Influence of Crop Rotation on Severity of Crown and Brace Root Rot Caused in Corn by *Rhizoctonia solani*

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ABSTRACT

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Field microplots were infested with anastomosis group (AG)-2 or AG-4 of *Rhizoctonia solani*, Rhizoctonialike binucleate fungi or uninfested and planted to 3-yr cropping systems of corn-peanut-corn, peanut-corn-corn, cucumber-cowpea (double-crop)-corn-peanut, or turnip-soybean (double-crop)-corn-peanut. Crown and brace root rot in corn was more severe each year in soil infested with AG-2 than with other treatments, but there were no differences among cropping systems. Corn yield for 3 yr averaged 22% less in soil infested with AG-2 than in uninfested soil. Root and hypocotyl disease severity in peanut was slight each year in all soil treatments, and there were no differences in yield. *R. solani* AG-2 type 2 was isolated from 1.5–11.0% of the seed from unblemished attached or loose peanut pods during the last 2 yr of the study. Rhizoctonia-like CAG-2 and CAG-4 were isolated from both unblemished and loose peanut pods in the third year. Only AG-4 caused fruit rot and reduced plant stand in cucumber. There were no differences in root disease severity or yield among soil treatments in turnip, cowpea, or soybean. *R. solani* AG-2 was recovered from soil after the first year of crops but not thereafter. *R. solani* AG-4 and Rhizoctonia-like CAG-2 and CAG-4 were recovered from soil after each cropping season. Population density of indigenous *R. zeae* in soil increased more following corn than following peanut during the last 2 yr of the experiment.

Additional key words: *Laetisaria arvalis*.

A disease caused in the crown and brace (lateral, adventitious) roots of corn by *Rhizoctonia solani* Kühn, anastomosis group (AG) 2, type 2, is widespread in Georgia (22). The disease has been identified in the United States only in 17 counties in the Georgia coastal plain, primarily on corn grown under intensive management with overhead irrigation. A similar crown and lateral root rot has been identified in France (20) and New Zealand (8). In Georgia, the pathogen can be isolated from unblemished peanut seed collected from pods loose in the soil after digging (4). Peanuts are grown in rotation with corn in many counties in the Georgia coastal plain. Isolates of *R. solani* AG-2 type 2 cause cankers in carrot (2,10,15), brown patch in St. Augustine grass (9,14), root diseases in radish (10) and sugar beet (13,17), and seedling diseases in flax, spinach, crucifers, snap bean, lima bean, pole bean, and cowpea (1,16,21,22).

The purpose of this research was to study crown and brace root rot of corn in soil infested with *R. solani* AG-2 and AG-4 and Rhizoctonia-like binucleate fungi (RLBF) in cropping systems including peanut and corn.

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MATERIALS AND METHODS

The experiments were done in field microplots prepared in the early 1960s by placing metal cylinders (96-cm diameter) into holes approximately 50 cm deep. The cylinders were filled with a 20 cm layer of gravel, a 10 cm layer of sand, and a 20 cm layer of Tifton loamy sand (approximately 85, 10, and 5% sand, silt, and clay, respectively). The metal was perforated adjacent to the gravel layer to allow excess water to drain laterally from the microplots, and the metal rim was 15-20 cm above the ground to prevent contamination from surface drainage. A variety of vegetable and forage crops were grown for several years, then monocrops of peanut were grown the 2 yr immediately preceding these experiments. Each microplot was fumigated by injecting 327 L of DD-MENCS (20% methylisothiocyanate and 80% chlorinated C_3 hydrocarbons) per hectare 25 cm deep into the soil 29 January 1980. The soil was stirred 20-30 cm deep by hand with a fork in March to hasten dissipation of the fumigant. Buried peanut pods and shells from the previous crops were inadvertently mixed with the topsoil during this procedure.

A factorial split-plot experiment was used with a randomized complete block design. Data were analyzed with least squares analysis of variance statistical procedure. Whole plots were 3-yr cropping systems replicated three times: corn (*Zea mays* L.)-peanut (*Arachis hypogaea* L.)-corn; peanut-corn-corn; cucumber (*Cucumis sativus* L.)-cowpea (*Vigna unguiculata* (L.) Walp.) (double crop)-corn-peanut; and turnip (*Brassica campestris* subsp. *rapifera* (Metzg.) Sinsk.)-soybean (*Glycine max* L.) (double-crop)-

corn-peanut. Subplots were fungi within cropping systems: *R. solani* AG-4; *R. solani* AG-2 (not designated to type); RLBF (not subdivided by anastomosis group); and uninfested control. Cultures of fungi were grown on 3% (w/w) cornmeal-sand (CMS) for 21–25 days in 1-L flasks. Isolates used were from crops and soil in the Georgia coastal plain. For each subplot treatment, several isolates were grown separately, and a mixture of five or six isolates was used in each treatment to infest each microplot 2 May 1980. Inoculum was incorporated 15 cm deep with a shovel at approximately 1:500 (v/v) CMS:soil (35–40 cm^3 of each isolate per microplot). Nothing was added to the control microplots. Approximately 0.004% (w/w) organic matter was added to the soil in the inoculum. This was considered insignificant compared with the 0.5% organic matter present in Tifton loamy sand soils in the Georgia coastal plain.

Crops were grown with fertility, insect control, and foliage disease control programs recommended by the University of Georgia Cooperative Extension Service. Herbicides were not used, but weeds were removed periodically by hand. Turnip leaves were harvested as greens, cucumber fruits for fresh market, and cowpea as green peas. Peanut and soybean were harvested at maturity. Corn ears were harvested when grain moisture was 25–30%, and yield was adjusted to grain at 15.5% moisture. Turnip and cucumber residues were incorporated 15 cm into the topsoil with a shovel 14–18 days before succeeding crops were planted. Corn roots and peanut pods were dug, evaluated for diseases, and the unused root and pod debris were returned to the soil surface and left during the fall of 1980. Peanut and corn were planted no-till directly into the undisturbed soil in 1981. In contrast, corn debris was incorporated 15 cm deep with a shovel in August, September, and December 1981, and 10–15 cm deep in March 1982. Peanut hulls and foliage were incorporated 15 cm deep in December 1981 and 5–10 cm deep with fertilizer just before planting in March 1982.

Root and hypocotyl disease severity. Number of seeds per microplot were as follows: corn, 8; peanut, 12 (20 in 1983); cucumber, 40; cowpea, 20; turnip, 200; and soybean, 20. When cucumber, cowpea, and soybean plants were 2–3 wk old, every other plant was dug and rated for root and hypocotyl disease severity on a scale of 1-5 in which 1 = < 2%, 2 = 2–10%, 3 = 11–50%, 4 = > 50% discoloration and decay, and 5 = dead or dying plant. In turnip, plants in three 5- to 7-cm sections of row were removed at random 3 wk after planting and rated. Corn and peanut were thinned to four and eight plants, respectively, 4–7 wk after planting and the plants that were removed were rated. The remaining corn plants were dug at harvest (14–18 wk) and the roots were rated.

Five lesions from roots or hypocotyls of juvenile plants in each subplot were surface disinfested 15–30 sec in 70% ethanol or 0.5% NaOCl, blotted dry on sterile filter paper, and incubated on water agar. Hyphal tips were transferred to potato-dextrose agar (PDA) and potato-dextrose yeast extract casein hydrolysate agar (22). *R. solani* and RLBF were identified by nuclear staining (12) and pairing with known tester isolates to determine anastomosis grouping (19).

Soil assays. Ten soil cores (2.5-cm diameter, 15-cm deep) were removed from each subplot in January or February each year from 1981 to 1983, and from turnip 12 June 1980, from cucumber 1 July 1980, and from one replication each in corn and peanut 12 May 1980. Cores were mixed, and composite samples from each subplot were processed with a multiple-pellet soil sampler (11) and assayed on tannic acid-benomyl medium (22). Plates were incubated 48 ±2 hr at 26 ±1 C and hyphal tips resembling *R. solani* or related fungi were transferred to PDA and potato-dextrose yeast extract casein hydrolysate agar and identified. Population densities of each fungus are presented in colony-forming units (CFU)/100 g of oven-dried soil.

Peanut harvest. In September, pods were dug with a shovel, inverted, and air-dried in each microplot. Plants with attached pods then were placed in mesh bags and dried in an oven at 35 C until the seed contained 10% moisture. Loose pods were removed separately from each microplot and dried in the same manner. Plants plus pods were weighed, then the pods were removed and weighed separately. Loose pods were separated into unblemished and decayed pods and weighed separately. Each year, 50 or 100 unblemished seed from pods attached to plants in each microplot were surface-disinfested in 0.5% NaOCl for 3 min and plated on tannic acid-benomyl medium to assay for basidiomycetes. Up to 100 seeds (if available) each from loose unblemished and loose decayed pods were assayed. Cultures were transferred to potato-dextrose yeast extract casein hydrolysate agar and identified.

In 1981, we obtained tester isolates of AG-2 types 1 and 2 of *R. solani*, and tester isolates CAG-2, 3, 4, and 5 (RBLF with perfect state = *Ceratobasidium*) for anastomosis grouping (7,19). These testers were used to assist in the identification of cultures during the last 2 yr of the study.

RESULTS

Corn. Root disease in corn was more severe each year in soil infested with AG-2 of *R. solani* than in other treatments (Table 1). Crown and brace roots with large (2–4 cm), brown cankers or terminal decay were frequently observed in both juvenile and mature plants in soil infested with AG-2, but infrequently in other treatments (Table 2). There were no differences in crown and brace root rot severity between cropping systems. Plants were significantly ($P = 0.05$) shorter (201 versus 220 cm) in soil infested with AG-2 than in uninfested soil in 1982, but not in other years. Stalk lodging occurred rarely in plants with root rot. Yield was significantly less ($P = 0.05$) in soil infested with AG-2 in 1981 than

TABLE 1. Root disease severity and yield of corn in soil infested with *Rhizoctonia solani* and Rhizoctonialike binucleate fungi in different cropping systems

			1980			1981			1982		
			RDI[w] at days:		Yield[x]	RDI at days:		Yield	RDI at days:		Yield
Treatments			29	94	(t/ha)	46	124	(t/ha)	40	117	(t/ha)
Cropping system											
1980	1981	1982									
Corn	Peanut	Corn	1.4	1.3	5.5	...[y]	...	...	1.7	2.3	9.3
Peanut	Corn	Corn	...	...	...	1.5	2.2	8.8	1.5	2.6	11.5
Cucumber-cowpea	Corn	Peanut	...	...	...	1.5	2.6	8.9	...	...	...
Turnip-soybean	Corn	Peanut	...	...	...	1.5	3.0	8.9	...	...	...
Soil treatment											
R. solani AG-4			1.0 b[z]	1.0 b	4.4	1.0 b	2.1 b	10.7 a	1.5 b	2.4 b	10.3
R. solani AG-2			2.8 a	2.2 a	5.3	2.9 a	3.5 a	5.8 b	2.0 a	3.1 a	9.0
Rhizoctonialike fungi			1.0 b	1.1 b	7.0	1.0 b	2.5 b	9.9 a	1.4 b	2.2 b	10.7
Control			1.0 b	1.0 b	5.2	1.0 b	2.3 b	9.0 a	1.5 b	2.1 b	11.8

[w] Root disease index: 1 = < 2%, 2 = 2-10%, 3 = 11-50%, and 4 = > 50% discoloration and decay; 5 = dead plants.
[x] Metric tonnes per hectare calculated from microplot yields.
[y] ... = No data.
[z] Numbers within columns followed by the same letter within cropping systems or soil treatments are not significantly different, $P = 0.05$. No letter indicates no significant differences.

in other treatments (Table 1). Yield for the 3 yr averaged 22% less in soil infested with AG-2 than in uninfested soil.

Peanut. There were no differences in yield among soil treatments. Root and hypocotyl disease severity was slight in all treatments each year, and not different among treatments. *R. solani* AG-4 was isolated from peanut hypocotyls and seed more frequently than other fungi. In the third year, *R. solani* was isolated from significantly more of the seed in unblemished loose pods in soil infested with AG-4 than from other treatments (Table 3). *R. solani* AG-2 type 2 was isolated from 1.5 to 11.0% of the seed from unblemished attached or loose pods in 1981–1982, and AG-2 (not identified to type) from 2.2 and 4.7% of the rotted and unblemished, respectively, loose pods in 1980. Rhizoctonia-like CAG-2 and CAG-4 were isolated from seed from both unblemished attached and loose pods in the third year, but there were no differences among treatments (Table 3). In the third year, AG-2 type 2 was isolated from a lesion on one peanut hypocotyl in a plot infested with AG-2, but not from lesions on hypocotyls in other treatments.

Cucumber. Only AG-4 caused fruit rot as shown by the reduction in percentage of fruits that were marketable (Table 4). Total yield was not influenced by soil treatments. Root disease severity was slight, and only AG-4 and RLBF were isolated from lesions on hypocotyls. Plant stand was less in plots infested with AG-4 compared with other soil treatments.

Other crops. There were no significant differences in root disease severity or yield among soil treatments in turnip, cowpea, or soybean. R. solani AG-4 primarily was isolated from hypocotyl lesions, but occasionally RLBF were isolated; AG-2 was only isolated from hypocotyls of cowpea.

Survival in soil. Population densities of AG-4 and RLBF were moderate to high and those of AG-2 were moderate in soil 10–60 days after infestation (Table 5). Only AG-4 occurred frequently in soil in all plots, possibly because of inoculum in buried peanut pods

TABLE 2. Crown and brace roots with lesions and terminal rot in corn in 1982 in two cropping systems in soil infested with *Rhizoctonia solani*, Rhizoctonialike binucleate fungi, or noninfested

Treatments			Crown and brace roots with lesions[x] at: 40 days Below ground	117 days Below ground	117 days Above ground	Roots with terminal decay at 117 days
Cropping system						
1980	1981	1982				
Corn	Peanut	Corn	3.2	37.0	13.8	22.4
Peanut	Corn	Corn	1.9	39.8	27.4	27.6
Soil treatment						
R. solani AG-4			1.0 b[y]	23.8 b	15.3 b	17.0 b
R. solani AG-2			7.5 a	109.2 a	37.3 a	75.0 a
Rhizoctonialike fungi			1.3 b	12.2 b	13.2 b	4.8 b
Control			0.5 b	8.7 b	16.7 b	3.2 b

[x] Means of five plants.
[y] Numbers within columns followed by the same letter withing cropping systems or soil treatments are not significantly different, $P = 0.05$. No letters indicates no significant differences.

TABLE 3. *Rhizoctonia solani* and Rhizoctonialike binucleate fungi isolated from peanut seed grown in two crop rotation systems in 1982

Treatments			Seeds from pods attached to plants at digging (%) AG-4[x]	CAG-2	CAG-4	Seeds from pods loose in the soil at digging (%) AG-4	AG2T2	AG2T1	CAG-2	CAG-4
Cropping system										
1980	1981	1982								
Cucumber-cowpea	Corn	Peanut	0.4[y]	0	0.7	6.3	1.2	0.1	4.5	14.0
Turnip-soybean	Corn	Peanut	1.2	1.0	0	24.6	0.0	0.5	5.7	2.7
Soil treatment										
R. solani AG-4			1.7	0.0	0.0	35.3 a	0.0	0.2	6.2	0.0
R. solani AG-2			0.5	1.7	0.0	6.5 b	2.3	0.0	10.8	5.2
Rhizoctonialike (binucleate) fungi			0.2	0.0	1.0	11.3 b	0.0	0.0	0.0	21.3
Control			0.8	0.3	0.3	5.6 b	0.0	1.0	3.0	7.8

[x] Anastomosis groups of *R. solani*: AG-4, AG-2 type 1, AG-2 type 2. Anastomosis groups of Rhizoctonialike, binucleate fungi: CAG-2 and CAG-4.
[y] Numbers followed by the same letter within cropping systems or soil treatments are not significantly different, $P. = 0.05$. No letters following the numbers indicates no significant differences.

TABLE 4. Yield of cucumber in soil infested with *Rhizoctonia solani*, Rhizoctonialike binucleate fungi, or uninfested

Soil treatment	Yield/0.73 m^2 Total No.	Total Kg	Marketable No.	Marketable Kg	Marketable (%) No.	Marketable (%) Wt
Rhizoctonia solani AG-4	20.7[x]	4.5	4.7 b	0.8 b	20 b	14 b
Rhizoctonia solani AG-2	22.7	4.2	12.3 ab	2.5 ab	56 ab	55 ab
Rhizoctonialike fungi	24.0	5.0	22.3 a	4.8 a	94 a	94 a
Control	21.7	4.8	15.0 ab	3.4 a	68 a	68 a

[x] Numbers within columns followed by the same letter are not significantly different according to Duncan's multiple range test, $P = 0.05$. No letters following the numbers indicates no significant differences.

and debris that were inadvertently mixed with topsoil 2 mo after the soil was fumigated. In midwinter 1981–1983, AG-4 was present in all treatments, but population densities were greater in soil originally infested with that isolate (Table 6). Peanut and turnip-soybean increased the population density of AG-4 more than cucumber-cowpea and corn in 1980, and peanut more than corn in 1982 (Table 6). *R. solani* AG-2 was detected the first winter, but not thereafter, and cropping systems had no significant effect on the distribution of the fungus. The RLBF were identified to anastomosis group in 1982 and 1983, and CAG-4 was the prominent type in the original infested plots; CAG-2 was present sporadically in other plots (Table 6).

R. zeae Voorhees was identified in 1982 and 1983, and populations increased following corn. *Laetisaria arvalis* Burdsall was detected in low numbers in a few plots in 1983.

DISCUSSION

The inoculum potential of *R. solani* AG-2 type 2 remained high in all cropping systems 1 and 2 yr after infesting soil, even though the pathogen could not be detected on soil plates. Rhizoctonia solani AG-2 was isolated from peanut seeds at digging in each crop, and it is possible that the pathogen may survive in soil primarily in peanut seeds, shells, or other plant debris that would not be detected with the multiple-pellet soil sampler. Also, after seeds were used for laboratory tests, few seeds were left to return to the soil. More inoculum might remain in grower fields per unit area than in the microplots in our experiments.

At the Coastal Plain Station, four of 11 isolates of AG-2 survived in buried pots of artificially infested fallow Dothan loamy sand during 283 days of natural weathering, and an average of 16 CFU/100 g soil were assayed on tannic acid-benomyl medium.

TABLE 5. Population densities of *Rhizoctonia solani* AG-4 and AG-2 and Rhizoctonialike binucleate fungi in soil in the spring after infestation

Soil treatment	CFU/100 g of soil[x]		
	AG-4	AG-2	RLBF
R. solani AG-4	21[y]	0 b	0 b
R. solani AG-2	5	9 a	1 b
Rhizoctonialike binucleate fungi	7	0 b	30 a
Control	6	0 b	0 b

[x] Average colony-forming units (CFU) in soil collected 10, 41, and 60 days after infestation in plots sown to corn and peanuts, turnip, and cucumber, respectively.

[y] Numbers within columns followed by the same letter are not significantly different according to Duncan's multiple range test, $P = 0.05$. No letters following the numbers in a column indicates no significant differences.

Four isolates caused root and hypocotyl rot on snap bean and five caused root rot in corn planted into the soil after 283 days (3). Therefore, AG-2 type 2 may be a soil inhabitant as well as a soil invader in the Georgia coastal plain. Population densities of AG-4, RLBF, *R. zeae*, and *L. arvalis* were more easily estimated with the soil sampler, and these organisms may exist in smaller particles of organic matter or as sclerotia free in soil in the Georgia coastal plain. However, antagonistic microorganisms may influence the growth of basidiomycetes from soil onto selective media (11), and AG-2 type 2 may be more sensitive to antagonists than AG-4. AG-2 isolates of *R. solani* were significantly more susceptible to antagonism by *Trichoderma harzianum* in vitro than other AGs of *R. solani* (5). Also, *L. arvalis* is common in the soils of the Georgia coastal plain, and the fungus could influence population densities and inoculum potential of *R. solani* AG2-2.

Even though AG-2 type 2 is not pathogenic on cucumber or turnip, the pathogen survived as well following those crops in double-crops with cowpea and soybean as it did following peanut. Also, the pathogen survived with a high inoculum potential following corn. We have found the disease in the Georgia coastal plain in corn following peanut, soybean, and continuous corn, and in one field previously in woodland. Thus, the pathogen is adapted to a wide variety of environments, and crop rotations may not be useful in reducing inoculum potential after the pathogen becomes established.

In New Zealand and in the Vendée area of western France, the only other areas where this disease is known (8,20), corn is rotated with ryegrass or grown as a continuous monocrop. Both areas have mild climates, but they differ from the subtropical climate of the Georgia coastal plain. Why the pathogen has been reported in only these areas is not known. Changes in cultural practices could influence survival and inoculum potential of the pathogen. The herbicide pendimethalin increased root disease severity in corn in Bonifay sand but not in Tifton loamy sand (23). Conservation tillage (subsoil-plant, disk, or no-till) is used more and conventional tillage (moldboard plow) less in the Georgia coastal plain and much of the corn is irrigated with overhead sprinkler systems. In France and New Zealand, plants with crown and brace root rot lodge frequently, making machine harvesting difficult. We observe lodging occasionally in fields, but lodging is less when corn grain is harvested at high moisture content (26%) and dried artificially than when the grain is allowed to dry naturally for several weeks in the field.

In New Zealand, the disease reduced grain yield 10% in artificially inoculated plots, and losses were estimated at 5% in grower fields (8). In microplots, we measured 0, 36, and 23% yield loss for three successive years. However, because of variation in pollination, the barrier of the microplot wall, more exposure of each plant to sunlight, and other changes in the canopy

TABLE 6. Population densities of *Rhizoctonia solani, R. zeae,* and Rhizoctonialike binucleate fungi in soil after different crop rotation systems

Treatments			CFU/100 g of soil[x]										
			30 January 1981			2 February 1982				12 January 1983			
			AG-4	AG-2[y]	RLBF[y]	AG-4	CAG-2	CAG-4	RZ[y]	AG-4	CAG-2	CAG-4	RZ
Cropping system													
1980	1981	1982											
Corn	Peanut	Corn	1.9 c[z]	0.5	5.0	42.8	2.1	15.9	15.9	1.6 b	0.0	2.2	18.0 a
Peanut	Corn	Corn	53.0 ab	0.8	21.9	40.7	5.5	24.2	0.0	2.2 b	2.2	0.0	9.8 ab
Cucumber-cowpea	Corn	Peanut	18.5 b	2.4	12.5	19.1	26.2	21.4	0.7	2.7 b	1.6	3.8	0.5 c
Turnip-soybean	Corn	Peanut	104.0 a	0.5	4.0	17.2	0.7	6.2	6.9	6.6 a	0.0	2.7	1.6 bc
Soil treatment													
R. solani AG-4			59.4	0.0 b	0.0	60.7 a	5.5	0.0 b	2.1	8.2 a	0.0	0.0 b	12.5
R. solani AG-2			43.4	2.3 a	11.8	31.7 ab	6.2	0.0 b	11.7	2.7 ab	0.0	0.0 b	4.4
Rhizoctonialike fungi			44.7	0.0 b	22.6	11.7 b	12.4	67.6 a	4.2	1.1 b	0.0	8.7 a	6.0
Control			29.8	0.0 b	8.4	15.9 b	10.4	0.0 b	5.5	1.1 b	3.8	0.0 b	7.1

[x] CFU = colony-forming units.

[y] Not differentiated by type, RLBF = Rhizoctonialike binucleate fungi, not differentiated by anastomosis groups; CAG-2 and CAG-4 are anastomosis groups of RLBF; RZ = *Rhizoctonia zeae*; Values are means of 12 microplots per treatment.

[z] Numbers followed by the same letter within cropping systems or soil treatments are not significantly different, $P = 0.05$. No letters following the numbers in a column indicates no significant differences.

environment, yield differences in microplots with corn might not simulate yield differences in fields. Tillage practices, difficult to reproduce in microplots, may influence residue distribution and soil compaction (18). The effects of crown and brace root rot on yield reduction may be greater if root growth is restricted by soil compaction.

The number of crown and brace roots necessary to sustain good growth and yield in corn may be minimal if roots are removed mechanically. In solution culture with corn seedlings, the seminal roots and 63% of the crown roots were severed with little reduction in growth (6). However, corn in fields subject to water and nutrient deficiences probably would have reduced growth and grain yield with moderate crown and brace root rot. More research is necessary to determine the relationship of crown and brace root rot to grain yield.

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