Effects of *Meloidogyne hapla* and *M. arenaria* on Black Rot Severity in New *Cylindrocladium*-Resistant Peanut Genotypes

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ABSTRACT

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Greenhouse and microplot experiments were done to determine the effects of *Meloidogyne hapla* and *M. arenaria* on the severity of Cylindrocladium black rot (CBR), caused by *Cylindrocladium crotalariae*, in the peanut (*Arachis hypogaea*) genotypes Florigiant, NC 10C, NC Ac 18416, and NC Ac 18016. In the greenhouse, severity of black rot was increased in Florigiant by either *M. hapla* or *M. arenaria* in treatments with fungal inoculum densities of 0.05 and 0.5 microsclerotia per gram of soil. Severity of black rot was not affected by these nematodes on NC 10C or NC Ac 18016. In microplots, disease ratings of roots from NC 10C, NC Ac 18416, and NC Ac 18016 were higher in plots infested with either nematode species and *C. crotalariae* than in plots with *C. crotalariae* alone. In field studies, initial and late-season populations of root-knot juveniles were correlated with incidence of CBR and area under disease progress curves for some genotypes, but results were not consistent from 1986 to 1987.

Development of Cylindrocladium black rot (CBR), a serious disease of peanut (*Arachis hypogaea* L.) in North Carolina and Virginia (4,18,22,23), is caused by the fungus *Cylindrocladium crotalariae* (C. A. Loos) D. K. Bell & Sobers (perfect stage *Calonectria crotalariae* (C. A. Loos) D. K. Bell & Sobers) (3). It is affected by many environmental and biotic factors (6,19,20,28) and is enhanced by cool, wet soils (19) and root damage caused by root-knot nematodes (*Meloidogyne* spp.) (10,11,12). A CBR-susceptible cultivar, Florigiant, and a highly CBR-resistant genotype, NC 3033, were predisposed to CBR by the northern root-knot nematode, *M. hapla* Chitwood (10,11). Race 2 of *M. arenaria* (Neal) Chitwood also promoted greater root rot severity, although these nematodes did not produce galls or reproduce on peanut (12).

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Since the reports by Diomande et al (10,11,12), new peanut genotypes have been developed with moderate levels of resistance to *C. crotalariae*. NC 8C was released in 1983, and NC 10C was released in 1988. NC 10C produces larger kernels than NC 8C and is the only CBR-resistant cultivar currently available. NC 8C and NC 10C are much more resistant to *C. crotalariae* than Florigiant, but both are more susceptible than NC 3033 (9). In areas of North Carolina infested with *C. crotalariae*, resistant genotypes represent the primary means of CBR control. Effects of root-knot nematodes on CBR severity have not been documented in moderately resistant peanut cultivars. In addition, effects of *M. arenaria* race 1 (which is pathogenic on peanut) on CBR severity have not been reported. Although *M. hapla* is reported to be the predominant *Meloidogyne* sp. in peanut in North Carolina and Virginia (25,26), *M. arenaria* race 1 has recently been found at high population densities in fields used for CBR control experiments.

The purpose of this research was to determine the effects of *M. hapla* and *M. arenaria* race 1 on CBR severity in peanut genotypes representing a range of levels of resistance to CBR, particularly in the moderately resistant genotypes NC Ac 18416 and NC 10C.

MATERIALS AND METHODS

Inoculum production. Fungal inoculum (24) for greenhouse and microplot tests was produced on potato-dextrose agar; microsclerotia (ms) were extracted as described by Phipps and Beute (21). Five isolates of *C. crotalariae* originating from peanut fields in North Carolina were used. Inocula of both species of *Meloidogyne* used in greenhouse and microplot tests were produced on tomato (*Lycopersicon esculentum* Mill. 'Rutgers') in the greenhouse. After allowing 10 wk for nematode reproduction, eggs were extracted by the NaOCl procedure (15). The *M. hapla* isolate MH 4494 was obtained from the International *Meloidogyne* Project, North Carolina State University, Raleigh. *M. arenaria* was isolated from egg masses derived from females collected in a peanut field in Martin County, NC. Species identity was confirmed using root galling symptoms, perineal patterns of adult females, and esterase phenotypes as determined by polyacrylamide gel electrophoresis (13). Electrophoretic determinations were done by P. Esbenshade and A. C. Triantaphyllou, North Carolina State University, Department of Genetics.

Greenhouse experiments. Tests were done to determine the relationships among initial population densities (Pi) of both species of nematode, fungal inoculum density, and peanut genotype during the early weeks of plant and disease development. Treatments consisted of 4 × 4 × 3 factorial combinations of four peanut genotypes, four inoculum densities (0, 0.05, 0.5, and 5 ms/g of soil) of *C. crotalariae*, and three Pi (0, 350, and 3,500 eggs per 500 cm^3 of soil) of nematodes. Genotypes used included a highly resistant breeding line, NC Ac

18016; moderately resistant genotypes NC Ac 18416 and NC 10C; and a highly susceptible cultivar, Florigiant. Experimental design was a randomized complete block with seven replications. Two experiments were conducted simultaneously. The experiments were identical, except one was done using *M. hapla*, the other using *M. arenaria*.

Portions of soil (500 cm^3 1:1 pasteurized soil to sand mix v:v) were infested with appropriate levels of inoculum of *C. crotalariae* applied in 10 ml of water. Soil was mixed thoroughly with 0.25 g of *Bradyrhizobium* spp. inoculum and placed in plastic pots 10 cm in diameter. Two germinated peanut seed were planted in each pot, and aqueous suspensions of nematode eggs were added to appropriate pots. Pots not receiving nematode inoculum received equal volumes of water. Plants were maintained in the greenhouse for 8 wk, at which time roots were removed, washed, and evaluated for root rot and galling. A root rot rating scale of 0–5 (where 0 represents completely healthy roots and 5 represents completely necrotic roots) was used to evaluate CBR symptoms (20). Roots were rated using an adaptation of the 1–10 galling index developed by Zeck (30), where 1 = no infection, 2 = 10%, 3 = 20%, 4 = 50%, 5 = 80%, and 6 = 100% of the root system galled; 7 = 75% of root system dysfunctional; 8 = no functional roots; 9 = dying plants; and 10 = dead plants. Comparisons of effects of nematode inoculation on galling of the peanut genotypes were made only for treatments receiving nematode inoculum alone. Thus, analysis was done using a 4 × 2 factorial treatment regime for both *M. arenaria* and *M. hapla* experiments.

Analysis of variance and Fisher's protected LSD values were calculated to determine significance of treatment effects (29).

Microplot experiments. Microplot tests were done at the Central Crops Research Station, Clayton, NC, in 1987 and 1988. Microplots had been constructed previously by burying 76-cm-diameter × 80-cm-high fiberglass cylinders 60 cm deep in the soil (2). Microplots were fumigated 6 wk before planting with methyl bromide/chloropicrin (98:2% w/w; 869 kg/ha).

A randomized complete block experiment included 24 treatments consisting of all possible combinations of peanut genotypes Florigiant, NC 10C, NC Ac 18416, and NC Ac 18016; 0 and 5 ms of *C. crotalariae* per gram of soil; and three nematode treatments (no nematode inoculum, *M. hapla*, and *M. arenaria*). The experiment was done as a 4 × 2 × 3 factorial. Nematode inoculum was five eggs per gram of soil, calculated for the top 15 cm of soil. Treatments were replicated four times.

Immediately before planting, ms and/or nematode eggs suspended in 4 L of water were added to appropriate plots. Plots receiving no inoculum received similar amounts of water. Inoculum was mixed thoroughly into the top 15 cm of soil. Twelve seed were planted per plot on 6 June 1987 and 15 May 1988. After emergence, plants were thinned to four per plot. Plants were maintained as recommended for peanut production. Each plot received one application of gypsum (calcium sulfate—800 kg/ha) and applications of chlorothalonil and carbaryl for leaf spot (caused by *Cercospora arachidicola* S. Hori) and insect control, respectively. Irrigation was applied as needed.

Twelve soil cores (2 cm in diameter) were taken from each plot of all treatments on 30 September 1987 and 3 October 1988 for estimation of nematode populations. Nematode extractions and counts were performed at the North Carolina Department of Agriculture Nematode Advisory Laboratory, Raleigh.

Dead, wilted, and chlorotic plants were counted immediately before harvest. Disease incidence was calculated as the percentage of symptomatic plants per plot. Analysis of disease incidence was done using only treatments with *C. crotalariae*. Plants were dug and inverted on 23 October 1987 and 14 October 1988. Roots were washed, and the taproot was split. The root system was evaluated for root rot and galling using indices previously described. Both the 0–5 root scale and the 1–10 galling scale were used for rating the entire root system plus pegs and pods of the mature plants. Data were analyzed using analysis of variance, and Fisher's protected LSD values were calculated for mean separation. Analysis of disease incidence was done only for plots with inoculum of *C. crotalariae* (4 × 3 factorial). Root gall index data was analyzed using only plots with nematode inoculum but with no fungal inoculum (4 × 2 factorial). Analysis of nematode populations was done only for plots with nematode inoculum (4 × 2 × 2 factorial).

Field experiments. Two peanut fields in Martin County, NC, were used in 1986 and 1987 to determine the relationship between population densities of root-knot nematodes in the field and CBR incidence and disease progress. The effect of peanut genotype on root-knot population density in the presence of *C. crotalariae* was also evaluated. Peanut genotypes included NC Ac 18016, NC Ac 18416, NC 10C, and Florigiant; moderately resistant genotypes NC 8C and NC Ac 18414; and highly resistant genotype NC 3033. Each field was divided into four 11- × 76.8-m quadrants (9). Two quadrants were situated in each of two adjacent areas of the field planted to peanut (quadrants 3 and 4 in 1986 and quadrants 1 and 2 in 1987) or corn (quadrants 1 and 2 in 1986 and quadrants 3 and 4 in 1987) in the previous year. Each quadrant was divided into 63 plots (3 subgroups of 21 contiguous plots, 3.7 × 3.7 m). Soil samples were taken from each plot to estimate microsclerotial inoculum density (ID) (14,21) and for nematode assays before planting. Within each subgroup, the 21 plots were ranked based on ID of *C. crotalariae* and were divided into three ID classes of seven plots, each representing relatively low, medium, and high ID classes in each subgroup. A nested experimental design was used with subgroups nested in quadrants and ID classes nested in subgroups.

Incidence of dead and wilted plants was determined each week from the appearance of the first symptoms until harvest. Incidence was calculated as percentage of dead and wilted plants of the total number of plants per plot. Area under the disease progress curve (AUDPC) was computed (9,27). Final incidence ratings

Table 1. Root rot severity ratings[a] for four peanut genotypes in the greenhouse, in relation to inoculum density of *Cylindrocladium crotalariae*, *Meloidogyne hapla*, and *M. arenaria*

	Inoculum density of *C. crotalariae* (microsclerotia per gram of soil)											
	0			0.05			0.5			5.0		
	Nematode Pi											
Nematode / Peanut genotype	0	350	3,500	0	350	3,500	0	350	3,500	0	350	3,500
M. hapla[b]												
Florigiant	0	0.6	0.4	1.1	1.4	2.7	1.9	1.9	2.5	3.0	3.2	3.3
NC 10C	0	0.5	0.5	1.1	1.0	0.9	1.2	1.7	1.8	2.6	2.3	2.4
NC Ac 18416	0	0.5	0.4	0.6	0.9	1.0	1.1	0.8	1.2	1.6	2.1	1.8
NC Ac 18016	0	0.4	0.4	0.7	0.6	0.8	0.9	0.8	0.9	1.5	1.8	1.6
M. arenaria[c]												
Florigiant	0	0.6	0.5	1.1	1.9	2.3	2.4	1.7	2.9	2.9	2.9	3.5
NC 10C	0	0.4	0.4	1.1	1.3	1.0	1.3	1.1	1.6	2.8	3.1	2.7
NC Ac 18416	0	0.4	0.5	0.6	0.9	1.5	0.9	1.2	1.4	1.8	1.8	1.8
NC Ac 18016	0	0.4	0.5	0.7	0.8	0.8	1.0	0.8	1.0	1.1	1.6	1.6

[a] Ratings done using 0 to 5 scale (0 = healthy roots, 5 = completely rotted roots).
[b] LSD = 0.73 ($P \leq 0.05$) for comparison of *C. crotalariae* and *M. hapla* effects within and across genotypes.
[c] LSD = 0.64 ($P \leq 0.05$) for comparison of *C. crotalariae* and *M. arenaria* effects within and across genotypes.

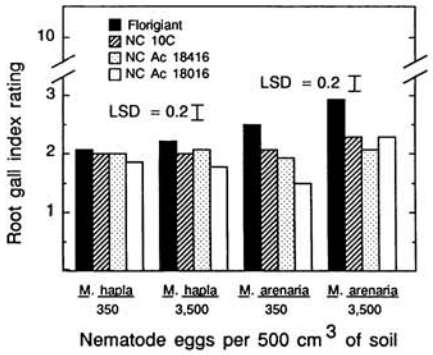

Fig. 1. Root galling in four peanut genotypes induced by 350 and 3,500 eggs of *Meloidogyne hapla* and *M. arenaria* per pot. LSD's for comparison of gall index ratings within nematode species.

were made 20 wk after planting in both years.

Each plot was sampled 5 wk before harvest in both years to estimate population densities of root-knot nematode juveniles. Number of root-knot juveniles per 550 cm^2 of soil was determined by the North Carolina Department of Agriculture Nematode Advisory Service.

Data were subjected to analysis of variance, and significance of treatment effects was determined using Fisher's LSD values (29). Relationships between initial or late-season nematode numbers and final incidence of CBR or AUDPC were determined for each genotype using Pearson's correlation coefficients (29). Correlations were calculated across all quadrants using 36 plots per genotype and within each quadrant using nine plots per genotype.

RESULTS

Greenhouse experiment. In both the *M. arenaria* and *M. hapla* experiments, genotype, fungal ID, genotype × fungal ID, and nematode effects on root rot severity were significant ($P < 0.05$). Genotype × nematode Pi, fungal ID × nematode Pi, and genotype × fungal ID × nematode Pi interactions were not significant ($P > 0.05$) in either experiment. Root rot severity was enhanced in Florigiant by the addition of either *M. hapla* or *M. arenaria* in soil with 0.5 ms of *C. crotalariae* per gram of soil (Table 1). At 0.05 and 0.5 ms/g of soil of fungal inoculum, addition of *M. hapla* or *M. arenaria* at 3,500 eggs per pot resulted in root rot ratings in Florigiant that were as high as those in pots receiving 5 ms/g of soil. Root rot severity was not altered by either nematode in plants of Florigiant in soils receiving 5 ms/g of soil (Table 1). Root rot in NC Ac 18416 was higher in plants grown in soil with 0.05 ms/g of soil plus 3,500 eggs of *M. arenaria* per pot than those grown with no nematode inoculum (Table 1) but was not affected by nematode inoculum at other fungal ID's or by *M. hapla*. Neither *Meloidogyne* sp. enhanced root rot in NC 10C or NC Ac 18016.

Table 2. Effect of *Meloidogyne arenaria, M. hapla*, and *Cylindrocladium crotalariae* on incidence of dead and wilted plants in CBR-resistant and susceptible peanut genotypes in microplots in 1988

Genotype	Dead and wilted plants (%)		
	C. crotalariae	*C. crotalariae* and *M. hapla*	*C. crotalariae* and *M. arenaria*
Florigiant	21.8	68.8	37.5
NC 10C	18.7	37.5	25.0
NC Ac 18416	6.3	6.3	12.5
NC Ac 18016	3.1	6.3	6.3
LSD ($P \leq 0.05$)		9.6[a]	

[a] LSD for comparisons across and within columns.

Moderate galling occurred on all genotypes at both Pi (Fig. 1). There were no differences among genotypes for *M. hapla* at 350 eggs per pot. Galling indices were slightly less on NC Ac 18016 than on NC Ac 18416 or Florigiant for *M. hapla* at 3,500 eggs per pot and were lower than all other genotypes at 350 eggs of *M. arenaria* per pot. Galling indices were higher in Florigiant than in other genotypes in pots receiving either Pi of *M. arenaria*.

Microplot experiments. In 1987, very few dead or severely wilted plants were observed, and these occurred only in plots of Florigiant. In 1988, CBR symptoms developed in all genotypes, but percent incidence of dead and wilted plants was greatest in Florigiant (Table 2). In 1988, genotype, nematode inoculum, nematode species, and genotype × nematode inoculum effects on incidence of dead and wilted plants were significant. Addition of either *M. hapla* or *M. arenaria* with *C. crotalariae* increased the incidence of dead and wilted plants in Florigiant. Incidence of dead and wilted plants for Florigiant and NC 10C was greater in plots receiving *C. crotalariae* and *M. hapla* than in those receiving *C. crotalariae* and *M. arenaria* (Table 2). Incidence of dead and wilted plants in NC Ac 18416 was higher, although not significantly, in plots infested with both *M. arenaria* and *C. crotalariae* than in other treatments with that genotype. Incidence of CBR in NC Ac 18016 was slightly higher in plots receiving either nematode plus *C. crotalariae* than that in plots receiving *C. crotalariae* alone, although differences were not significant.

In 1987, genotype, fungal inoculum, nematode infestation main effects and genotype × fungal inoculum, and nematode and genotype × nematode inoculum species interaction effects on root rot severity were significant. Root rot ratings on Florigiant plants grown in soil with *C. crotalariae* alone were higher than those of any other genotype receiving this treatment (Fig. 2). Root rot ratings for NC 10C and NC Ac 18416 were similar in plots infested with only *C. crotalariae* and were only slightly higher than those of NC Ac 18016 (Fig. 2). Root rot ratings on Florigiant plants grown in plots infested with *C. crotalariae* and *M. hapla* were higher than those of any other treatment. Root rot in NC 10C was enhanced by addition of either species of *Meloidogyne*, although *M. arenaria* had the greater effect (Fig. 2). A combination of *C. crotalariae* and *M. arenaria* increased root rot severity in NC 10C to levels similar to those observed in Florigiant. *M. arenaria* caused a large increase in root rot severity in NC Ac 18416, but *M. hapla* did not. When added to fungal inoculum, both *M. arenaria* and *M. hapla* resulted in higher root rot index values in NC Ac 18016 than did the fungus alone.

In 1988, genotype, fungal inoculum, nematode inoculum, and genotype × fungal inoculum interaction had significant effects on root rot severity. Florigiant had root rot ratings greater than any other genotype in plots infested with *C. crotalariae* alone, and ratings were near the maximum of 5 (Fig. 2). No increase in root rot in Florigiant was observed with the addition of either nematode with *C. crotalariae* because of the severity of root rot caused by the fungus alone. For plants grown in soil with *C. crotalariae* alone, ratings in NC 10C were higher than those of NC Ac 18416 or NC Ac 18016; root rot ratings for NC Ac 18416 and NC Ac 18016 were similar in soils receiving *C. crotalariae* alone. In the resistant genotypes, *M. arenaria* had a greater effect on root rot than did *M. hapla*. Addition of *M. hapla* with fungal inoculum had no significant effect on root rot in NC 10C, NC Ac 18416, or NC Ac 18016. Root rot ratings of plants grown in soil with *M. arenaria* and *C. crotalariae* were higher than those with the fungus alone for all genotypes except Florigiant. Addition of *M. arenaria* or *M. hapla* plus *C. crotalariae* resulted in root rot ratings in NC 10C as high as those observed in Florigiant (Fig. 2).

Among treatments not receiving inoculum of *C. crotalariae* but receiving nematode inocula, genotype, nematode species, and genotype × species interaction effects on root galling were significant in 1987. Galling indices for all genotypes were higher in plots infested with *M. arenaria* than those for plots infested with *M. hapla* in both years (Fig. 3). In 1987, galling indices in plots re-

ceiving *M. arenaria* were lower for NC Ac 18016 than for other genotypes (Fig. 3). In 1988, the effects of nematode species on galling were significant, whereas genotype and genotype × nematode effects were not. Galling indices in plots with *M. arenaria* were higher than those with *M. hapla* (Fig 3). Galling was observed on peanut pods in plots infested with *M. arenaria* but not in plots infested with *M. hapla*.

No main effect of any factor had significant ($P > 0.05$) effect on population of either nematode among the treatments with nematode inoculum in either year. Differences observed were for specific combinations of factors. In 1987, final populations of *M. arenaria* were similar regardless of peanut genotype or fungal inoculum level (Fig 4). In 1988, final populations of *M. arenaria* were greatest in plots of Florigiant and NC 10C receiving nematodes alone than in soil infested with both organisms (Fig. 4). In both years, populations were similar in plots infested with *M. arenaria* and *M. arenaria* plus *C. crotalariae* except for NC 10C in 1988, when populations were higher in plots without fungal inoculum than in plots with fungal inoculum. Plots planted to Florigiant that received *M. hapla* plus *C. crotalariae* had the lowest nematode numbers, whereas plots planted to NC AC 18016 and infested with nematode and inoculum of *C. crotalariae* supported the greatest levels of *M. hapla* (Fig. 4). Numbers of *M. hapla* were similar on NC 10C and NC Ac 18416 at either fungal inoculum level (Fig. 4). In 1988, *M. hapla* numbers were greatest in plots planted to NC 10C or NC Ac 18416 without fungal inoculum and in plots planted to NC Ac 18016 with both nematode and fungal inoculum (Fig. 4).

Field experiments. In 1986, the number of nematodes recovered from plots of NC 10C was greater than from any other genotype (Table 3). No differences were observed between the other moderately resistant genotypes and Florigiant in 1986 and 1987. Numbers of nematodes generally were lower on NC 3033 and NC Ac 18016 than on the more susceptible genotypes in both years (Table 3). In 1986, nematode densities tended to be larger in quadrants planted to peanut the previous year, whereas in 1987, they tended to be larger in quadrants planted to corn the previous year.

In 1986, nematode Pi were weakly correlated with AUDPC for CBR across all quadrants of Florigiant ($r = 0.39$, $P = 0.01$) and NC 8C ($r = 0.34$, $P = 0.04$). No significant correlation between Pi and disease incidence or AUDPC occurred within individual quadrants for any genotype. In 1987, no correlations between initial root-knot population levels and CBR incidence or AUDPC were detected across quadrants. Initial nematode numbers and CBR incidence were correlated ($r = 0.69$, $P = 0.03$) in NC Ac 18416 in quadrant 4. AUDPC and Pi were also correlated ($r = 0.85$, $P = 0.01$) in these plots.

Late-season root-knot populations and CBR incidence were weakly correlated ($r = 0.32$, $P = 0.05$) across quadrants of NC Ac 18016 in 1986. Correlations between root-knot population numbers and AUDPC were also detected in NC Ac 18416 ($r = 0.32$, $P = 0.05$). Nematode numbers and CBR incidence were highly correlated ($r = 0.83$, $P = 0.01$) in NC 8C in quadrant 1. Strong correlations between both CBR incidence ($r = 0.83$, $P = 0.01$) and AUDPC ($r = 0.78$, $P = 0.01$) nematode numbers were detected in NC Ac 18414 in quadrant 2. Correlations between CBR incidence and late-season root-knot levels in 1987 were detected in NC 3033 ($r = 0.90$, $P = 0.01$) and Florigiant ($r = 0.70$, $P = 0.03$) in quadrants 1 and 2, respectively. Correlation between nematode densities and AUDPC was detected only in NC 3033 in quadrant 1 ($r = 0.98$, $P = 0.01$) in 1987.

DISCUSSION

Effects of root-knot nematodes may be of greater importance in moderately CBR-resistant genotypes than previously recognized. Although NC 10C has greater resistance to *C. crotalariae* than does Florigiant, it has less resistance than NC Ac 18016 and NC 3033 (9). Diomande and Beute (11) proposed that *M. hapla* may contribute more to the CBR syndrome in CBR-resistant NC 3033 than in Florigiant. Results of the microplot study in 1987 indicate that effects of either *M. hapla* or *M. arenaria* may be more important in NC 10C than in genotypes with higher levels of resistance. This was apparent for *M. aren-*

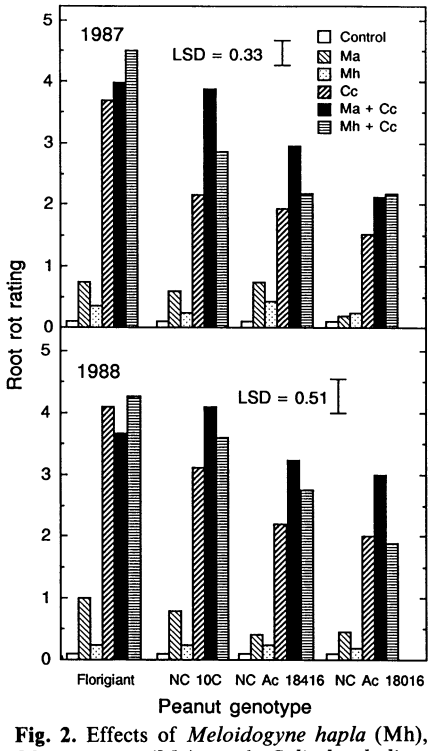

Fig. 2. Effects of *Meloidogyne hapla* (Mh), *M. arenaria* (Ma), and *Cylindrocladium crotalariae* (Cc) on root rot of four peanut genotypes in 1987 and 1988 microplot experiments (0 = healthy root system, 5 = completely rotted). LSD for comparison of treatment effects among genotype and treatment combinations.

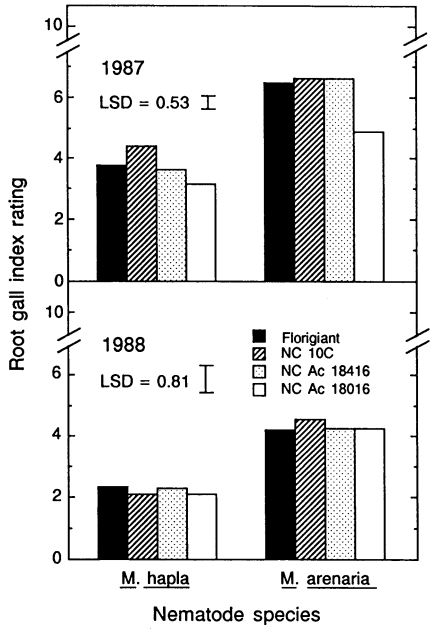

Fig. 3. Root galling of four peanut genotypes induced by *Meloidogyne hapla* and *M. arenaria* in 1987 and 1988 microplot tests (0 = no galling, 8 = 100% of roots galled, 10 = dead roots). LSD for comparison of genotype and nematode species effects.

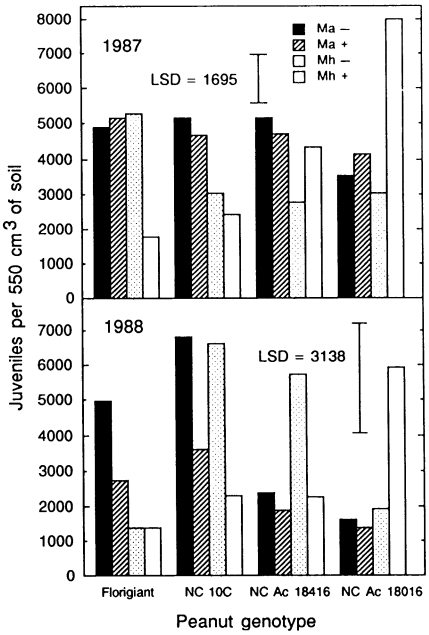

Fig. 4. Effects of peanut genotype on populations of *Meloidogyne hapla* (Mh) and *M. arenaria* (Ma) in soils with (+) and without (–) inoculum of *Cylindrocladium crotalariae* in microplot studies in 1987 and 1988 (numbers per 550 cm^3 of soil). LSD for comparison of treatment effects among genotype and treatment combinations.

aria in 1988 also. In addition, both species of nematode may contribute more to root rot severity in NC 10C than in susceptible Florigiant at moderate levels of inoculum. Given the additional stress of infestation with higher levels of root-knot nematodes, root rot severity in NC 10C may approach that of susceptible Florigiant. In 1988, root rot on plants of Florigiant was not affected by addition of either *Meloidogyne* spp. with inoculum of *C. crotalariae*, because very severe root destruction occurred in Florigiant without any nematodes. Critical ID levels required for severe damage from *C. crotalariae* are higher for resistant genotypes than for Florigiant, even in the presence of additional stress from root-knot nematodes. This response is illustrated by little enhancement of CBR severity by *M. hapla* or *M. arenaria* in the resistant peanut genotypes in the greenhouse study. Inocula of *C. crotalariae* at 0.5 ms/g of soil or lower were not sufficient to promote severe root rot in NC Ac 18016, NC Ac 18416, and NC 10C in the greenhouse, even in the presence of large numbers of root knot nematodes. Management of these nematodes in fields with average ID of *C. crotalariae* in the range of 2–5 ms/g of soil should contribute more toward CBR control in cultivars with moderate resistance to *C. crotalariae* than in susceptible cultivars.

Although *M. hapla* is more often reported on peanut in North Carolina (25,26), *M. arenaria* was also detected in both test fields used in 1986 and 1987 studies. Differences in amount of damage induced by *M. arenaria* may be responsible, in part, for a smaller response in root rot ratings in the presence of *Meloidogyne* inoculum in NC Ac 18016 than in NC 10C and Florigiant. Similarly, the trend toward greater response in root rot ratings to *M. arenaria* than to *M. hapla* in NC 10C and NC Ac 18416 may be attributable, to some extent, to more damage caused by *M. arenaria*, as indicated by galling ratings. Our ratings for microplot or greenhouse tests, however, did not consider differences between the two species in the types of galling they cause. More information is needed on the incidence of *M. arenaria* and its effects, alone or in combination with *C. crotalariae*, on peanut in North Carolina.

Although NC 3033 and NC AC 18016 had lower late-season nematode population levels than the other genotypes, they also had less extensive root systems, which may have limited nematode reproduction. Nematode data from microplots in 1988 and final counts from the field in 1986 suggested that NC 10C promoted development of greater root-knot nematode populations in some circumstances than did the other genotypes. Evidence for differences among genotypes in galling and nematode reproduction in this study is not conclusive. Specific tests of reactions of the different genotypes to *Meloidogyne* and comparisons of root mass in these genotypes are needed. Resistance to *M. hapla* or *M. arenaria* currently is not available in commercial Virginia-type peanut cultivars (16) but has been reported in other species of *Arachis* (17). Eventual incorporation of moderate levels of resistance to *M. hapla* and/or *M. arenaria* into cultivars with resistance to *C. crotalariae* should enhance effective resistance to the fungal pathogen.

Detection of significant correlations between initial and late-season nematode populations in CBR-susceptible and CBR-resistant genotypes suggests that CBR incidence and disease progress are related to the density of root-knot nematodes present in the field. Correlations for some genotypes between nematode numbers, CBR incidence, and AUDPC within individual quadrants indicate that dispersion and level of the nematodes within a field and across different cropping histories may influence CBR incidence. Our inability to detect a correlation between CBR incidence and nematode levels, in many cases, may have been attributable to the greater importance of inoculum density of the fungal pathogen itself and/or environmental factors such as temperature or moisture that influenced CBR development in those plots. Correlations between final populations of *M. hapla* and CBR incidence were detected by Diomande and Beute for both NC 3033 and Florigiant (11).

NC 10C was released as a CBR-resistant cultivar for use in peanut production areas infested with *C. crotalariae*. NC 10C has agronomic characteristics that are more acceptable to buyers, shellers, and processors than those of its predecessor, NC 8C (9). Although both cultivars may suffer severe damage in areas with high inoculum densities of *C. crotalariae*, NC 10C appears to respond more drastically to increases in inoculum of this pathogen (9). Therefore, practices that reduce inoculum density of the pathogen, such as crop rotation (5,7) and fumigation with metam sodium (1,8), appear to be more important in NC 10C than in NC 8C (9). Likewise, factors that affect inoculum efficiency of *C. crotalariae*, such as use of later planting date (28) and control of root-knot nematodes, may be more important in managing CBR in moderately resistant genotypes than in Florigiant.

Table 3. Effect of previous crop and peanut genotype on final populations of root-knot nematodes in 1986 and 1987 field tests[a]

Year	Quadrant 1		2		3		4		
Genotype	C[b]	P[c]	C	P	C	P	C	P	Mean[d]
1986[e]									
Florigiant	460		394		768		998		655
NC 8C	659		550		746		1,184		785
NC 10C	1,021		416		1,579		1,929		1,236
NC Ac 18416	532		312		816		1,563		806
NC Ac 18414	737		481		766		950		734
NC 3033	297		314		632		836		520
NC Ac 18016	218		339		546		681		446
1987[f]									
Florigiant		653		1,120	3,864		2,281		1,979
NC 8C		473		986	2,184		4,341		1,996
NC 10C		1,414		1,653	1,890		2,830		1,947
NC Ac 18416		1,254		983	1,757		2,017		1,502
NC Ac 18414		101		324	488		735		412
NC 3033		291		659	924		535		602
NC Ac 18016		267		413	602		677		490

[a] Values represent mean number of juveniles extracted from 550 cm^3 of soil collected 5 wk before harvest from nine plots in 1986 and 1987.
[b] C = corn planted in this portion of the field during previous cropping season.
[c] P = peanut planted in this portion of the field during previous cropping season.
[d] Mean of 36 plots per genotype.
[e] LSD = 320 ($P \leq 0.05$).
[f] LSD = 608 ($P \leq 0.05$).

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LITERATURE CITED

1. Bailey, J. E. 1983. Use of fumigants for control of black root rot (CBR). Virginia-Carolina Peanut News 29:14.
2. Barker, K. R., Daughtry, B. I., and Corbett, D. W. 1979. Equipment and techniques for establishing field microplots for the study of soilborne pathogens. J. Nematol. 11:106-108.
3. Bell, D. K., and Sobers, E. K. 1966. A peg, pod, and root necrosis of peanut caused by a

species of *Calonectria*. Phytopathology 5:1361-1364.
4. Beute, M. K. 1980. Cylindrocladium Black Rot (CBR) disease of peanut (*Arachis hypogaea*). Pages 171-176 in: Proc. Int. Workshop Groundnuts, ICRISTAT, India.
5. Black, M. C., and Beute, M. K. 1984. Effects of rotations with susceptible and resistant peanuts, soybeans, and corn on inoculum efficiency of *Cylindrocladium crotalariae* on peanuts. Plant Dis. 68:401-405.
6. Black, M. C., and Beute, M. K. 1984. Relationships among inoculum density, microsclerotium size, and inoculum efficiency of *Cylindrocladium crotalariae* causing root rot on peanuts. Phytopathology 74:1128-1132.
7. Black, M. C., Pataky, J. K., Beute, M. K., and Wynne, J. C. 1984. Management tactics that complement host resistance for control of Cylindrocladium black rot of peanuts. Peanut Sci. 11:70-73.
8. Cline, W. O., and Beute, M. K. 1986. Effect of metam sodium, peanut genotype and inoculum density on incidence of Cylindrocladium black rot. Peanut Sci. 13:41-45.
9. Culbreath, A. K., Beute, M. K., and Wynne, J. C. 1990. Use of spatial patterns and inoculum density of *Cylindrocladium crotalariae* in field evaluation of moderately resistant peanut genotypes. Phytopathology 80:1395-1400.
10. Diomande, M., and Beute, M. K. 1981. Effects of *Meloidogyne hapla* and *Macropostonia ornata* on Cylindrocladium black rot of peanut. Phytopathology 71:491-496.
11. Diomande, M., and Beute, M. K. 1981. Relation of *Meloidogyne hapla* and *Macropostonia ornata* populations to Cylindrocladium black rot in peanuts. Plant Dis. 65:339-342.
12. Diomande, M., Black, M. C., Beute, M. K., and Barker, K. R. 1981. Enhancement of *Cylindrocladium crotalariae* root rot by *Meloidogyne arenaria* (Race 2) on a peanut cultivar resistant to both pathogens. J. Nematol. 13:321-327.
13. Esbenshade, P. R., and Triantaphyllou, A. C. 1985. Use of enzyme phenotypes for identification of *Meloidogyne* species. J. Nematol. 17:6-20.
14. Hau, F. C., Campbell, C. L., and Beute, M. K. 1982. Inoculum distribution and sampling methods for *Cylindrocladium crotalariae* in a peanut field. Plant Dis. 66:568-571.
15. Hussey, R. S., and Barker, K. R. 1973. A comparison of methods of collecting inocula of *Meloidogyne* spp. including a new technique. Plant Dis. Rep. 57:1025-1028.
16. Minton, N. A., and Hammons, R. O. 1975. Evaluation of peanut for resistance to the root-knot nematode, *Meloidogyne arenaria*. Plant Dis. Rep. 59:944-945.
17. Nelson, S. C., Starr, J. L., and Simpson, C. E. 1990. Expression of resistance to *Meloidogyne arenaria* in *Arachis batizocoi* and *A. cardenasii*. J. Nematol. 23:423-425.
18. Pataky, J. K., and Beute, M. K. 1983. Peanut yield, market quality and value reductions due to Cylindrocladium black rot. Peanut Sci. 10:62-66.
19. Phipps, P. M., and Beute, M. K. 1977. Influence of soil temperature and moisture on the severity of Cylindrocladium black rot in peanut. Phytopathology 67:1104-1107.
20. Phipps, P. M., and Beute, M. K. 1977. Sensitivity of susceptible and resistant peanut cultivar to inoculum densities of *Cylindrocladium crotalariae* microsclerotia in soil. Plant Dis. Rep. 57:1035-1039.
21. Phipps, P. M., Beute, M. K., and Barker, K. R. 1976. An elutriation method for quantitative isolation of *Cylindrocladium crotalariae* microsclerotia from peanut field soil. Phytopathology 66:1255-1259.
22. Rowe, R. C., Beute, M. K., and Wells, J. C. 1973. Cylindrocladium black rot of peanuts in North Carolina—1972. Plant Dis. Rep. 57:387-389.
23. Rowe, R. C., Beute, M. K., Wells, J. C., and Wynne, J. C. 1974. Incidence and control of Cylindrocladium black rot of peanuts in North Carolina during 1973. Plant Dis. Rep. 58:348-352.
24. Rowe, R. C., Johnston, S. A., and Beute, M. K. 1974. Formation and dispersal of *Cylindrocladium crotalariae* microsclerotia in infected peanut roots. Phytopathology 64:1294-1297.
25. Sasser, J. N., Barker, K. R., and Nelson, L. A. 1975. Chemical soil treatment for nematode control on peanut and soybean. Plant Dis. Rep. 59:154-158.
26. Sasser, J. N., Barker, K. R., and Nelson, L. A. 1975. Correlation of field populations of nematodes with crop growth responses for determining relative involvement of species. J. Nematol. 7:193-198.
27. Shaner, G., and Finney, P. E. 1977. The effect of nitrogen fertilization on expression of slow mildewing resistance in Knox Wheat. Phytopathology 67:1051-1056.
28. Sidebottom, J. R., and Beute, M. K. 1989. Control of Cylindrocladium black rot of peanut with cultural practices that modify soil temperature. Plant Dis. 73:672-675.
29. Steel, R. G. D., and Torrie, J. H. 1980. Principles and procedures of statistics, 2nd ed. McGraw-Hill, New York.
30. Zeck, W. M. 1971. A rating scheme for field evaluation of root-knot nematode investigation. Pflanzenshutz-Nachr. 24:141-144.