Development of Stem Rot (Caused by *Sclerotium rolfsii*) in Peanut in Alabama

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ABSTRACT

Stem rot, or southern blight, caused by the fungus *Sclerotium rolfsii*, is an important disease of peanut in the southeastern U.S. Incidence and apparent onset of stem rot varies from year to year depending on planting date, weather conditions, and other factors. In order to more fully understand the effects of weather on stem rot, disease progress was evaluated through the 1995, 1996, and 1997 cropping seasons. Evidence of *S. rolfsii* was observed on peanut roots and crowns as early as 20 d after planting (DAP), which was 1 to several wk before stem rot lesions or plant wilt were observed. Disease measures tended to be lower in 1997 than in preceding years even though more rainfall and more consistent soil moisture were noted in 1997. Soil moisture was frequently in excess of field capacity from rainfall and may have contributed to suppressing stem rot development in 1997, perhaps by limiting oxygen availability. In 1995 and 1996, rainfall patterns were more normal and irrigation contributed to greater stem rot incidence. However, low moisture, specifically 7 d with < 1.8 cm rain, was associated with increases in numbers of dead plants, perhaps due to cumulative stress from disease and lack of moisture. Areas under disease progress curves for stem rot tended to be greater for early plantings compared to late plantings. However, by ca. 118 DAP, early plantings did not consistently have a greater incidence of dead plants, probably due to environmental conditions immediately preceding that date.

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Key Words: *Arachis hypogaea*, groundnut, southern blight, white mold, planting date, irrigation.

Stem rot, or southern blight, caused by the fungus *Sclerotium rolfsii* Sacc. (teleomorph *Athelia rolfsii* (Cursii) Tu & Kimbrough), is an important disease of peanut (*Arachis hypogaea* L.) in the southeastern U.S. Annually, this disease decreases the yield potential of peanut by at least 5%, but losses can be substantially greater in some years and fields (Sturgeon, 1986; Bowen *et al.*, 1992). Stem rot is frequently the major limiting factor in attaining maximal yields in peanut production (Bowen *et al.*, 1996).

Wilting or flagging of the central stem that is due to stem rot often appears in mid-July or approximately 60 to 75 d after planting (DAP) (Aycock, 1966). Frequently, a mycelial mat of *S. rolfsii* develops at the base of affected plants. Plants or individual branches affected by stem rot will often die, resulting in a loss of yield. Further losses due to *S. rolfsii* can occur when the fungus attacks the peanut pods, which often occurs when soil moisture is particularly low (Porter *et al.*, 1982).

130Incidence and apparent onset of stem rot varies from year to year due to a number of factors. A higher incidence of stem rot has been observed in earlier- than later-planted peanuts (Brenneman and Hadden, 1996; Hagan *et al.*, 2001). In addition, this disease has been more prevalent in environments with greater moisture (Aycock, 1966; Shew and Beute, 1984; Culbreath *et al.*, 1992). Higher temperatures have also been associated with greater stem rot incidence (Bowen *et al.*, 1992; Backman and Brenneman, 1997; Brenneman *et al.*, 1999). Conversely, stem rot incidence on peanut was greater in the cool and dry year of 1993 than in the following year, which was wetter than average and with typical high temperatures (Davis *et al.*, 1996; Wolf *et al.*, 1997). These contrasting observations led to investigations to refine the understanding of stem rot development in peanuts by evaluating the progress of this disease through three production seasons. The specific objective was to determine the effects of weather, especially moisture, on stem rot development.

Materials and Methods

A field with a history of stem rot at the Wiregrass Research and Extension Center, in Headland, AL, was used throughout this study. Soil was a Dothan sandy loam with < 1% organic matter. The field had been planted to peanut for 2 yr preceding this study and had side-roll irrigation. The effects of planting date (early and late) and irrigation (irrigated vs. rainfed) on stem rot were evaluated in each of 3 yr (1995, 1996, and 1997) since these management practices (subsequently referred to as "treatments") imposed different environmental conditions on the crop. A split-plot design was used with irrigation as the main plot and planting date as the subplot. Treatments were replicated three times. Treatments were imposed on an area of 56 rows (spaced 0.9 m apart), and trimmed to 6.1 m in length. Adequate spacing between treatments was allowed to minimize accidental irrigation of non-irrigated (i.e., rainfed) treatments. Within each treatment, 14 four row plots were marked and sampling order was randomly assigned to each plot. The two center rows of each plot were assessed for stem rot incidence at regular intervals in their assigned sequence during each growing season.

Planting dates of cv. Florunner peanut were 26 April and 9 May 1995, 27 April and 16 May 1996, and 17 April and 16 May 1997 for the early and late planting dates, respectively. Peanut seed was planted at 112 kg/ha, ca. one seed every 5.5 cm. Applications of chlorothalonil (1.3 a.i. kg/ha) to control foliar diseases began ca. 30 DAP and continued on 10 to 14 d intervals as per Alabama Cooperative Extension System recommendations (Weeks *et al.*, 1993). Irrigated plots received water as needed, generally 1.3 cm following 7 d without rain.

In 1995 and 1997, samples were taken 14 times in both planting dates through each season beginning 20 to 49 DAP. Weekly samples were taken from 12 June to 12 Sept. (47 to 139 DAP) for the early planting and from 19 June through 19 Sept. (41 to 133 DAP) for the late planting in 1995. In 1997, weekly samples were collected from 5 June through 3 Sept. (49 to 139 DAP) and 12 June through 10 Sept. (27 to 117 DAP) for the early and late plantings, respectively. In 1996, sampling started on 24 May (27 DAP) for the early planting and 5 June (20 DAP) for the late planting, and continued on 9 to 12 d intervals through 22 Aug. Rain events > 5 cm within a 24 hr period occurred on 7, 30, and 31 Aug. and 4 Sept. 1996; and sampling was terminated after 22 Aug. Thus, sampling in 1996 was done on 10 and 9 dates for the early and late planting dates, respectively. On 12 Sept. 1996, only aboveground counts were determined for the early planting (138 DAP) and belowground counts for the late planting (119 DAP).

On the first three sampling dates of each season, all plants in the two center rows of sampled plots were counted. On every sampling date, wilted and dead plants were counted in each of the two center rows of each plot, and mycelial mats of *S. rolfsii* at the base of plants were counted in a randomly determined 1 m section of each of two rows. Following collection of aboveground fungal and stem rot counts, the two center rows of plots were dug to evaluate belowground plant parts for symptoms of stem rot and signs of *S. rolfsii* activity. Roots, crowns, and lower branches of individual plants were examined. Plants were categorized according to levels of disease severity such that: signs = no lesions but presence of mycelia on roots or lower branches; slight damage = dark brown elongate lesions < 2.5 cm in length on < 20% of plant parts; minimal damage = lesions ≥ 2.5 cm in length, affecting 20 to 40% of plant parts; moderate damage = lesions affecting 40 to 60% of plant parts; substantial damage = 60 to 80% of plant affected by stem rot; and severe damage = 80% to 100% of plant parts affected by stem rot. Early each season and for arbitrary samples throughout the season, plant parts with white mycelia were collected and returned to the laboratory where they were cut into 1 to 2 cm sections, surface sterilized by rinsing in 0.5% sodium hypchlorite, and then in sterile water. Samples were then plated on potato dextrose agar in 95 mm dia. petri plates. Cultures were kept at room temperature until sclerotia formed. The fungus *S. rolfsii* was recovered from all samples.

Soil samples were collected to a depth of 5 to 10 cm from beneath the canopy of outer rows of each sampled plot. Three subsamples of soil from each plot, each ca. 80 cm^2 (for a total of ca. 200 cm^2), were thoroughly mixed in a sealed plastic bag and transported to the laboratory. To determine soil moisture, soil was weighed, dried overnight at 40 C and weighed again. Soil moisture was calculated as [(wet wt - dry wt) x 100]/dry wt.

Weather data were obtained from the daily summary of conditions from the Auburn Univ. Weather Mesonet. Mesonet data are collected on 10 sec intervals over a 24 hr period ending at 7 a.m. central time via a CR10 station (Campbell Scientific, Ogden, UT) located ca. 3 km from the field site. Available data included daily minimum, maximum, and mean ambient (at 1.5 m aboveground) and soil (at 9.6 cm depth under bare soil) temperatures, as well as precipitation.

All disease counts were transformed to counts per 12.2 m row. Stem rot incidence (not including counts of aboveground mycelial mats) was calculated by dividing disease counts by stand counts in each year. In addition, the incidences of plants in each damage category (slight, minimal, etc.) were summed to create the variable "damaged plants." Correlation coefficients were calculated between all variables (i.e., each disease category to all other disease categories). In addition, using data from rainfed plots only, the frequencies of increase or decrease in incidence for both damaged and dead plants were determined between all consecutive pairs of sampling dates for all 3 yr. Frequencies of occurrences of minimal (< 1.8 cm) or adequate (≥ 1.8 cm) rainfall accumulation during the 7 d preceding the latter of the two consecutive dates were also determined. Thirty-year normal rainfall amounts are > 2.7 cm for 7 d intervals in June, July, and Aug. at the location of this study. The null hypothesis that rainfall had no effect on changes in incidence of disease was tested using a contingency table of frequencies and the χ^2 statistic. Data were analyzed using SAS release 8.02 (SAS Institute, Cary, NC). Probability levels for significance were $P < 0.05$, unless otherwise stated.

Areas under curves (AUC's) for counts of mycelial mats, incidence of belowground signs, and incidences of damaged and dead plants were calculated according to the method used by Shaner and Finney (1977). AUC's were calculated over a time period of 92 d for both planting dates in 1995 and 1997. In 1996, AUC's were calculated over 90 and 79 d for the early and late plantings, respectively. AUC's for the late planting in 1996 were adjusted by a factor of 1.14 (90/79) prior to analysis. AUC data for each disease count were subjected to analysis of variance (ANOVA) with irrigation as the main plot and planting date as the subplot. Means were compared using Fisher's protected least significant difference test (FLSD) at $P \leq 0.05$.

Florunner matures at ca. 135 DAP (Bostick *et al.*, 1999). Incidence of dead plants nearest to Florunner maturity was determined in each of the 3 yr at ca. 118 DAP: 24 Aug. (120 DAP) and 5 Sept. (118 DAP) in 1995 for the early and late plantings, respectively; 22 Aug. (117 DAP) in 1996 for the early planting; and 13 Aug. (118 DAP) and 10 Sept. (117 DAP) in 1997 for the early and late plantings, respectively. Incidences of dead plants at ca. 118 DAP were subjected to ANOVA for comparisons between years and main effects.

Results

Stand counts averaged 214.0, 149.4, and 213.6 plants per 12.2 m row for 1995, 1996, and 1997, respectively. There were no significant effects due to planting date or irrigation on stand in any year. Between 1 and 28 May 1996, 0.6 cm rain was recorded compared to > 5.0 cm for the same periods in 1995 and 1997. The lower stand counts in 1996 were attributed to the dry conditions.

In general, through each growing season incidences of wilted plants and plants with belowground signs were generally low (i.e., < 10%) and could be variable from week to week, as seen by disease progress curves from the early planting, rainfed plots in each year (Fig. 1). However, aboveground mycelial mats could be numerous. *Sclerotium rolfsii* activity was initially observed as the presence of mycelium (i.e., "signs") on belowground plant parts in destructively sampled plots. On subsequent sam-

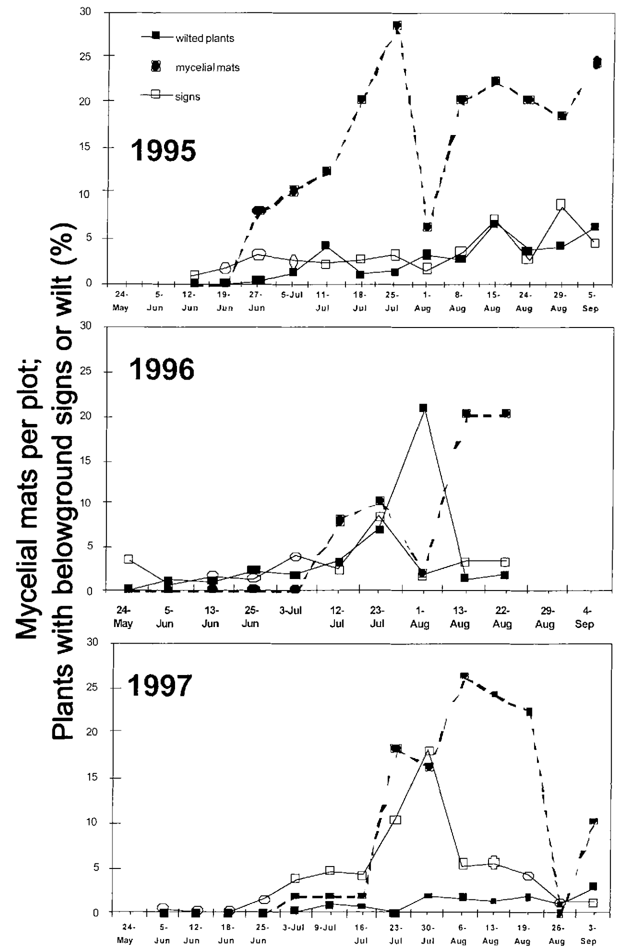

Fig. 1. Counts of aboveground mycelial mats (per 12.2 m row), and incidences of plants with belowground signs of *Sclerotium rolfsii* and of wilted peanut plants in early-planted rainfed plots during three cropping seasons.

pling dates, dark brown elongate lesions (i.e., slight damage) were observed on belowground plant parts. As the season progressed, the incidence of plants with slight damage generally increased, as did the incidence of plants in progressively greater damage categories (such as moderate then severe damage categories). Subsequently, incidences of dead plants also increased. Incidences of plants with belowground signs of *S. rolfsii* mycelium were positively correlated to incidences of plants with slight damage ($P < 0.001$; $r = 0.64$, 0.53, and 0.31 in 1995, 1996 and 1997, respectively). Incidences of plants in each damage category were positively correlated to the incidences of plants in each of the next greater damage category (e.g., slight damage to minimal damage, minimal to moderate, etc.) for each year ($r > 0.64$ in all cases). The positive correlations indicate that a progression of disease occurred from belowground symptoms to slight damage and then to increasingly greater damage levels.

Numbers of aboveground mycelial mats were often positively correlated with incidences of wilted, damaged, and dead plants, and to plants with belowground signs of *S. rolfsii* in each of the 3 study yr (Table 1). In 1995 and 1997, incidences of wilted plants were positively correlat-

Table 1. Correlation coefficients calculated between counts of aboveground mycelial mats, and incidences of wilted plants, plants with belowground signs, damaged plants, and dead plants in each of 3 yr.

Year (# obs.)		Wilted plants	Belowground signs	Damaged plants	Dead plants
1995 (161)	Aboveground mycelial mats	0.33*	0.44*	0.61*	0.46*
	Wilted plants	–	0.24*	0.49*	0.34*
	Belowground signs	–	0.53*	0.39*	
	Damaged plants	–	0.72°		
	Dead plants			–	
1996 (112)	Aboveground mycelial mats	-0.05	0.36*	0.64°	0.42*
	Wilted plants	–	-0.02	-0.02	0.01
	Belowground signs		–	0.37*	0.06
	Damaged plants			–	0.66*
	Dead plants				–
1997 (168)	Aboveground mycelial mats	0.24*	0.38*	0.50*	0.09
	Wilted plants	–	0.12	0.52*	0.60*
	Belowground signs		–	0.04	-0.08
	Damaged plants			–	0.68*
	Dead plants				–

*Denotes significance at P = 0.01.

ed to other disease incidences; and in 1995 and 1996, incidences of belowground signs were positively correlated to incidences of dead and of damaged plants (Table 1). In addition, incidences of damaged plants were positively correlated to dead plants (r > 0.66) in each year (Table 1).

1995 Disease Progress. No wilted, damaged, or dead plants, or aboveground mycelial mats of *S. rolfsii* were found in plots on the first plant sampling of the early planting (47 DAP, 12 June). Only on subsequent sampling dates were wilted plants, dead plants, and aboveground mycelial mats observed. Numbers of mycelial mats and incidence of dead plants increased through the 1995 growing season to 24 per 12.2 m row and 7.3%, respectively, by 4 Sept. in later-planted plots. The incidence of wilted plants remained < 6% through the season for all treatments.

A few plants (< 2%) were found with belowground signs of *S. rolfsii* activity on 12 June (47 DAP), as evidenced by white mycelia present on primary roots just below the soil surface. The incidence of plants with belowground signs of *S. rolfsii* also increased through the growing season from 0% to as great as 12% by 19 Sept. in irrigated plots of the late planting (data not shown). On belowground plant parts, stem rot damage was initially observed on 19 June 1995 in all treatments (Fig. 2). In both the early and late plantings, the incidence of damaged plants increased substantially after 5 July and, by 4 Sept., incidence was > 30% in all treatments (Fig. 2). The incidence of damaged plants increased more rapidly in irrigated plots than in rainfed plots between 18 July and 8 Aug. Soil moisture was consistently greater (ca. 2%) in irrigated than in rainfed plots during this time interval. Incidence of dead plants increased rapidly in both plantings after 8 Aug. (Fig. 3).

1996 Disease Progress. Sampling for stem rot began on 24 May in 1996 (28 DAP for the early planting) and a low incidence of wilted (0.2%) and dead (0.7%) plants were found in irrigated plots (data not shown). The incidence of wilted plants increased during July to as great as 21 and 13% in Aug. in rainfed plots of the early and late plantings, respectively (e.g., Fig. 1), then declined. Fewer wilted plants were observed in irrigated plots. No aboveground mycelial mats were observed before 3 July on any plants, after which the number of mycelial mats increased to as many as 30.5 per 12.2 m row in rainfed, late-planted plots by mid-Aug.

Plants with belowground signs of *S. rolfsii* were observed at 28 DAP (24 May) for the early planting and at 20 DAP (5 June) for the late planting. The incidence of plants with belowground signs remained low (< 10%) throughout the 1996 growing season (e.g., Fig. 1). Very low levels of stem rot damage were initially observed on belowground plant parts during June and incidence remained < 10% until 12 July, after which there was a substantial increase in the incidence of plants with damage in each treatment (Fig. 2). In the early planting, the incidence of damaged plants increased more rapidly in irrigated than in rainfed plots. Dead plants were not consistently observed before 1 Aug. (Fig. 3). However, by 22 Aug. (the last sampling date due to excessive rain), the incidence of dead plants had increased to > 9% in early planted plots and to ca. 3% in the late planted plots. In the early planting on 12 Sept. (138 DAP), the incidence of dead plants was 11.6 and 13.2% in rainfed and irrigated plots, respectively.

1997 Disease Progress. Few aboveground mycelial mats or wilted, damaged, or dead plants were found in any plots before 16 July 1997 (90 DAP for the early planting; 61 DAP for the late planting) (Fig. 1). The incidence of wilted plants increased most slowly during the 1997 growing season when a 5.6% incidence was observed on 10 Sept. in rainfed plots of the late planting. Aboveground mycelial mats increased to as many as 28 per 12.2 m in irrigated plots by 13 Aug. for the late planting, and then declined (Fig. 1).

On the first sampling dates in 1997 (5 June, 49 DAP for the early planting and 12 June, 27 DAP for the late planting), plants with belowground signs were found at a low incidence (< 2%) in each treatment (Fig. 1). The incidence of plants with belowground signs increased through the growing season to a maximum on 30 July in each treatment, after which there was a decline. Plants with belowground damage were found initially on 9 July for early planted plots and consistently after 30 July in all treatments (Fig. 2). Incidence of damaged plants increased to 26 and 16% incidence in rainfed and irrigated plots, respectively, for the early planting and to ca. 14% in both irrigated and rainfed plots for the late planting (Fig. 2). The incidence of dead plants remained low (< 2%) until

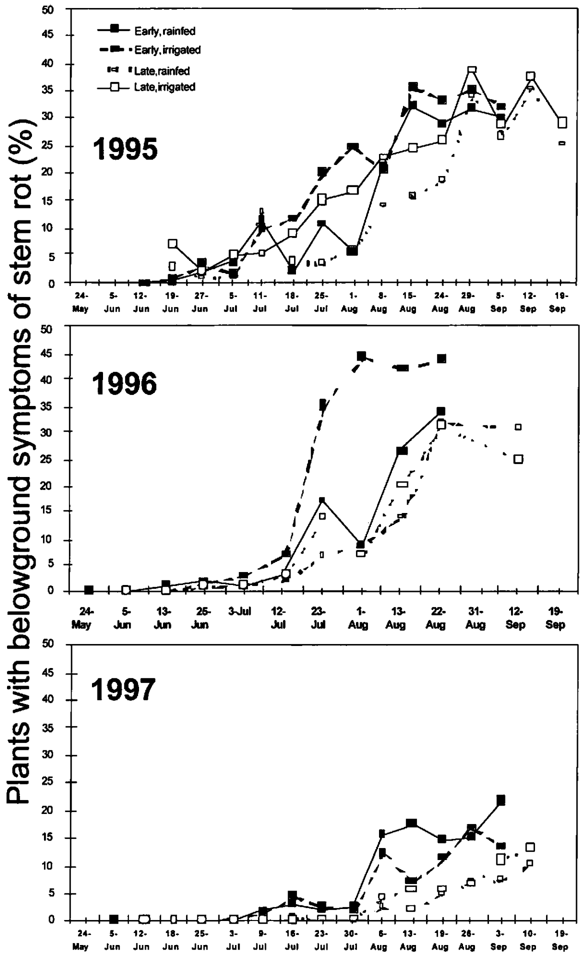

Fig. 2. Incidences of peanut plants with belowground damage due to *Sclerotium rolfsii* in each of four treatments during three cropping seasons. Treatments were "Early" and "Late" planting in both irrigated and rainfed plots.

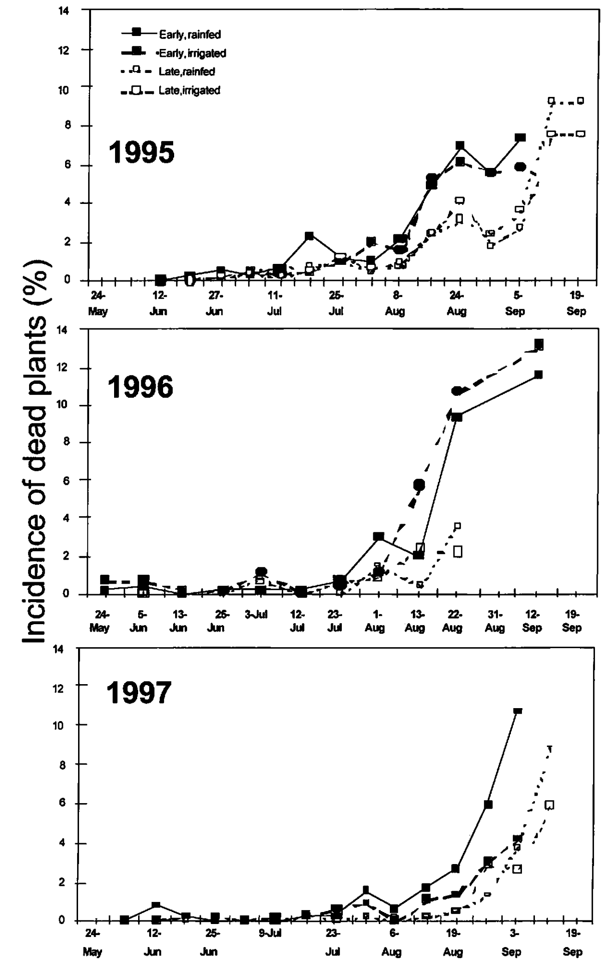

Fig. 3. Incidences of dead plants in rainfed and irrigated plots of early and late plantings through three growing seasons.

mid-Aug., after which there was a moderate increase to 10.8 and 4.2% by 3 Sept. in rainfed and irrigated plots, respectively, in the early planting (Fig. 3). Incidence of dead plants in late planted plots remained low until 26 Aug., then increased to 8.9 and 5.8% by 10 Sept. in rainfed and irrigated plots, respectively (Fig. 3).

Environment and its Effects. Season-long mean ambient and estimated soil temperatures were consistently lower for the early plantings in each year than for the late plantings (Table 2). Rainfall was greater in 1997 than in the preceding 2 yr when nearly twice the number of rain-days occurred, which resulted in substantially greater mean soil moisture season-long in both plantings (Table 2). Soil moisture on individual sampling dates in each year varied from < 1% to > 10%, with consistently higher moisture in irrigated plots than in rainfed plots (Fig. 4). Mean soil moisture ≥ 10% was observed in irrigated plots on five sampling dates in 1997, but on only two sampling dates in 1995 and 1996 (Fig. 4).

Chi-square analysis indicated that increases in incidence of damaged plants were not associated with minimal or adequate rainfall. However, minimal rainfall (< 1.8 cm over preceding 7 d) was associated with increases in incidences of dead plants (χ^2 = 17.9; P < 0.001). Specifically, out of 67 sampling dates in both plantings over 3 yr, 29 of the 38 (76%) occurrences of increase in the

Table 2. Mean ambient and soil temperatures, cumulative rainfall, numbers of rain days (> 0.25 cm), and mean soil moisture (%), from planting date through the last sampling date for each of three study yr.

Year	Planting	Interval	Air temp.[a]	Soil temp.[a]	Rain-fall[a]	Rain-days[a]	Soil moist.[b]
			------ C	------	cm	no.	%
1995	Early	26 April - 4 Sept.	26.3	27.3	38.8	45	4.9
	Late	9 May -12 Sept.	26.9	27.9	40.7	46	5.0
1996	Early	27 April -22 Aug.	25.7	29.3	39.8	31	3.2
	Late	16 May -22 Aug.	26.4	30.0	35.3	29	3.3
1997	Early	17 April - 3 Sept.	25.1	26.7	51.6	63	7.1
	Late	16 May -10 Sept.	26.6	28.4	41.0	55	6.6

[a]Temperature and rainfall data collected ca. 3 k from field site. Air temperature taken at 1.5 m aboveground; soil temperature is from 9.6 cm depth under bare soil (soil is nearly identical to that at field site).

[b]Rainfed plots only.

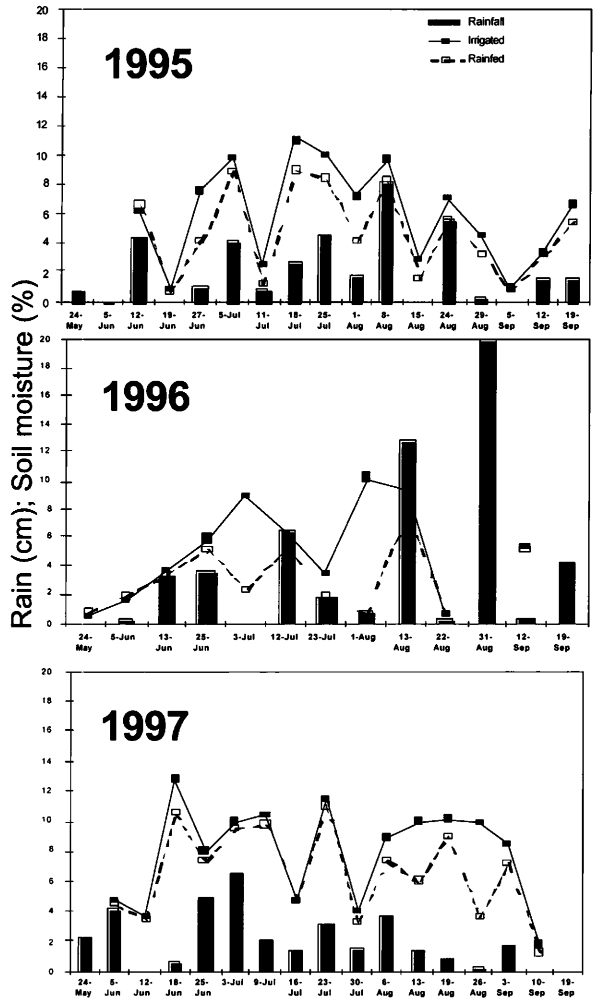

Fig. 4. Measured soil moisture in irrigated and rainfed plots, and cumulative rainfall for 7 d preceding sampling dates during three cropping seasons.

incidence of dead plants followed 7 d with < 1.8 cm cumulative rainfall. Among the 29 sampling dates when the incidence of dead plants did not increase, adequate rainfall preceded 22 dates (76%).

Treatment Effects. AUC's for each of the disease variables were significantly (P < 0.01) affected by year, as well as by year x irrigation or by 3-way interactions. Thus, ANOVA's for AUC's were separated by year. AUC's for wilted plants were not affected by planting date or the planting date by irrigation interaction during any year. However, irrigation had a significant effect on AUC's for wilted plants in 1995 and 1996, with consistently greater AUC's for wilted plants in rainfed plots (data not shown). The AUC's for aboveground mycelial mats in 1995 and 1996 were greater in irrigated than in rainfed plots, as were AUC's for belowground signs in 1995 (Table 3). In 1996, AUC's for damaged plants were greater in irrigated plots than in rainfed plots. Irrigation did not have an effect on the AUC's for dead plants in 1995 and 1996, but it did in 1997. Planting dates also affected AUC's which were greater in the early planting than the late planting for aboveground mycelial mats in 1996 (data not shown), and for damaged and dead plants in 1996 and 1997 (Table 3; Figs. 2 and 3). Belowground signs were greater in the late planting than the early planting in 1995, but the opposite effect was observed in 1997 (Table 3). The planting date by irrigation interaction was significant in 1997 when rainfed plots of the early planting had a greater AUC for dead plants (= 140.6) than other treatments (70.5 for the irrigated early planting; 78.2 and 70.7 for rainfed and irrigated, respectively, of the late planting). There was no other planting date by irrigation interaction on AUC's for disease variables in any year.

Incidence of dead plants at ca. 118 DAP was significantly affected by year and the year by planting date interaction; no other effects were significant. Incidence of dead plants in 1996 (10%) was greater than in 1995 and 1997 (4.8 and 4.4%, respectively). In 1995, incidence of dead plants was greater in the early planting than in the

Table 3. Areas under curves (AUC) for counts of aboveground mycelial mats, and incidences of plants with belowground signs of *S. rolfsii*, damaged plants, and dead plants for three growing seasons (1995-1997).

Disease variable	Treatment[a]	1995[b]	1996[b]	1997[b]
		---------	AUC	--------
Mycelial mats	Rainfed	1269*	586*	677
	Irrigated	1714	921	695
	FLSD[c]	372	152	347
Belowground signs	Rainfed	350*	238	294
	Irrigated	650	317	343
	FLSD	148	194	66
Damaged plants	Rainfed	1313	806*	448
	Irrigated	1642	1331	395
	FLSD	456	465	111
Dead plants	Rainfed	194	81	110*[d]
	Irrigated	177	107	71
	FLSD	37	35	20
Belowground signs	Early planted	403*	343	416*
	Late planted	589	212	222
	FLSD	148	194	66
Damaged plants	Early planted	1410	1495*	568 *
	Late planted	1547	641	275
	FLSD	456	465	111
Dead plants	Early planted	187	134*	105*[d]
	Late planted	184	54	74
	FLSD	37	35	20

[a]Early plantings were 26 April 1995, 27 April 1996, and 17 April 1997; late plantings were 9 May 1995, 16 May 1996, and 16 May 1997.

[b]AUC's were calculated over 92 d in 1995, 90 d in 1996, and 92 d in 1997 for both planting dates in each year.

[c]FLSD is Fisher's protected least significant difference with P = 0.05.

[d]The interaction of irrigation by planting date was significant for AUC's of dead plants in 1997; AUC's = 140.6 and 70.5 for rainfed and irrigated plots, respectively, of the early planting and 78.2 and 70.7 for rainfed and irrigated plots, respectively, of the late planting; LSD = 34.2.

*Denotes significance at P = 0.05.

late planting (6.5% compared to 3.2%; $P < 0.01$). However, the late planting had a greater incidence of dead plants in 1997 than the early planting (7.3 and 1.4%, respectively; $P < 0.01$).

Discussion

In this study, different plots were assessed for stem rot incidence at intervals through three growing seasons. Due to the clustered spatial pattern of this disease (Shew *et al.*, 1984), stem rot incidence would be expected to differ from plot to plot. Because different plots were assessed, the apparent decline of some disease counts between sampling dates could be due to non-uniform occurrence of the disease across the field. Alternatively, since aboveground mycelial mats were found to be positively related to soil moisture in 2 of 3 yr (data not shown), signs of this disease may have been less visible in dry conditions. Thus, fluctuating soil moisture could have affected disease counts on individual sampling dates.

AUC's for belowground signs were lower than AUC's for aboveground mycelial mats in each year. In this study, aboveground mycelial mats were counted regardless of the presence or absence of stem rot lesions. However, plants with belowground signs were distinguished from plants with lesions; therefore, counts of aboveground mycelial mats were more inclusive than were counts of belowground signs. Nevertheless, counts of aboveground mycelial mats were positively correlated to incidences of belowground signs in each year. In addition, incidences of belowground signs were consistently correlated to incidences of plants with minimal damage. The presence of mycelium on belowground plant parts has been called a "saprophytic phase" (Rideout *et al.*, 2002). Disease progress data and correlation analyses in this study indicate that this stage may precede pathogenesis.

In each of the 3 yr, plants with belowground signs of *S. rolfsii* were observed at the first sampling date, as early as 20 DAP in the late planting of 5 June 1996. *Sclerotium rolfsii* is thought to produce oxalic acid and polygalacturonases in advance of penetration of the host, and these compounds damage plant cells (Punja, 1985). Therefore, plants with damage would be expected to be found soon after observations of *S. rolfsii* mycelia on the roots and crown. This progression of disease is supported in the current study by the positive correlation of the incidence of plants with signs to the incidence of plants with minor damage. However, lesions were sometimes not observed for several weeks after the initial observation of belowground signs on plants. For example, in 1997 the initial observation of damage was delayed after observing belowground signs compared to the two preceding years. Since moisture levels in 1997 differed from moisture in the two preceding years, these results indicate that progression from the saprophytic stage to stem rot disease damage is influenced either directly or indirectly by the environment.

Moisture is important for growth of *S. rolfsii* and development of stem rot (Aycock, 1966; Shew and Beute, 1984; Punja, 1985). As observed in the current study, AUC's for aboveground mycelial mats, belowground signs, damaged plants, and dead plants were greater in 1995, when the number of rain days and mean soil moisture were greater, than in 1996. In addition, irrigated plots tended to have higher incidences of stem rot than rainfed plots in 1995 and 1996, and soil moisture was consistently higher in irrigated than in rainfed plots in these 2 yr. In 1997, due to frequent and regular rainfall from mid-June into Aug., soil moisture did not differ substantially between irrigated and rainfed plots through most of the season, and AUC's for aboveground mycelial mats, belowground signs, and damaged plants did not differ due to irrigation in this year.

Warm, wet weather has previously been associated with increased occurrence of stem rot (Aycock, 1966; Shew and Beute, 1984; Bowen *et al.*, 1992; Backman and Brenneman, 1997; Brenneman *et al.*, 1999). Among the 3 yr of this study, mean ambient temperatures were similar; however, rainfall was greatest in 1997. AUC's for damaged plants were lower in 1997 than in the preceding 2 yr, despite having greater rainfall. Davis *et al.* (1996) had also observed less stem rot in 1994 (a year with greater than normal rainfall) than in 1993. Further, Davis *et al.* (1996) noted that soil moisture through most of the 1994 growing season was probably near field capacity. Volumetric soil moisture at field capacity of the Dothan sandy loam of the current study is ca. 9.5% (calculated from data in Quisenberry *et al.*, 1987). During 1997, soil moisture was frequently near or above this level. Oxygen would become limited in soil when moisture is at or above field capacity (Brady, 1974). Because *S. rolfsii* is a strict aerobe (Aycock, 1966), high soil moisture coupled with reduced oxygen availability may kill sclerotia or restrict the growth of *S. rolfsii*, suppressing subsequent disease development. Alternatively, frequent rainfall could have cooled the soil enough to suppress disease development. However, monthly averages of estimated soil temperatures were not consistently lower in 1997 than in the preceding years.

Moisture may be needed for stem rot development, but increases in incidence of plant death were associated with dry periods in this study. Specifically, χ^2 analysis showed that plants died more readily following 7 d with < 1.8 cm cumulative rainfall. It is possible that plants stressed from infection by *S. rolfsii* died readily with additional stress from lack of moisture. However, other factors also could have predisposed plants to death. For example, tomato spotted wilt disease was noted in plots throughout each season at a very low incidence (e.g., two symptomatic plants were observed in each plot in 1997) and asymptomatic but virus-infected plants could have contributed to the observed incidence of dead plants. Fluctuations in soil moisture have been shown to promote germination of sclerotia (Beute and Rodríguez-Kábana, 1979), and this could have increased the rate of plant death. Fluctuations in soil moisture could stress plants and contribute directly to plant death. This possibility, however, is not supported by the number of dead plants ca. 118 DAP in 1997 when the early planting had a greater incidence of dead plants but fewer occurrences of fluctuations in soil moisture than did the later planting.

Time of planting also had an effect on measures of stem rot. In 2 of 3 yr (1996 and 1997), AUC's for damaged plants and for dead plants—and in 1995, incidence of dead plants ca. 118 DAP—were greater in early than in late plantings. These results are comparable to those observed by Brenneman and Hadden (1996) and Hagan *et al.* (2001), who noted that the incidence of stem rot was lower in later- than in earlier-planted peanuts. Hagan *et al.* (2001) speculated that hot, wet weather in July favors *S. rolfsii* activity during pod development in earlier planted peanuts while later plantings would be exposed to cooler, drier weather that represses stem rot development. These speculations contradict results of the current study in which low moisture was associated with higher incidences of dead plants. However, Stewart *et al.* (1997) observed that later-planted peanut plants were smaller than those planted earlier. Smaller plants would better tolerate lower moisture levels, and consequently, may not die as readily. One could envision that extreme moisture deficits that occur late in the season could overcome the effects of plant size. In the current study in 1997, a greater incidence of dead plants was observed in the later planting than in the early planting ca. 118 DAP. While there was less rain immediately preceding the 118 DAP sampling of the late planting than the early planting in 1997, this was also the case in 1995. However, 1997 was unusual in that the daily maximum temperatures for 14 d preceding 118 DAP were higher for the late planting (mean = 33.6 C for 28 Aug. through 10 Sept.) than for the early planting (30.4 C for 31 July through 13 Aug.). Thus, higher daily maximum temperatures in early Sept. could have contributed to greater plant stress and rapid increases in plant death compared to early Aug. in 1997.

Substantial increases in incidences of plants with damage due to stem rot were frequently observed to occur over relatively short periods of time. For example, in rainfed plots of the early planting in 1995, incidence increased from 5% on 1 Aug. to over 20% on 8 Aug. Similar increases in dead plants were observed. Given this rapidity of disease increase, any count of disease preceding inversion by more than a couple of days could be inaccurate compared to counts of stem rot foci done after inversion. This discrepancy between in-season disease counts to focal counts at inversion was also noted by Rideout *et al.* (2002).

The apparent decrease in severity of stem rot from the first to the 3rd study year was unexpected, given that plots were maintained in the same field. Up to 3 yr of continuous planting of peanuts, without rotation to a non-host crop, has been shown to increase stem rot incidence in previous studies (Brenneman *et al.*, 1995; Johnson *et al.*, 1999; Timper *et al.*, 2001). Decreases in stem rot, however, have also been observed in fields continually cropped to peanuts (Bowen *et al.*, 1996). Peanuts had been continuously cropped in the field of the current study in 2 consecutive yr prior to the start of this study. Thus, by 1997, there had been 5 yr of continuous peanut cropping. In the study by Bowen *et al.* (1996), "continuous peanut" rotation was defined as 3 or more yr of peanut production. Soil suppressiveness to a number of diseases is known to develop in fields that have been in a long-term rotation to the same host (Papavizas, 1985). It is possible that the lower levels of stem rot observed in 1997 was not due to excessive moisture, as presented above, but due to development of soil suppressiveness. Additional studies are needed to further clarify the effects of soil moisture on stem rot development, and the possibility of the development of suppressiveness to stem rot of peanuts.

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