Influence of *Meloidogyne incognita* and *Thielaviopsis basicola* Populations on Early-Season Disease Development and Cotton Growth

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ABSTRACT

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Microplot studies were used to examine the effect of various population densities of *Meloidogyne incognita* and *Thielaviopsis basicola* on cotton-plant development and disease severity. Plots were infested with 0, 20, or 100 *T. basicola* chlamydospores/g and 0, 5, or 10 *M. incognita* eggs and juveniles/cm³ of soil in a factorial arrangement in 1997 and 1998. Combinations of *M. incognita* and *T. basicola* reduced plant survival in both years compared to the noninfested control, except in 1998 for the high rate of *T. basicola* over all nematode rates. Plant height-to-node ratios were reduced by pathogen combinations compared to the noninfested control or to either pathogen alone. Plant dry weight was reduced by *M. incognita* in 1998 and the high rate of *T. basicola* in 1997. Root necrosis was increased by increasing rates of *T. basicola* in 1997 and by *M. incognita* over all rates of *T. basicola* in both years. Colonization of root tissue by *T. basicola* was increased by the low inoculum density of the nematode at 20 CFU/g soil in 1997 and 100 CFU/g in 1998. Nematode reproduction with the high *M. incognita* treatment rate was reduced in both years of the study by the high *T. basicola* rate. This study suggests the importance of population level of each pathogen to the severity of disease and confirms the potential of this disease interaction to impact cotton production.

Additional keywords: black root rot, root-knot nematode, upland cotton

The root-knot nematode, *Meloidogyne incognita* (Kofoid & White) Chitwood, is an important pathogen of many crops, including cotton (*Gossypium hirsutum* L.), produced in Arkansas and the Mississippi River Delta. The nematode is found in an estimated 30% of Arkansas cotton fields (1). The soilborne fungus, *Thielaviopsis basicola* (Berk. & Broome) Ferraris (= *Chalara elegans* Nag Raj & Kendrick), the causal organism of black root rot of cotton, a seedling disease characterized by severe rotting of the cortex of the hypocotyl and roots, is present in 70% of Arkansas cotton fields (11). Both the root-knot nematode and black root rot can be of concern for cotton growers in Arkansas.

In the spring, root-knot nematode juveniles emerge from eggs and migrate in the soil toward potential host roots. Juveniles enter cotton roots behind the root cap and establish a feeding site within the root.

During the growing season, as subsequent generations of the nematode establish additional infections on the same root system, damage to the host increases. As a result of root-knot nematode parasitism, cotton plants are often delayed in maturity, may exhibit reduced growth, and produce lower yields than noninfected plants in the same field. Root-knot nematode infection rarely causes plant death, and the disease is commonly misdiagnosed as a cultural or environmental problem.

T. basicola overwinters as thick-walled chlamydospores that germinate in the presence of a host and adequate soil moisture. The fungus is considered to be ecologically an obligate parasite (6,9), invading root hairs or epidermal cells directly and establishing a biotrophic relationship with the host initially. Colonization of cotton seedlings by *T. basicola* results in a characteristic black root rot, which may encompass most of the cortical tissue of the root system. The pathogen generally cannot infect the intact endodermis, and vascular tissues below the discolored cortical tissue remain healthy and white. However, *T. basicola* hyphae and chlamydospores have been observed within the vascular system of upland cotton roots when grown in the presence of unnaturally high populations of the fungus (8). Black root rot of cotton is favored by soil temperatures from 16 to 20°C (10) and is an important component

of the cotton-seedling disease complex in the Mississippi River Delta. As with root-knot, black root rot rarely results in plant death, although diseased plants develop slowly, causing delayed maturity and reduced yields. As the growing season progresses, black-root-rot severity decreases as soil temperature increases and secondary root growth sloughs off the diseased tissues.

Recent studies have shown that *T. basicola* and root-knot nematodes are frequently found together in Arkansas cotton fields (12). Microplot studies have revealed that stand establishment and early-season vigor of cotton seedlings grown in soils containing both organisms are lower than where plants are grown in soil containing either pathogen alone (15). In addition, plants that survived in soils infested with both the root-knot nematode and *T. basicola* had reduced seed-cotton yields, fewer bolls per plant, and lower boll retention in the second fruiting position compared to plants grown in soils infested with either pathogen alone or in noninfested plots (15). Histopathological studies have demonstrated that cotton plants grown in soils infested with both *T. basicola* and *M. incognita* had extensive vascular necrosis and contained fungal spores inside xylem tissue (16). This was not observed for plants grown in soils containing only the fungus. The objective of this study was to evaluate the relative impact of populations of *T. basicola* and *M. incognita* on early-season disease and plant development of cotton plants grown in microplots.

MATERIALS AND METHODS

Concrete microplots (76 by 80 cm in diameter), located at the University of Arkansas Southwest Research and Extension Center, Hope, containing Smithdale fine sandy loam soil (fine loamy siliceous, thermic Typic Paleudult), were used in 1997 and 1998 for these studies. Plots were covered with plastic film and fumigated with methyl bromide (100 g/m²) 2 months prior to use each year. The plastic film was removed and the plots were allowed to aerate for at least 3 weeks prior to soil infestation and planting. Inoculum of *T. basicola* consisted of chlamydospores harvested from 6-week-old cultures grown on 10% carrot juice agar. Inoculum was removed from plates in deionized water with a rubber scraper, separated from endocon-

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idia, and digested with chitinase (3). *M. incognita* race 3 inoculum was maintained in a greenhouse on tomato (*Lycopersicon esculentum* Mill. cv. Rutgers). Nematode inoculum was prepared and quantified according to Walker et al. (15).

Soil in the microplots was infested with *T. basicola* to obtain 20 or 100 spores/g of soil in the upper 15 cm in both years. The spores were applied to the surface of each plot in 250 cm³ of water using a sprinkle can. Inoculum of *M. incognita* was applied to the surface of microplots to obtain a final density of 5 or 10 eggs and juveniles/cm³ of soil each year. Noninfested plots served as a control. Inoculum of both pathogens was incorporated by mixing soil thoroughly with a shovel and a rake to a depth of 15 cm. Treatments consisted of a noninfested control, both rates of *M. incognita* alone, both rates of *T. basicola* alone, and all combinations of *M. incognita* and *T. basicola*. A total of 32 acid-delinted, fungicide-treated (triadimenol [Baytan], thiram, and metalaxyl; 0.1, 0.312, and 0.155 g a.i./kg seed, respectively) cotton seeds of cv. Deltapine 5415 were planted in each plot immediately following infestation. Microplot infestation

and planting occurred on 24 April 1997 and 17 April 1998 when the average daily soil temperature at 10 cm was >16°C for a 48-h period. Soil fertility was assayed and microplots were amended with N, P, and K prior to planting according to the Arkansas Cooperative Extension Service guidelines for cotton production (2). Soil and air temperatures were monitored daily.

The number of live plants was determined when the second true leaf was fully expanded, 33 and 31 days after planting (DAP) in 1997 and 1998, respectively. At 8 weeks after planting, 10 plants were arbitrarily selected from each plot and the height (in millimeters) from the cotyledonary node to the tip of the main terminal and the number of nodes were evaluated to determine plant height-to-node ratio (HNR). The portion of plant above the cotyledonary node was dried at 70°C in an oven for 5 days and weighed.

Root systems from each plant were rinsed with water and rated for disease severity on a scale of 1 to 5, where 1 = 0%, 2 = 1 to 10%, 3 = 10 to 25%, 4 = 26 to 50%, and 5 = 51 to 100% of root system discolored. Root systems were evaluated for nematode galling on a scale of 0 to 5,

where 0 = no galls per root system, 1 = 1 to 2, 2 = 3 to 10, 3 = 11 to 30, 4 = 31 to 100, and 5 = >100 galls/root system. Root systems from each plant were cut into 2- to 3-cm lengths, mixed and separated into two equal fractions based on weight. One root fraction was rinsed in running tap water for 20 min, surface-disinfested by immersion for 1.5 min in 0.5% NaOCl, blotted dry, and plated on the selective medium TB-CEN (13) amended with Penicillin G (60 mg/liter) (Sigma-Aldrich, Inc., St. Louis). This root fraction was rated for percent *T. basicola* colonization on a scale of 1 to 5, where 1 = 0%, 2 = 1 to 10%, 3 = 11 to 25%, 4 = 26 to 50%, and 5 = 51 to 100% of root segments colonized after 10 to 14 days. The other root fraction was used to extract root-knot eggs in 0.5% NaOCl for 4 min (7). Eggs from the root fraction were quantified, and transformed to a log₁₀ + 1 scale for statistical analysis. Following egg extraction, the root fraction was dried in an oven at 70°C for 5 days and weighed.

A randomized complete block design with a factorial arrangement of treatments was replicated nine times each year. Data were analyzed as a split-plot design with year as the main plot and the *T. basicola* ×

Table 1. Main and interaction effects (*P* values) for cotton plants grown in microplots infested with *Meloidogyne incognita* (Mi) and *Thielaviopsis basicola* (Tb) at different rates in 1997 and 1998^a

Source	Stand ^b	HNR ^c	Weight ^d	Necrosis ^e	Galling ^f	Colonization ^g	Eggs ^h
Year	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Mi	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.08
Tb	0.0001	0.0001	0.0001	0.0001	0.01	0.0001	0.0001
Mi × year	0.59	0.0001	0.0001	0.0001	0.13	0.07	0.39
Tb × year	0.01	0.0001	0.0001	0.0001	0.07	0.0001	0.002
Mi × Tb	0.14	0.03	0.18	0.10	0.14	0.014	0.02
Year × Mi × Tb	0.12	0.94	0.37	0.32	0.39	0.0001	0.34

^a Analysis based on nine replications from 1997 and 1998; *P* values ≤ 0.05 are significant.

^b Stand at second true leaf stage.

^c Height-to-node ratio = plant height from the cotyledonary node per number of nodes 56 days after planting.

^d Total plant dry weight in grams.

^e Root necrosis based on a scale of 1 to 5, where 1 = 0%, 2 = 1 to 10%, 3 = 11 to 25%, 4 = 26 to 50%, and 5 = 51 to 100% root discolored 56 days after planting.

^f Nematode galling of root based on a scale of 0 to 5, where 0 = no galls, 1 = 1 to 2, 2 = 3 to 10, 3 = 11 to 30, 4 = 31 to 100, and 5 = >100 galls/root system 56 days after planting.

^g Root colonization by *T. basicola* based on a scale of 1 to 5, where 1 = 0%, 2 = 1 to 10%, 3 = 11 to 25%, 4 = 26 to 50%, and 5 = 51 to 100% of root system having growth of *T. basicola* when plated on TB-CEN.

^h Extracted nematode eggs (log₁₀ + 1).

Table 2. Cotton seedling stand at second fully expanded true leaf stage (33 and 31 days after planting in 1997 and 1998, respectively), total plant dry weight, cotton seedling root necrosis, and *Meloidogyne incognita* eggs from plants grown in microplots infested with different rates of *M. incognita* (Mi) and *Thielaviopsis basicola* (Tb)^a

Main effect	Plant stand ^b		Plant dry weight (g) ^c		Root necrosis ^d		Eggs ^e	
	1997	1998	1997	1998	1997	1998	1997	1998
Tb CFU/g soil								
0	16.5	22.3	0.90	4.29	1.45	1.31	2.67	2.78
20	11.2	19.2	0.70	4.87	2.50	1.14	2.56	2.84
100	11.0	22.0	0.56	4.05	3.94	1.19	2.20	2.76
LSD within year	2.1		0.27		0.23		0.18	
LSD between years	3.8		0.63		0.28		0.26	

^a Data are the means of nine replications from 1997 and 1998. Means are not significantly different if the magnitude of the difference is not greater than the LSD value according to Fisher's protected least significant difference (LSD) at *P* ≤ 0.05.

^b Plant stand based on a total of 32 seeds planted.

^c Measured 56 days after planting.

^d Necrosis based on a scale of 1 to 5, where 1 = 0%, 2 = 1 to 10%, 3 = 11 to 25%, 4 = 26 to 50%, and 5 = 51 to 100% of the root system discolored.

^e Extracted nematode eggs expressed as log₁₀ + 1.

M. incognita factorial treatments as the split plot. Treatment means were separated with Fisher's protected least significant difference (LSD) at $P \leq 0.05$. When interactions were significant ($P \leq 0.05$), appropriate interaction means were examined and means separation calculated (Fisher's protected LSD). Treatments not receiving nematodes or fungi were omitted from analysis for nematode eggs and root galling and *T. basicola* colonization, respectively. All data were analyzed using SAS (version 6.12; SAS Institute, Cary, NC).

RESULTS

In 1997, microplot soil temperatures were typical for most years. An average soil temperature of 20.2°C during the first week after planting in 1998 was 4.3°C above that in 1997 and, over the duration of this study, was 2.8°C above the average temperature of 24.4°C in 1997. The effect of the warmer temperatures in 1998 on the parameters examined in this study was primarily a magnitude effect, resulting in increased plant growth and nematode effects and decreased black root rot. However, the nature of the relationship between *T. basicola* and *M. incognita* on each other and on plant growth were consistent over both years of this study.

A significant *T. basicola* × year interaction ($P = 0.01$) was present for stand at the second true leaf stage, indicating that the influence of *T. basicola* changed with the year (Table 1). Seedling survival for all treatments was lower in 1997 than in 1998. Seedling survival was reduced at the low rate of *T. basicola* (20 CFU/g) over all *M. incognita* rates in both 1997 and 1998 and by the high rate of *T. basicola* (100 CFU/g) over all *M. incognita* levels in 1997 compared to noninfested soil (Table 2). The number of surviving plants was reduced in the presence of *M. incognita* over all rates of *T. basicola* treatments in both years compared to soil not infested with *M. incognita* (Table 3).

A treatment × year interaction for plant HNR was present for both *T. basicola* and *M. incognita*, indicating that relative response changed with year (Table 1). A *T. basicola* × *M. incognita* interaction was consistent over years, with the response for *M. incognita* or *T. basicola* changing as the rate of the other pathogen changed. HNRs were not affected by *T. basicola* rates in the absence of *M. incognita*, but were lower compared to noninfested soil for all treatments receiving either rate of *M. incognita* (Table 4). HNRs were reduced for all combinations of the pathogens compared to the control or with either pathogen alone, except for the combination of *T. basicola* at 20 CFU/g + *M. incognita* at 5 eggs and juveniles/cm³. No differences were observed in HNR between the two nematode rates. In 1997, *T. basicola* reduced HNR over all *M. incognita* treatments and the high rate of *T. basicola* re-

duced HNR compared to the low rate of *T. basicola*.

A treatment × year interaction for plant dry weight was present for both *T. basicola* and *M. incognita*, indicating that responses changed with year (Table 1). Plant weight for all treatments was lower in 1997 than in 1998. Total plant weight was lower with *T. basicola* at 100 CFU/g across all *M. incognita* levels in 1997 than in plots that were not infested with *T. basicola* (Table 2). Plant dry weight was decreased in the presence of *M. incognita* across all *T. basicola* levels in 1998 (Table 3).

A treatment × year interaction for root necrosis was present for both *T. basicola* and *M. incognita*, indicating that differences in root necrosis changed with year (Table 1). Root necrosis was greater in 1997 than in 1998 across all treatment combinations. In 1997, root necrosis was greater in the presence of *T. basicola*, particularly at the high rate of *T. basicola* (Table 2). Root necrosis was greater in the presence of the nematode than in the nematode's absence and, in 1997, necrosis was greatest for the high rate of the nematode across all *T. basicola* rates (Table 3).

A similar trend was present in 1998, with significant necrosis occurring for plants grown in soils with *M. incognita* across all *T. basicola* treatments.

Root galling as a result of *M. incognita* infection was more severe in 1998, at 4.18, than in 1997, at 3.52. Galling severity over all *T. basicola* treatments was greater for the high rate of *M. incognita* compared to the low rate of the nematode, at 4.09 and 3.47, respectively. A reduction in root galling was evident in the presence of the low rate of *T. basicola* compared to galling in the absence of the fungus. Root galling indices were 4.02, 3.52, and 3.80 for 0, 20, and 100 *T. basicola* CFU/g of soil, respectively (LSD = 0.32).

A significant interaction for root colonization by *T. basicola* was found between *T. basicola*, *M. incognita*, and year, indicating that *M. incognita* levels and *T. basicola* levels averaged over either main effect changed with year (Table 1). In 1997, increased root colonization was observed for the low rate of *T. basicola* in the presence of the low nematode rate in comparison to the low rate of the fungus in the absence of the nematode (Table 5). In 1998, root colo-

Table 3. Cotton seedling stand at second fully expanded true leaf stage (33 and 31 days after planting in 1997 and 1998, respectively), total plant dry weight, and cotton seedling root necrosis for cotton plants grown in microplots in 1997 and 1998 infested with different rates of *Meloidogyne incognita* (Mi) and *Thielaviopsis basicola* (Tb)^a

Main effect	Stand ^d	Weight (g) ^b		Necrosis ^c	
		1997	1998	1997	1998
Mi/cm ³					
0	21.7	0.85	5.05	2.03	1.00
5	15.3	0.68	4.04	2.70	1.31
10	13.8	0.66	4.11	3.16	1.33
LSD within year	1.52		0.27		0.23
LSD between years	...		0.63		0.28

^a Data are the means of nine replications from 1997 and 1998. Means are not significantly different if the magnitude of the difference is not greater than the least significant difference (LSD) value according to Fisher's protected LSD at $P \leq 0.05$.

^b Plant dry weight 56 days after planting.

^c Root necrosis based on a scale of 1 to 5, where 1 = 0%, 2 = 1 to 10%, 3 = 11 to 25%, 4 = 26 to 50%, and 5 = 51 to 100% of the root system discolored.

^d Plant stand based on a total of 32 seed planted, both years combined.

Table 4. Cotton seedling height-to-node ratio, 56 days after planting, for plants grown in microplots infested with different rates of *Meloidogyne incognita* (Mi) and *Thielaviopsis basicola* (Tb)^a

Main effect	Tb CFU/g soil			Year	
	0	20	100	1997	1998
Mi/cm ³					
0	26.58	25.26	25.90	16.47	35.35
5	22.16	20.81	19.04	13.73	27.61
10	22.92	19.52	17.88	14.00	26.21
LSD = 1.90					
LSD within year	...	...	...	1.55	
LSD between years	...	...	...	2.27	
Year					
1997	17.51	14.68	12.02	...	...
1998	30.26	29.04	29.86	...	...
LSD within year		1.55		...	...
LSD between years		2.27		...	...

^a Height-to-node ratio = plant height (mm) from the cotyledonary node per number of nodes. Data are the means of nine replications from 1997 and 1998. Means are not significantly different if the magnitude of the difference is not greater than the least significant difference (LSD) value according to Fisher's protected LSD at $P \leq 0.05$.

Table 5. Colonization of cotton roots by *Thielaviopsis basicola*, 56 days after planting in 1997 and 1998, from cotton plants grown in microplots infested with different rates of *Meloidogyne incognita* (Mi) and *T. basicola* (Tb)^a

Main effect	Mi/cm ^{3b}					
	1997			1998		
	0	5	10	0	5	10
Tb CFU/g soil						
20	2.81	4.23	2.21	1.22	1.33	1.11
100	5.00	4.33	4.42	1.25	2.12	1.48
LSD within year			0.55			
LSD between years			0.67			

^a Root colonization by *T. basicola* based on a scale of 1 to 5, where 1 = 0%, 2 = 1 to 10%, 3 = 11 to 25%, 4 = 26 to 50%, and 5 = 51 to 100% of root system having growth of *T. basicola* when plated on TB-CEN. Data are the means of nine replications. Means are not significantly different if the magnitude of the difference is not greater than the least significant difference (LSD) value according to Fisher's protected LSD at $P \leq 0.05$.

^b *M. incognita* rates expressed as Mi/cm³ of soil.

nization was greater at the high rate of *T. basicola* in combination with the low density of *M. incognita* compared to treatments that included the fungus in the absence of the nematode. In general, colonization was lower in 1998 than 1997.

A significant interaction was present for nematode reproduction, for *M. incognita* $\times$ *T. basicola*, and *T. basicola* $\times$ year (Table 1). A *M. incognita* $\times$ *T. basicola* interaction indicated that the number of *M. incognita* eggs was influenced by changes in either treatment. Nematode reproduction was greater in 1998 than in 1997 over those treatments which received *T. basicola* (Table 2). In 1997, a reduction in eggs was observed for the high rate of *T. basicola* across all *M. incognita* levels compared to those plots not infested with *T. basicola*. In both years, the number of eggs recovered was greater for the high rate of the nematode in comparison with the low rate in the absence of the fungus (Table 6). However, nematode reproduction for the high *M. incognita* rate was reduced both years in the presence of the high rate of *T. basicola*.

DISCUSSION

Earlier research had identified the season-long effects of *M. incognita* and *T. basicola* on cotton production (15). The objectives of this study were to examine the effects of different populations of these pathogens on seedling mortality, various plant-growth parameters, and disease development. Inoculum levels of *M. incognita* were selected to approximate pre-planting densities found in Arkansas cotton fields. Inoculum levels of *T. basicola* were representative of populations in cotton fields in Arkansas, with many soils having *T. basicola* populations above 100 CFU/g of soil.

M. incognita or *T. basicola* rarely cause cotton plant mortality, although severe infestations by *M. incognita* can cause plant death late in the growing season (14). In this study, some mortality was observed with *M. incognita* alone, but greater mortality was observed where both *M. incognita* and *T. basicola* were combined. In-

creased plant mortality was associated with increasing nematode populations in the presence of *T. basicola*, indicating the importance of the nematode in the disease complex. Plant HNR has been a sensitive indicator of the interaction between these pathogens on cotton in other studies (15,16). The response of this parameter was consistent, decreasing for increasing rates of both pathogens.

The plant-growth data indicate that increasing the density of either pathogen population increases the adverse effects of disease on cotton plants. The nature of this pathogen-pathogen relationship should permit the management of either pathogen to interrupt the concomitant effects of both pathogens on plant growth. Host-plant resistance may be effective for the management of this interaction, but currently there is no known resistance in *G. hirsutum* to *T. basicola* and high levels of resistance to the root-knot nematode has not been successfully incorporated into agronomically acceptable cotton cultivars. In addition, resistance to the root-knot nematode did not appear to reduce the effects of this interaction, because the nematode may still disrupt the endodermis, a barrier to fungal colonization of plant vascular tissues before resistance is expressed (N. R. Walker et al., unpublished). Management of the nematode through chemical nematicides could minimize the threat of severe stand losses and reduction in early-season growth in those fields that have high populations of both the nematode and the fungus. Suppression of *T. basicola* with sterol-inhibiting fungicides may also minimize losses due to this interaction (4,5).

Greater root necrosis was associated with increasing *T. basicola* inoculum rates. *T. basicola* generally colonizes only cortical tissues of upland cotton in the presence of an intact endodermis (16). In both years of this study, increased root-necrosis severity was associated with root-knot nematode parasitism. Histological studies have demonstrated that parasitism by the nematode permits fungal colonization of

Table 6. *Meloidogyne incognita* eggs, 56 days after planting in 1997 and 1998, from cotton plants grown in microplots infested with different rates of *Meloidogyne incognita* (Mi) and *Thielaviopsis basicola* (Tb)^a

Main effect	Tb CFU/g soil		
	0	20	100
Mi/cm ³			
5	3.95	3.97	3.81
10	4.29	4.05	3.69
LSD		0.35	

^a Means transformed to a natural logarithm scale for analysis. Data are the means of nine replications. Means are not significantly different if the magnitude of the difference is not greater than the least significant difference (LSD) value according to Fisher's protected LSD at $P \leq 0.05$.

vascular tissues (16), possibly contributing to greater root necrosis. In 1998, low levels of root vascular-tissue discoloration were observed in treatments that were infested with both the nematode and fungus (data not shown). This was not observed for treatments not having the nematode. In this study, *T. basicola* also had an adverse effect on nematode reproduction, an observation that is consistent with previous studies (15,16).

In biological systems, it can be difficult to identify pathogen population levels that are above a population threshold for crop damage across a broad range of environmental conditions. This study attempted to identify the relative influence of *M. incognita* and *T. basicola* population levels on cotton growth responses. Generally, disease severity increased with increasing rates of either pathogen. However, the environment can play a significant role in determining which pathogen contributes a greater effect in this interaction, as was seen in 1998 when *T. basicola* populations had less impact on plant development and lower black-root-rot incidence and severity than in 1997. Consequently, identification of thresholds was not possible.

Soils in Arkansas contain population levels of both pathogens that can reduce stand, delay crop maturity, and reduce yields. This interaction may be misdiagnosed early, as other pathogens in the seedling disease complex, or later, as soil fertility problems. The chronic effects of these pathogens could potentially be a greater hindrance to maximum cotton productivity than the acute effects these pathogens initially have on stand establishment.

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