disease development.

Cool, dry conditions, in 1997, did not allow for a continued high risk after disease onset. As demonstrated in 1996, DAP-dependent threshold algorithms resulted in sprays being applied earlier than those of the fixed FDI 32 algorithm and demonstrated a trend towards improved disease control and yield. At location C, reduced vine growth delayed the development of Sclerotinia blight and resulted in a lower disease risk. Compared to other locations, the number of fungicide sprays at location C was reduced by all algorithm treatments with the exception of the mod. vine/air-soil temp. with DAP-dependent thresholds, which was the most sensitive of the algorithms to 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 level imposed at >120 DAP. Spray programs calling for fungicide applications on or prior to 25 Aug performed similarly at location C in 1997.

Tests involving fungicide PIs demonstrated that iprodione and fluazinam provide optimum disease suppression when applied at a PI of 14 days before restarting the algorithm. This period of fungicide protection is less than the recommended 3 to 4-wk spray interval currently used with the demand program. The shorter fungicide protection periods correspond to previous work which demonstrated that iprodione remained significantly fungicidal for 2-wk (3). However, these data represent only one year in which significant differences could be detected between fungicide PI's sprayed according to the original FDI 32 algorithm and further testing is required to determine if these reduced protection intervals consistently allow for efficient use of fungicide.

A program similar to the Virginia Leaf Spot Advisory (5) is needed to provide an early warning system to growers in advance of outbreaks of Sclerotinia blight of peanut. This would be a valuable addition to programs that provide prescription strategies for disease management in peanuts (10). Results from 1994 and 1995 suggested that the original FDI algorithm with thresholds of 16, 24, and 32 can perform as well or better than the currently used demand program. The disease warnings based on these thresholds would have been issued prior to or near the same time of demand treatments and would have allowed growers to time fungicide sprays more efficiently without intensive weekly scouting. Data from 1996 and 1997 consistently indicated that algorithms with the modified vine growth and temperature parameters coupled with DAP-dependent thresholds also allow for the timing of fungicide sprays before disease onset occurs without the need for intensive disease scouting. These variable FDI threshold algorithms with expanded temperature and moisture parameters when using PI's of 10 to 14 days show the greatest potential for optimizing fungicide efficiency for control of Sclerotinia blight of peanut.

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