Inducing Soil Suppression to Cylindrocladium Black Rot of Peanut Through Crop Rotations with Soybean

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ABSTRACT

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Crop rotations involving corn, soybean, and peanut were established in microplots and field plots to determine their effect on Cylindrocladium black rot (CBR) development in peanut. Corn is a nonhost to the pathogen *Cylindrocladium crotalariae*. Soybean is a host, but may reduce inoculum efficiency of microsclerotia. In the field, cultivar Ransom soybean or Pioneer corn hybrid 3389 planted in alternate years reduced the rate of CBR increase in a partially resistant peanut cultivar, NC 8C. The fastest rate of disease increase was observed in rotations where either corn or soybean was grown 2 yr before and peanut was grown the year immediately before the peanut crop. However, continuous monoculture of peanut resulted in a moderate rate of increase and low CBR incidence after 3 yr. Preplant microsclerotia densities each year in field plots were affected by overwintering conditions and were similar among rotations. In a microplot experiment with similar rotations, CBR severity was not reduced in peanut directly following soybean. The microsclerotia densities were higher following peanut and soybean than following corn and were higher in microplots than in field plots. In other microplot experiments involving peanut genotypes Florigiant and NC 18416, CBR severity was reduced following soybean regardless of inoculum density. Five soybean cultivars, in addition to Ransom, reduced CBR severity in NC 8C peanut, but the effects varied with year. Rotations with soybean also increased populations of *Meloidogyne* spp., the root-knot nematode, and *Sclerotium rolfsii*, the causal agent of southern stem rot of peanut. The increases in other pests may reduce the potential gain in yield from soybean and peanut rotations.

Additional keywords: *Arachis hypogaea*, cropping systems

Cylindrocladium crotalariae (Loos) Bells & Sobers (teliomorph = *Calonectria crotalariae* (Loos) Bells & Sobers) (3) is a soilborne pathogen that causes Cylindrocladium black rot (CBR) of peanut (*Arachis hypogaea* L.). The pathogen can infect and rot any belowground portion of the plant including roots, pegs, and pods. The overwintering structure and primary inoculum for this pathogen is microsclerotia that are produced in host roots and nodules (13,21,25).

Severity of CBR increases as the density of microsclerotia in the soil increases (10,24). Even resistant genotypes become diseased at high inoculum densities. On the susceptible cultivar Florigiant, 0.5 microsclerotia per gram of soil caused severe disease, whereas 50 or more microsclerotia per gram of soil were required to obtain the same severity in the resistant breeding line NC 3033 (20).

Biotic and abiotic factors modify the relationship between inoculum density and disease development. For instance, infection by the northern root-knot nematode, *Meloidogyne hapla* Chitwood, and ring nematode, *Criconemella ornata* Raski, reduces the number of microsclerotia required to induce 50% CBR incidence in NC 3033 and Florigiant (8). Cool temperatures and high soil moisture also enhance disease development (19). Currently, the disease is controlled with resistant cultivars, rotations to nonhosts such as corn (*Zea mays* L.) (23), and fumigation with metham-sodium. The first cultivar that was developed that combined moderate resistance to CBR with good agronomic characteristics was NC 8C (17). Even with currently recommended rotations and fumigation, inoculum densities in the field are often sufficient to cause severe disease in NC 8C.

C. crotalariae also attacks soybean (*Glycine max* (L.) Merr.) roots and stems (23), although yield is seldom reduced in North Carolina. Because the microsclerotia produced on soybean are pathogenic on peanut (21,24), it is recommended that peanut not follow soybean in a rotation (14,21,23). However, Black and Beute (5) observed that inoculum produced on soybean was less efficient at causing peanut root rot than inoculum produced on peanut. In a 3-yr study conducted in microplots, they established all possible crop sequences among corn, Ransom soybean, Florigiant, and NC 3033 peanut. In the final year, the preplant inoculum densities following Florigiant and soybean were similar and greater than those following NC 3033 and corn. However, root rot was more severe in peanut that followed NC 3033 than in peanut that followed soybean. A greater number of microsclerotia produced on soybean were required to cause the same root rot severity on peanut.

Black and Beute (6) proposed several mechanisms to explain the lower efficiency of microsclerotia following previous cropping to soybean. They suggested that because nodules are more susceptible to infection than nonnodulated root tissue (11) and because soybean adds nitrogen to the soil, rotations with soybean may result in a peanut that has fewer nodules and is less prone to infection (18). They also observed that actinomycete and bacterial populations were higher in microplots after soybean than following either corn or peanut (6). The actinomycetes isolated did not suppress CBR development in the greenhouse, but did increase peanut growth in the absence of the pathogen. Other unidentified shifts in soil microbial populations also could influence disease development (6).

The objective of this study was to further characterize the effects of previous cropping to soybean on CBR development in peanut. A 3-yr rotational study was initiated on a commercial peanut farm to determine if soybean and corn grown 1 or 2 yr before peanut would suppress CBR incidence under field conditions. Microplot studies were initiated to further study these rotations and to determine if soybean cultivars other than Ransom, the cultivar used by Black and Beute (5), also would produce a suppressive effect. In addition, the effect of soybean/peanut/corn rotations on the development of southern stem rot in peanut was investigated.

MATERIALS AND METHODS

Field crop rotational experiment. A 3-yr crop rotation study was initiated in 1984 in a peanut field in Martin County, NC, where a high incidence of CBR had

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been observed in peanut grown in 1983. Treatments were eight 3-yr rotations among corn (C), peanut (P), and soybean (S) including C-C-P, P-C-P, S-C-P, C-P-P, S-S-P, P-S-P, S-P-P, and P-P-P, where the order of the three letters represents the crops grown in 1984, 1985, and 1986, respectively. The recommended rotations in North Carolina are C-C-P, P-C-P, and S-C-P. Additional rotations allowed comparisons in 1986 of CBR incidence in peanut following either 1 yr (P-S-P) or 2 yr (S-S-P) of continuous soybean. The effect of a single-year rotation to soybean also could be tested in 1985 (S-P-P). The S-C-P and S-P-P rotations tested possible residual effects of soybean after the second year. The P-P-P monoculture was included as a control for rotation effects. The experimental design was a randomized complete block with five replications.

Plots were large (7.3 [eight rows] × 18.3 m) to minimize spread of crop residues and inoculum to adjacent plots as well as to make it easier to relocate plots each year. Location of plots was measured from permanent structures around the field. There were no alleys between plots.

Plots were sampled each April to estimate preplant inoculum density of *C. crotalariae*. Soil samples were taken 15–20 cm deep on a grid pattern every 0.5 m with a 2-cm-diameter probe (12). In 1984 and 1987, soil was bulked and mixed for a single composite sample from each plot. In 1985 and 1986, a single composite sample was taken from one-third sections (7.3 × 6.1 m) of each plot resulting in three samples per plot. From each composite sample, a single subsample (approximately 200 g) was assayed for the pathogen by elutriation and plating on semiselective medium (22). Inoculum densities in microsclerotia per gram of oven-dry (105 C) soil were calculated. In addition, a single subsample (about 1.3 kg) from each plot was assayed for plant parasitic nematodes by the North Carolina Department of Agriculture Soil Testing Laboratory.

Ransom soybean and Pioneer 3389 corn were grown all 3 yr. NC 8C peanut was grown in 1985 and 1986, when disease evaluations were made. NC 2 peanut, a CBR-susceptible cultivar, was grown in 1984 due to the nonavailability of NC 8C. Corn was planted approximately six seeds per meter; peanut and soybean were planted approximately 13 seeds per meter. All crops were planted in rows 0.91 m apart. Planting dates were 4 May 1985, and 17 May 1986.

In all years, carbofuran (1.7 kg a.i./ha) was applied in the furrow at planting. Alachlor (0.1 kg a.i./ha) was applied preemergence in all plots, and atrazine (0.05 kg a.i./ha) was applied to plots planted to corn. All subsequent weed control was done by hand. Corn was fertilized at planting and 1 mo after planting with 5-10-30 (450 kg/ha). Finely ground gypsum was applied to peanut at the rate of 670–900 kg/ha at the end of June each year to promote good pod growth. Every 2 wk from mid-July to mid-September chlorothalonil (0.45 kg a.i./ha) was applied to peanut with a backpack sprayer for leaf spot control.

Development of CBR was assessed from aboveground symptoms of wilting, chlorosis, and plant death. Assessments were made from mid-July until harvest every other week in 1984 and 1985, and every week in 1986. The number of symptomatic plants was determined in the inner 12.2 m of each row for the middle four rows of each plot. Counts were converted to percent incidence by dividing by the number of plants per section of row assessed. After harvest, plant residues were incorporated into the soil before frost by disking.

Data on percent CBR incidence were analyzed separately for each year and assessment date by analysis of variance (AOV) ($P \leq 0.05$). Data from 1986 also were analyzed by repeated measures analysis. In addition, linear and quadratic regressions of disease over time were fitted for each treatment. Square root transformations of the percent disease incidence were taken to normalize the variance. Appropriateness of models was evaluated by R^2 values and examination of residuals plots. A linear model was fitted to the data from each treatment. The resulting regressions were compared by a reduced vs. full model F test ($P \leq 0.05$) (15). In addition, analyses of covariance (AOC) ($P \leq 0.05$), with log of the microsclerotia, *Meloidogyne* spp., *Criconemella* spp. (ring nematode), and *Tylenchorhynchus* spp. (stunt nematode) densities as the covariate, were calculated to account for differences in pathogen density between plots. The effect of rotational treatments on changes in microsclerotia density and nematode density was also determined from year to year by AOV ($P \leq 0.05$). Daily mean ambient air temperature and rainfall from December through March from 1984 to 1987 were obtained from either the weather station at Williamston (5 km east) or Lewiston (32 km north) (1).

Microplot experiments. Four microplot experiments were conducted at the Central Crops Research Station at Clayton, NC. These included a crop rotation study similar to the one conducted in the field, two tests to determine whether soybean cultivars other than Ransom soybean suppress infection by *C. crotalariae*, and a test to determine the effects of rotations with soybean on southern stem rot caused by *Sclerotium rolfsii* Sacc. as well as CBR.

Microplots for all experiments were established previously by burying 76-cm-diameter × 80-cm fiberglass cylinders 60 cm deep in a Norfolk loamy sand (2). All microplots except those used in the soybean/peanut evaluation and the *S. rolfsii*/CBR test had been previously infested with *C. crotalariae* (2). Preplant inoculum densities were estimated each year by taking 15–20 soil samples with a 2-cm-diameter probe to a depth of 15–20 cm. Samples were bulked, mixed, and assayed for *C. crotalariae* as previously described. Planting dates for all experiments were 11 June 1984, 10 May 1985, and 15 May 1986. Seedlings were thinned to give four peanut, six corn, or 10 soybean plants per plot. Pesticides and fertilizers were identical to those applied in the field for the appropriate crop and were broadcast at the same rates.

Incidence of CBR was assessed weekly in all plots planted to peanut by counting the number of dead or wilted plants per microplot. Peanuts were dug on 19 October 1984, 13 October 1985, and 1 October 1986, and roots of each of the four plants per plot were rated in the field for root rot severity on a scale from 1 to 5 (1 = healthy, 5 = dead plant) (20). Data on aboveground incidence and root rot severity from the four plants were averaged to give a single incidence and severity rating per plot.

Peanut plants were allowed to dry after harvest. Corn stalks were cut at the ground and removed. Soybean stems bearing pods were cut and removed. The remaining soybean stems were cut into 6- to 10-cm pieces. Peanut plants and pods and soybean stems subsequently were buried 20 cm deep in each plot.

Microplot crop rotational experiment. A 3-yr crop rotation study was initiated in 1984 in microplots that had been infested with several field isolates of *C. crotalariae* in 1979. Treatments were similar to the field rotational experiment and included C-C-P, P-C-P, S-C-P, C-P-C, S-S-P, P-S-P, S-P-S, and P-P-P rotations. Treatments were arranged in a completely random design with five replications. Ransom soybean, Pioneer 3389 corn, and NC 8C peanut were grown in all years. Data were analyzed by AOV and AOC ($P \leq 0.05$), with the log of the microsclerotia density as the covariate. Significance of treatments was determined by Waller-Duncan k-ratio t tests and appropriate single degree of freedom contrasts ($P \leq 0.05$).

Soybean evaluations. Two experiments were initiated to determine the ability of soybean cultivars other than Ransom to generate soils suppressive to CBR. Soybean cultivars used included Forrest and Essex (maturity group V), Centennial and Davis (maturity group VI), and Ransom and Coker 237 (maturity group VII). The first experiment (soybean evaluation) was a 4-yr study to determine the effect of soybean cultivars on CBR severity in NC 8C peanut following 1 or 2 yr of soybean. The second experiment (soybean/peanut

evaluation) was a 2-yr study to determine the effect of the six soybean cultivars and NC 8C peanut on CBR development in Florigiant (susceptible), NC 8C (moderately resistant), and NC 3033 (highly resistant) peanut the following year. The objective was to determine whether peanut with varying levels of CBR resistance would react differently to soil-suppression effects generated by soybean.

The soybean evaluation experiment was conducted in microplots previously infested with *C. crotalariae*. In 1984, all microplots were planted to soybean. In 1985, half of the plots were planted to NC 8C peanut to determine CBR severity in peanut, and the other half were planted to the same cultivar of soybean to determine if the suppressive effect could be intensified with 2 yr of soybean culture. In 1986, the plots planted to peanut in 1985 were planted to the original soybean cultivar, and the plots planted to soybean in 1985 were planted to NC 8C peanut. In 1987, all plots were planted to NC 8C peanut. The experimental design was a randomized complete block with three replications. Data were analyzed by AOV and AOC ($P \leq 0.05$), with the log of the microsclerotia density as the covariate. Treatment effects were evaluated by appropriate single degree of freedom contrasts ($P \leq 0.05$).

The soybean/peanut evaluation experiment was conducted in microplots not previously infested with *C. crotalariae*. Soil had not been previously fumigated. In 1985, six field isolates of the pathogen were grown on PDA in the dark for 6 wk. Mycelium, microsclerotia, and agar were ground in a blender, and agar and mycelium were washed from the suspension over a 75-μm mesh sieve (5). Microsclerotia were incorporated into the soil of each microplot in early May to give an approximate density of 15 microsclerotia per gram in the upper 10 cm. Six weeks later, 10% of the plots were sampled for inoculum density as previously described. The average microsclerotia density of these plots was assumed to be the microsclerotia density for all plots.

Following infestation of microplots, NC 8C peanut and the six soybean cultivars were planted. In 1986, plots were planted with either Florigiant, NC 8C, or NC 3033 peanut. The treatment design was a complete factorial with five blocks. Data were analyzed by AOV and AOC ($P \leq 0.05$), with the log of the microsclerotia density as the covariate.

Southern stem rot experiment. A microplot study was initiated in 1985 to determine effects of soybean rotations on both southern stem rot of peanut (caused by *S. rolfsii*) and CBR. In early May of 1985, all microplots were infested with *C. crotalariae* to an approximate inoculum density of 15 microsclerotia per gram as previously described. In addition, half the plots were infested with 100 culturally produced, nonsterile sclerotia (4) of *S. rolfsii* (broadcast on the surface of the soil on 11 July 1985).

Microplots were planted in 1985 with either corn (a nonhost to both pathogens), Ransom soybean (to generate soils suppressive to CBR), or one of three peanut genotypes including Florigiant, NC 8C, and NC 18416 (partially resistant to *S. rolfsii*). In 1986, all microplots were planted with either Florigiant, NC 8C, or NC 18416. If peanuts were grown in 1985, the same genotype was planted in 1986. CBR severity was assessed weekly as previously described. Southern stem rot was assessed on 5 September, 15 September, and 16 October 1986. Light to dark brown stem rot lesions were counted in each plot and divided by the number of plants per plot. Because it was impossible to determine the number of lesions on dead plants, these were excluded from the analysis.

Plots were sampled for an estimation of the number of sclerotia of *S. rolfsii* on 10 June and 15 August 1986. Soil samples were taken 10 cm deep with a 2-cm-diameter probe. Ten to 15 samples were taken in each plot and were bulked and mixed. From this composite sample, a single subsample (400 g) was assayed for the pathogen by a wet-sieving methanol procedure (26). Data were analyzed by AOV and AOC ($P \leq 0.05$), with either log of the microsclerotia density of *C. crotalariae*, sclerotia density of *S. rolfsii*, or both as the covariate. Significance of treatments was determined by Waller-Duncan *k*-ratio *t* tests ($P \leq 0.05$).

RESULTS

Field crop rotational experiment. The average preplant inoculum density across all plots was 3.4, 3.4, 3.6, and 10.3 microsclerotia per gram of soil in 1984, 1985, 1986, and 1987, respectively. Initial inoculum density was significantly greater in 1987. Rotational treatment only affected microsclerotia density in 1985 as determined by single degree of freedom contrasts (Fig. 1).

Preplant nematode populations were affected by the rotational treatment, but effects varied among years. Populations of *Meloidogyne* and *Criconemella* spp. were lowest in 1985, and the crop grown in 1984 did not affect the preplant densities of these species in 1985 (Fig. 2). In contrast, preplant density of *Meloidogyne* spp. in 1986 was greater in plots having either soybean or peanut in 1985; density of *Criconemella* spp. in 1986 was greater in plots having peanut in 1985 (Fig. 2). In both 1985 and 1986, preplant density of *Tylenchorhynchus* spp. increased after corn, increased slightly after soybean, and decreased after peanut (Fig. 2). The crop grown in 1984 did not affect the preplant population density of any nematode species examined in 1986.

Air temperature means and minimums from December through March were similar for all three winters, but the winter of 1986–1987 was the wettest (1). From December through March, there was 26 cm of precipitation during 1984–1985, 14 cm during 1985–1986, and 39 cm during 1986–1987 (1).

Incidence of CBR in peanut averaged 42, 50, and 21% in 1984, 1985, and 1986, respectively. Incidence did not differ significantly among treatments in 1985. In 1986, the rate of increase was faster in rotations S-P-P and C-P-P, as determined by *F* tests, than any other rotation (Table 1). CBR incidence for rotation P-P-P was lower in 1986 than in the 2 previous years. The log of nematode and microsclerotia preplant

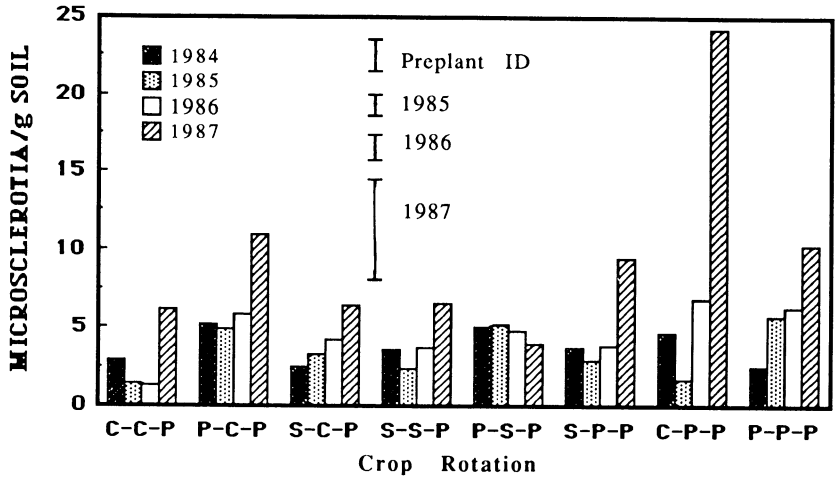

Fig. 1. Effect of crop rotations on preplant microsclerotia density of *Cylindrocladium crotalariae* from 1985 to 1986. Rotations were between Pioneer corn hybrid 3389 (C), Ransom soybean (S), and NC 8C peanut (P), where the order of the three letters represents the crops grown in 1984, 1985, and 1986, respectively. The microsclerotia density in 1984 represents the preplant density at the beginning of the experiment.

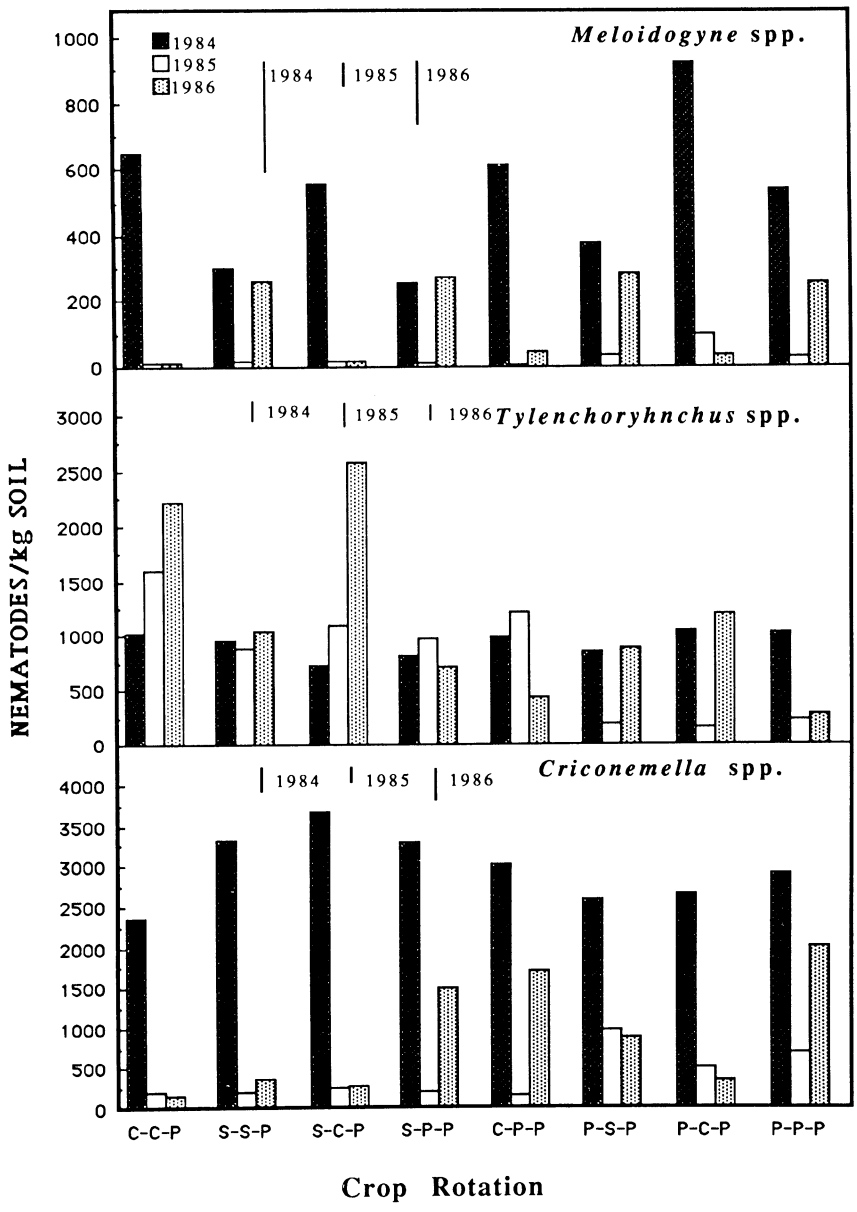

Fig. 2. Effect of crop rotations on preplant populations of plant parasitic nematodes from 1985 to 1986. Rotations were between Pioneer corn hybrid 3389 (C), Ransom soybean (S), and NC 8C peanut (P), where the order of the three letters represents the crops grown in 1984, 1985, and 1986, respectively. Population density in 1984 represents the initial population before any rotational treatments were imposed.

Table 1. Effect of crop rotation on rate of Cylindrocladium black rot (CBR) increase and percent incidence of plants with aboveground symptoms at harvest for cultivar NC 8C peanut in 1986

Rotation[x]	Slope[y]	Intercept	Disease incidence (%)
S-P-P	1.16*[z]	−0.55	27.3
C-P-P	1.15*	−0.15	28.7
P-C-P	0.92	0.32	22.9
S-S-P	0.99	−0.38	21.4
S-C-P	0.83	0.13	19.4
P-P-P	0.97	−0.33	18.8
P-S-P	0.89	−0.37	16.4
C-C-P	0.70	0.59	15.1

[x]Rotations were between Pioneer corn hybrid 3389 (C), cultivar Ransom soybean (S), and NC 8C peanut (*P*), where the order of the three letters represents the crops grown in 1984, 1985, and 1986, respectively.

[y]Rate of CBR increase as determined by developing linear regression line for each plot with square root transformations of the percentage of plants showing aboveground symptoms for each of five sampling dates through the season.

[z]Slopes followed by an asterisk differ significantly from C-C-P.

densities were not significant covariates in an analysis of disease incidence at harvest and did not alter treatment effects for either year.

Microplot crop rotational experiment. The average preplant microsclerotia density in microplots was 14.0, 29.7, and 15.4 microsclerotia per gram of soil in 1984, 1985, and 1986, respectively (Table 2). In 1985 and 1986, microsclerotia density was reduced in plots where corn had been planted the previous year as determined by single degree of freedom contrast statements. The crop planted in 1984 did not affect microsclerotia density in 1986.

Root rot severity on NC 8C peanut was 3.6, 4.3, and 2.8 in 1984, 1985, and 1986, respectively (Table 2). Severity of CBR varied with rotational treatments only in 1986 (Table 2).

Severity of CBR was significantly reduced in the rotations C-C-P and S-C-P compared with other treatments. In contrast to the field rotational experiment, the log of the microsclerotia density was a significant covariate and accounted for the differences among treatments (Table 2).

Soybean evaluations. The preplant microsclerotia density in the soybean evaluation experiment was 23.0, 43.1, 18.8, and 17.3 microsclerotia per gram of soil for 1984, 1985, 1986, and 1987, respectively. Initial inoculum density was greatest ($P \leq 0.05$) in 1985. The microsclerotia density was similar among treatments each year.

The greater inoculum density in 1985 resulted in greater CBR severity in NC 8C peanut that year than any other year (Table 2). CBR root rot severity in NC 8C peanut in 1987 was less following soybean than following peanut. Differences in root rot severity in peanut following different soybean cultivars were not consistent over years. In 1985, CBR severity in NC 8C peanut was greatest following 2 yr of previous cropping to soybeans from maturity group V (Forrest and Essex) than following any other cultivar as determined by single degree of freedom contrast statements (Table 3). Results from 1986 were the opposite: peanut following 1 yr of previous cropping to soybean from maturity group V had the least root rot (Table 3). In 1987, there were no differences between root rot in peanut following soybean from different maturity groups.

In the soybean/peanut evaluation experiment, neither preplant microsclerotia density nor CBR severity was affected by the crop grown in 1985 (Table 4). CBR was most severe in Florigiant, intermediate in NC 8C, and least in NC 3033 (Table 4). The microsclerotia density was a significant covariate to CBR severity but did not affect treatment differences.

Southern stem rot experiment.

Preplant propagule densities of *C. crotalariae* and *S. rolfsii* in 1986 were least following corn (Table 5). The microsclerotia density was a significant covariate in analysis of CBR severity but affected treatments equally. CBR severity and stem rot incidence were less following corn than following either soybean or peanut (Table 5). For Florigiant and NC 18416, CBR severity was also less following soybean than following peanut (Table 5). The presence of *S. rolfsii* did not affect CBR incidence or severity.

DISCUSSION

Previous studies (5) indicated a potential for improving the control of root rot of *C. crotalariae* on partially resistant peanut genotypes by induction of a suppressive soil condition through rotation with Ransom soybean. The mechanisms of this suppression are not known. It is known, however, that microsclerotia densities following soybean are as great as following peanut, and that the microsclerotia are viable and have high general and low specific virulence (5). Because the development of CBR is determined by inoculum density, it was thought that the effect of cropping with soybean was to modify soil biota or soil chemistry so that either plant resistance was enhanced or inoculum efficiency was reduced.

One of the primary goals of this study was to determine if CBR severity could be reduced in a commercial peanut field with rotations to soybean. Because of the high variation among plots, differences in disease incidence at harvest in 1986 were not significant even though there was a 13% difference between the highest and lowest treatment mean (Table 1). However, rate of disease increase was faster following 1 yr of peanut (S-P-P and C-P-P) (Table 1). Of the three rotations currently recommended, C-C-P produced the lowest final disease incidence (15%) and the slowest rate of increase (slope = 0.7) (Table 1). The rotation P-S-P was comparable to this (Table 1), indicating that peanut/soybean rotations were viable rotations under our test conditions. One- (P-S-P) and two- (S-S-P) year rotations to soybean produced similar results, suggesting that the suppressive effect was not enhanced by continued cropping to soybean. The suppressive effect of soybean also did not persist after the first year. The rotation S-P-P produced the greatest final incidence and the fastest rate of disease increase (Table 1).

Surprisingly, 4 yr of continuous monoculture of peanut (P-P-P) did not produce the greatest incidence of CBR in the field. Final incidence in 1986 (18.8%) was similar to C-C-P (15.1%) (Table 1). The rate of disease development also was less than for treatments where peanut followed only 1 yr of peanut (S-P-P, C-P-P). Incidence was less in P-P-P plots in 1986 than during the 2 previous years. This study suggests that continuous cropping to peanut may reduce CBR incidence after the second or third year.

The mechanisms for suppression with continuous monoculture of peanut may be different from the suppression produced by soybean. If they were similar, the rotation S-P-P would have resulted in a rate of CBR increase similar to P-P-P. Continuous culture of peanut may affect the virulence of the pathogen population or may create microbial changes in the soil that are detrimental to the pathogen. Some populations of *C. crotalariae* shift in virulence over time after continuous cropping to peanut, especially after cropping to a resistant genotype (7). Monoculture of a host has resulted in a decrease of disease development for other soilborne pathogens over time. For example, yield losses caused by the take-all disease caused by *Gaumannomyces graminis* (Sacc.) v. Arx & H. Olivier var. *tritici* Walker will first increase then decrease with successive cropping of wheat in some soils (27).

Cropping history does affect CBR development in the field, but it does not appear to be the overriding factor determining disease severity. In 1985, there were no effects of the crop grown in 1984 on CBR incidence. CBR incidence averaged greater than 50% for the three treatments planted to peanut that year. Inoculum efficiency appeared to have been so high that any effect due to previous crops was overwhelmed. To reduce inoculum efficiency in 1986, planting was delayed from early May to mid-May. Cool soil temperatures enhance CBR development, and delaying planting to allow soils to warm can reduce CBR development by as much as

Table 2. Effect of crop rotation on preplant microsclerotia (ms) density of *Cylindrocladium crotalariae* and root rot severity of Cylindrocladium black rot in cultivar NC 8C peanut in microplots from 1984 to 1986

Rotation[u]	Inoculum density[v]	Root rot[w]	Inoculum density	Root rot	Inoculum density	Root rot	Adjusted root rot[x]
C-C-P	9.7 a[y]	...[z]	2.2 a	...	0.5 b	1.3 c	2.2 a
S-S-P	19.9 a	...	39.6 a	...	19.9 a	3.2 ab	2.6 a
S-C-P	7.4 a	...	34.7 a	...	1.2 b	2.0 bc	2.5 a
S-P-S	17.1 a	...	24.0 a	4.4 a	17.2 a	...	...
C-P-C	30.7 a	...	15.5 a	4.0 a	27.6 a	...	...
P-S-P	6.5 a	4.3 a	39.8 a	...	24.6 a	3.6 a	3.1 a
P-C-P	12.6 a	3.7 a	36.3 a	...	14.5 a	3.5 a	3.2 a
P-P-P	11.6 a	2.8 b	43.5 a	4.5 a	20.5 a	3.6 a	3.1 a

[u] Rotations were between Pioneer corn hybrid 3389 (C), cultivar Ransom soybean (S), and NC 8C peanut (P), where the order of the three letters represents the crops grown in 1984, 1985, and 1986, respectively.
[v] Preplant inoculum density; microsclerotia per gram of soil oven-dry weight.
[w] Root rot severity: 1 = healthy root system, 5 = completely rotted root system. All values are an average of four peanut plants per plot and five replications.
[x] Root rot severity adjusted after the differences in microsclerotia density among plots were taken into account by analysis of covariance.
[y] Values in the same column followed by the same letter do not differ.
[z] Peanuts not planted in this rotation this year.

Table 3. Effect of 1- and 2-yr crop rotations with six soybean cultivars (or cultivar NC 8C in 1987) on preplant inoculum densities of *Cylindrocladium crotalariae* and root rot severity of Cylindrocladium black rot in NC 8C peanut

					1987			
	1985[v]		1986[y]		Peanut[z]		Soybean[y]	
Soybean cultivar[u]	Root rot[w]	Inoculum density[x]	Root rot	Inoculum density	Root rot	Inoculum density	Root rot	Inoculum density
Essex	4.33	54	1.67	26	1.45	10	1.50	30
Forrest	4.42	43	2.00	9	1.75	11	2.00	18
Centennial	3.33	51	3.02	11	2.67	12	1.83	20
Davis	3.50	58	2.92	18	2.41	22	1.45	23
Coker 237	3.00	56	2.60	25	3.17	11	1.40	16
Ransom	3.58	47	3.77	32	2.73	16	1.75	18
LSD	0.89	12	1.05	18	1.81	14	0.89	18
Mean	3.69	52	2.66	20	2.36	14	1.66	21

[u] Forrest and Essex are soybean maturity group V, Centennial and Davis are soybean maturity group VI, and Ransom and Coker 237 are maturity group VII.
[v] Severity following 1 yr of soybean.
[w] Root rot severity: 1 = healthy root system, 5 = completely rotted root system. All values are an average of three peanut plants per plot and three replications.
[x] Preplant inoculum density; microsclerotia per gram of soil oven-dry weight.
[y] Severity following 2 yr of soybean.
[z] Severity following 1 yr of NC 8C peanut.

40% (28). In our experiment, delayed planting resulted in a lower average disease incidence (21%); differences between rotations in the rate of CBR increase were evident. These results suggest that crop rotations to soybean or even to corn are not effective by themselves in controlling CBR if the environment is conducive to disease development.

In microplots with the same rotations as in the field experiment, crop rotations affected CBR development by altering preplant inoculum density and not by reducing the efficiency of inoculum. The failure of soybean to reduce the efficiency of inoculum in this microplot experiment may be explained in part by the high microsclerotia density. The average preplant inoculum density in the field rotational experiment from 1984 to 1986 was 3.4 microsclerotia per gram of soil; in the microplot rotational experiment it was 19.7 microsclerotia per gram of soil. High inoculum density would overwhelm the moderate resistance found in NC 8C and may negate any possible suppressive soil factor.

Table 4. Effect of crop rotation with six soybean cultivars and cultivar NC 8C peanut in 1985 on preplant microsclerotia density of *Cylindrocladium crotalariae* and root rot severity of Cylindrocladium black rot on three peanut genotypes in 1986

Peanut genotype[v]	Previous crop[w]	Inoculum density[x]	Root rot[y]	Adjusted root rot[z]
Florigiant	NC 8C	14.2	4.06	3.92
	Coker 237	20.1	4.20	4.28
	Centennial	25.2	4.13	4.43
	Essex	10.1	3.49	3.86
	Forrest	14.9	4.25	4.26
	Ransom	18.8	4.27	4.28
	Davis	30.8	4.60	4.59
NC 8C	NC 8C	34.8	3.77	3.58
	Coker 237	18.7	3.38	3.39
	Centennial	23.3	3.17	3.34
	Essex	13.9	3.56	3.51
	Forrest	20.3	3.50	3.15
	Ransom	20.6	3.37	3.28
	Davis	16.4	3.27	3.42
NC3033	NC 8C	6.9	2.82	2.65
	Coker 237	18.6	2.87	2.82
	Centennial	19.3	2.94	2.85
	Essex	21.1	2.79	2.80
	Forrest	26.4	2.54	3.34
	Ransom	16.0	3.10	3.19
	Davis	18.4	2.88	2.90

[v] Florigiant is susceptible, NC 8C is moderately resistant, and NC 3033 is highly resistant to Cylindrocladium black rot.
[w] Forrest and Essex are soybean maturity group V, Centennial and Davis are soybean maturity group VI, and Ransom and Coker 237 are maturity group VII.
[x] Preplant inoculum density; microsclerotia per gram of oven-dry soil.
[y] Root rot severity: 1 = healthy root system, 5 = completely rotted root system. All values are an average of four peanut plants per plot and five replications.
[z] Root rot severity adjusted for differences in microsclerotia density among plots.

Table 5. Effect of previous crop on preplant microsclerotia (ms) density of *Cylindrocladium crotalariae* and sclerotia density of *Sclerotium rolfsii* and the severity and incidence of Cylindrocladium balck rot and southern stem rot in three peanut genotypes

		S. rolfsii		*C. crotalariae*	
Peanut genotype	Previous crop	Sclerotia/kg	Lesions/plant	Inoculum density[w]	Root rot[x]
Florigiant	Florigiant	30.2 a[y,z]	6.7 a	12.8 a	3.2 a
	Soybean	21.1 a	6.9 a	17.1 a	2.9 ab
	Corn	6.0 b	2.7 b	3.8 b	2.3 b
NC 8C	NC 8C	12.6 a	6.5 a	7.9 a	3.5 a
	Soybean	11.6 a	6.7 a	13.5 a	3.4 a
	Corn	2.5 b	2.7 b	3.5 a	2.3 b
NC 18416	NC 18416	20.7 a	8.5 a	10.0 a	4.2 a
	Soybean	15.6 a	6.6 a	19.5 a	3.4 b
	Corn	6.0 b	2.7 b	2.7 b	3.2 b

[w] Preplant inoculum density; microsclerotia per gram oven-dry weight.
[x] Root rot severity: 1 = healthy root system, 5 = completely rotted root system. All values are an average of four peanut plants per plot and five replications.
[y] Values determined by counting stem rot lesions caused by *S. rolfsii* per plot and dividing by the number of plants per plot. All values are an average of four peanut plants per plot and five replications.
[z] Values in the same column and genotype followed by the same letter do not differ.

Survival of microsclerotia through the winter is reduced by a combination of cold and dry soils (16,29). Deep burial of inoculum protects microsclerotia from harsh overwintering conditions. Pataky and Beute (16) observed that 55% of the microsclerotia in infested soil buried 25 cm deep survived the 24-wk period from November until May at the Central Crops Research Station in North Carolina. In contrast, only 0.5% of the microsclerotia on the surface of the soil survived the same period. In this study, plant residues in microplots were buried approximately 20 cm deep in the soil. Protruding microplot structures (about 150 cm) may have prevented excessive drying or freezing of soil. Residues in the field were disked before frost, but this operation would not allow as uniform or as deep a placement of residues in the soil as in microplots. A combination of these factors may result in better survival of inoculum in microplots.

Because microsclerotia survived in high numbers in microplots, the preplant inoculum density accurately reflected the host status of the plants grown the year before. In contrast, preplant inoculum density in field plots often was not determined by the host status of the crop grown the year before, but by the overwintering conditions in a particular year. The combination of cold, dry soils in the winters of 1984–1985 and 1985–1986 resulted in low microsclerotia survival. Data from this study and other studies (9,21) suggest that the overwintering conditions can be as important in determining initial inoculum density as crop rotations.

Peanut genotypes with varied resistance to *C. crotalariae* reacted similarly to induced suppression by soybean. Black and Beute observed a reduction in CBR severity for both Florigiant and NC 3033 following soybean (5). In this study, CBR root rot severity was reduced in Florigiant (Table 5), NC 18416 (Table 5), and NC 8C (Tables 1 and 3) grown after soybean. Resistant and susceptible peanut genotypes react similarly when infected with *C. crotalariae*. Both genotypes will produce periderms to wall off the infected cortex from the stele, but susceptible genotypes are less efficient than resistant genotypes at producing periderms and the pathogen often grows faster and can penetrate the stele before the barrier is complete (11).

Of the soybean cultivars tested, none was clearly better in the induction of CBR suppressive soils. Differences between soybean maturity groups were not consistent over years. This may have been because soybean cultivars from different maturity groups were planted and harvested at the same time. Cultivars would not have been at the same growth stage at the same calendar date, which may have affected the induction of

suppression.

Soybean and peanut have several plant pathogens in common. Cropping to soybean increased or maintained populations of *Meloidogyne* spp. and *S. rolfsii*. Of the two pathogens, the increase in *Meloidogyne* spp. is most important because *M. hapla* has been shown to greatly increase the efficiency of microsclerotia of *C. crotalariae* (8).

Growing soybean in rotation with peanut did reduce CBR development under certain conditions but was not the most important factor determining disease severity. High inoculum density and high disease pressure by planting early appears to reduce the effectiveness of this strategy. Planting soybean increased microsclerotia densities in microplots, but in the field harsh overwintering conditions appear to affect subsequent preplant microsclerotia density as much as does crop rotation. Planting soybean also increases *Meloidogyne* spp. and populations of *S. rolfsii*. Further research into the mechanisms of suppression may elucidate ways to solve some of these problems.

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