Root Rot Induced in Snap Bean by *Rhizoctonia solani* AG-4 and AG-2 Type 2 in Conservation Tillage Following Corn

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ABSTRACT

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A snap bean double-crop was planted no-till for 3 years following field corn with symptoms of crown and brace root rot induced by *Rhizoctonia solani* AG-2 type 2, and for 2 years following sweet corn in soil infested with inoculum of *R. solani* AG-4 and disk harrowed. Yield of green pods from plants grown in soil infested with *R. solani* AG-2 type 2 was only one-third of the yield from plants grown in noninoculated soil (1,056 vs. 3,185 kg/ha) in the first year, but yields were not different in the other 2 years. Seed and soil fungicide treatments were rarely beneficial in increasing plant stand or yield. In soil infested artificially with a low inoculum density of *R. solani* AG-4 (3–7 cfu/100 g of oven-dry soil), yield of green pods was consistently 20–30% less than yield in noninoculated soil. Tolclofos-methyl (but not PCNB or metalaxyl) reduced root and hypocotyl disease severity but did not increase yield. Yield of different cultivars varied with different levels of soil infestation with inoculum of *R. solani* AG-4, but compared with noninoculated soil, yield of all cultivars was low (680–2,360 kg/ha) in infested soil.

Isolates of *Rhizoctonia solani* Kühn anastomosis group (AG)-4 and AG-2 type (T) 2 are indigenous in soils of the Georgia coastal plain. *R. solani* AG-4 has a wide host range (14,24,26) and AG-2T2 induces crown and brace root rot in corn (16,17,19). Isolates of both anastomosis groups may cause severe root and hypocotyl rot in snap bean (*Phaseolus vulgaris* L.) (3,14,15). Root diseases are limiting factors in the production of snap bean, particularly in fall crops in multiple-cropping systems (2,22,23). Corn is a common rotation crop with legumes in Georgia, and snap bean is planted frequently following corn harvest for fall production of green pods for fresh market.

Conventional tillage with a moldboard (turning) plow buries plant debris infested with *R. solani* and reduces root and hypocotyl disease severity (23), but conservation tillage practices are encouraged by soil conservationists in order to reduce soil erosion (24). This investigation was undertaken to study the ecology and control of root and hypocotyl diseases induced by *R. solani* in fall snap bean planted in a double-crop system with corn using conservation tillage practices.

MATERIALS AND METHODS

Research was conducted on Fuquay loamy sand (loamy, siliceous, thermic, Arenic Plinthic Paleudults), pH 5.8–6.3, 0.5% organic matter, at the Coastal Plain Station. All crops were grown with supplemental water from overhead sprinkler irrigation. For 3 successive years (1984–1986), a snap bean double-crop was planted no-till following field corn with symptoms of crown and brace root rot induced by *R. solani* AG-2T2. In 1985 and 1986, snap bean was planted following sweet corn in soil that was infested with inoculum of *R. solani* AG-4 and was disk harrowed. All experiments were planted with rows 0.9 m apart, and seeds spaced 4–6 cm apart, 2–3 cm deep.

Plants were side-dressed with 168 kg/ha NH_4NO_3 3–4 wk after planting and with 45 kg/ha N and 44 kg/ha K 2 wk later. Fungicide treatments were applied as drenches with a sprinkler can in a band 15–20 cm wide, one half in the furrow and the other half over the row immediately after covering, followed by an irrigation of 0.5 cm. Diazinon granules (1.6 kg/ha a.i.) were sprinkled over the row after planting to control soil insects. Carbaryl sprays were used to control worms on foliage and pods. Plots were irrigated as needed to prevent drought stress.

In all experiments, stand counts were taken weekly until 4–6 wk after planting. Snap beans were harvested at the mature green pod stage for fresh market.

Experiments with *R. solani* AG-2T2. Cultures of isolate RHS-36 from corn were grown 3–5 wk on 3% cornmeal-sand (w/w) in 1–3 L flasks. Inoculum was spread by hand on the soil and incorporated 5–8 cm deep with a machine-driven rotary tiller before planting field corn. Whole plots were infested with a high inoculum density (1,144 or 1,430 kg/ha), a low inoculum density (144 or 238 kg/ha), or noninoculated. Subplots were treated with a pencycuron drench (915 mg a.i./m^2) over the row after planting, or were not treated. After corn plots were harvested for grain in July, foliage, stalks, and remaining ears were chopped with a rotary flail mower to 15 cm above the ground. Fertilizer (NH_4NO_3, 168 kg/ha) was broadcast over the corn debris and the experiment was irrigated with 1.25 cm of water. The herbicide glyphosate was used to control weeds and volunteer corn.

Snap bean cultivars Greencrop (white seed) in 1984 and 1985, and Atlantic (dark seed) and Greencrop in 1986 were planted by hand adjacent to the corn rows on 5 September, 23 July, and 23 July in 1984, 1985, and 1986, respectively. A randomized complete block design with split or split-split plots was used. Whole plots were four to 10 replications of soil infested or noninoculated with *R. solani* AG-2T2. Subplots were seed or soil treatments with fungicides. In 1984, seed that had been commercially treated with captan (0.6 g a.i./kg) was overcoated with a slurry of furmecyclox (1.0 g a.i./kg), carboxin (0.8 g a.i./kg), metalaxyl (0.3 g a.i./kg), or nontreated. Each subplot was one row (0.76 m) of 20 seed.

In 1985, fungicides were applied as drenches (500 ml/m of row). Subplot treatments were metalaxyl (0.56 kg/ha a.i.), tolclofos-methyl (1.68 kg/ha a.i.), pencycuron (1.52 kg/ha a.i.), flutolanil (2.24 kg/ha a.i.), and a nontreated control. In 1986, subplots were snap bean cultivars Atlantic and Greencrop, with or without a drench of tolclofos-methyl (1.68 kg/ha a.i.).

Experiments with *R. solani* AG-4. In 1985 and 1986, sweet corn was grown from May to July. Corn stalks were shredded with a rotary mower and 168 kg/ha NH_4NO_3 and 224 kg/ha of cornmeal-sand inoculum of *R. solani* AG-4 were broadcast. The experimental area was disk harrowed 10–15 cm deep, and plots were irrigated with 1.25 cm of water. One week later, furrows were made with a planter or by hand, and snap bean was planted by hand.

In experiment one, a randomized complete block design with four replications was used. Treatments (kg/ha a.i.) were fungicides, tolclofos-methyl, 0.56, 1.12, and 1.68; PCNB, 1.68; metalaxyl,

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Table 1. Postemergence damping-off and yield in snap bean in soil inoculated with *Rhizoctonia solani* AG-2T2 or noninoculated with different seed treatments in 1984

Treatment	Postemergence damping-off (%)		Green pods (kg/ha)	Fungi isolated from seedlings (%)[x]			
				Rhizoctonia solani			
	12 Days	23 Days		AG-2T2	AG-4	CAG-2[y]	*Pythium myriotylum*
Soil treatment							
Inoculated	1.3	31 a[z]	1,056 b	51	2	16	4
Noninoculated	1.1	6 b	3,185 a	6	19	10	0
Seed treatment							
Furmecyclox	0.2 b	7 b	1,751	62	8	23	0
Carboxin	3.2 a	19 a	1,767	35	0	8	19
Metalaxyl	0.2 b	10 b	1,688	67	0	28	0
Control	1.2 b	11 b	1,858	21	16	5	0

[x] Data on fungi isolated from seedlings was not analyzed statistically.
[y] CAG-2 is a *Rhizoctonia*-like binucleate fungus.
[z] Numbers followed by the same letter within soil or seed treatments are not significantly different, according to linear contrasts and Duncan's multiple range tests, respectively ($P = 0.05$).

Table 2. Plant stands and yield in snap bean following corn in soil inoculated or noninoculated with *Rhizoctonia solani* AG-2T2 in 1986

Treatment	Plants/3.05 m of row			Green pods (kg/ha)
	7 Days	14 Days	21 Days	
Soil treatment				
Inoculated—HID[y]	39 a[z]	34 a	27	641
Inoculated—LID[y]	34 b	29 b	24	547
Noninoculated	37 a	31 b	26	898
Cultivar and fungicide				
Atlantic, nontreated	45	30	26	671 a
Atlantic, tolclofos-methyl	30	31	27	717 a
Greencrop, nontreated	36	32	25	438 b
Greencrop, tolclofos-methyl	29	33	27	897 a

[y] HID = high inoculum density (1,144 kg/ha), LID = low inoculum density (143 kg/ha).
[z] Numbers followed by the same letter within columns of soil or cultivar and fungicide treatments are not significantly different, according to Duncan's multiple range test ($P = 0.05$). No letters indicates no significant differences.

0.68; and the nontreated control. Each plot was one row 7.6 m long. Greencrop snap bean, treated commercially with captan + streptomycin, was planted 3–4 cm deep, 100 seeds/row, and fungicides were applied as drenches, 500 ml/m of row. Four weeks after planting, all plants were dug from 50 cm of row on each end of each plot and evaluated for symptoms of both root and hypocotyl disease severity on a 1–5 scale: 1 = <2, 2 = 2–10, 3 = 10–50, and 4 = >50% discoloration and decay; 5 = dead plant. This rating system includes all discoloration and decay, regardless of the cause.

In a second experiment, with the cultivar Bush Blue Lake, a split-split plot design was used. Whole plots were infested (448 kg/ha of inoculum) or noninoculated. Subplots were fungicide seed treatments of oxadixyl (0.2 g a.i./kg of seed), metalaxyl (0.2 g a.i./kg of seed), and metalaxyl + carboxin (0.2 g a.i. + 0.78 g a.i./kg of seed), and fungicide drenches of metalaxyl + tolclofos-methyl (0.56 + 1.68 kg/ha a.i.), PCNB (1.68 kg/ha a.i.), and the control. Plants were dug from 30 cm of row of each subplot (8–15 plants) and evaluated for root and hypocotyl disease severity 16 days after planting.

In a third experiment, whole plots were infested with 448 or 224 kg/ha of inoculum, or noninoculated. Subplots were cultivars Nemasnap, Atlantic, Greencrop, and Eagle, and breeding lines R-924 (M. H. Dickson, New York, State Agricultural Experiment Station, Geneva), 5W-372A and 5W-372B (G. F. Freytag, Tropical Agricultural Research Station, ARS-USDA, Mayaguez, Puerto Rico), and XPB-189 (Asgrow Seed Company).

Isolation of fungi from plants and soil. In each experiment, fungi were isolated from root and hypocotyl lesions from dead and dying seedlings selected at random in each treatment. The tissues were washed in running tap water (20–27 C), cut into 2–6 mm sections, surface-disinfested 20–30 sec in 70% ethanol, blotted dry on sterile filter paper, and incubated on petri dishes of water agar at 25–30 C. Hyphal tips were transferred to PDA and identified.

Soil samples (five cores, 15 cm deep, 2.5 cm diameter) were taken in the row between plants 3–5 wk after planting in experiments with *R. solani* AG-4. Soil was assayed for *R. solani* on tannic acid-benomyl agar (TABA) (16) with a multiple-pellet soil sampler (6), and for *Pythium* spp. by soil dilutions on PAR medium (7). Soil was not assayed in experiments following corn with crown and brace root rot because *R. solani* AG-2T2 is isolated infrequently from soil assayed on TABA (17).

R. solani and binucleate *Rhizoctonia*-like fungi from plants and soil were identified to AG or CAG by pairing with known tester isolates (4,10). All data were analyzed by least SAS squares analysis of variance and general linear models statistical procedures (11).

RESULTS

Experiments with *R. solani* AG-2T2. In the first experiment, emergence of snap bean seedlings averaged 93%, and there were no significant differences among treatments. Postemergence damping-off was negligible 12 days after planting in the first experiment, but was fivefold greater in infested soil than in noninoculated soil 23 days after planting (Table 1). Yields of green pods in infested soil were only one-third of the yields in noninoculated soil. *R. solani* AG-2T2 was isolated frequently from lesions on roots and hypocotyls of dead or dying plants grown in infested soil, but infrequently from plants grown in noninoculated soil (Table 1). The binucleate *Rhizoctonia*-like fungus CAG-2 was isolated infrequently and *R. solani* AG-4 and *Pythium myriotylum* Dresch. were isolated rarely from seedlings in infested soil. In seedlings grown in noninoculated soil, *R. solani* AG-4 and CAG-2 were isolated more frequently than *R. solani* AG-2T2, and *P. myriotylum* was not isolated.

Seed treatments with fungicides did not reduce postemergence damping-off nor increase yields. Increased postemergence damping-off occurred with the carboxin treatment, and *P. myriotylum* was only isolated from seedlings grown from seed treated with carboxin (Table 1).

In the second year, emergence averaged 88% and there were no significant

differences among treatments. Postemergence damping-off was slight at 2 wk (average 2.4%) but severe at 5 wk (average 36%) after planting, and there were no significant differences among soil or fungicide treatments. Fungi were isolated from approximately 120 dead and dying seedlings 31 and 38 days after planting. *R. solani* AG-2T2 was isolated from only one seedling grown in infested soil, and from none grown in noninoculated soil. *Fusarium* spp. (34%) and CAG-2 (30%) were isolated most frequently, and *Macrophomina phaseolina* (Tassi) Goid., *R. solani* AG-4, *F. oxysporum* Schlecht., *P. myriotylum*, and *F. solani* (Mart.) Appel & Wr. were each isolated from 5% of the seedlings. From 31 plants collected 9–11 wk after planting, CAG-5 (29%), *F. solani* (29%), CAG-2 (26%), and *P. myriotylum* (13%) were isolated most frequently. Marginal leaf necrosis was common on primary leaves 2 wk after planting, and a foliage spray of $MgSO_4$ was applied 4 wk after treatment to correct a possible Mg deficiency. Plants were stunted and stands were uneven. Few pods were produced, and yield of green pods was not taken.

In the third year, emergence 1 wk after planting was similar in noninoculated soil and soil infested with a high inoculum density (1,144 kg/ha), but was reduced in soil infested with a low inoculum density (143 kg/ha). Plant stand 2 wk after planting was less in noninoculated soil and in soil infested with a low inoculum density than in soil infested with a high inoculum density, but at 3 wk and later there were no differences among treatments. There were no differences in plant stand between the cultivars Atlantic and Greencrop or between treatment with tolclofos-methyl and no fungicide treatment. Yields of green pods were low and not different in infested and noninoculated soils. Treatment with tolclofos-methyl increased yield in Greencrop but not in Atlantic (Table 2).

Experiments with *R. solani* AG-4. In the experiment with soil fungicides in 1985, none of the treatments influenced emergence 6 or 15 days after planting. Emergence averaged 86% 2 wk after planting. An analysis of the rate of tolclofos-methyl indicated a linear increase in stand of live plants and a linear reduction in root and hypocotyl disease severity as rates increased from 0.56 to 1.68 kg/ha. The low and intermediate rates were usually ineffective in controlling root disease. Tolclofos-methyl at 1.68 kg/ha a.i. reduced postemergence damping-off significantly and increased stand of live plants 15 and 22 days after planting compared with PCNB and metalaxyl treatments (Table 3). At 4 wk after planting, tolclofos-methyl (1.68 kg/ha) reduced root and hypocotyl disease compared with levels observed in plots treated with PCNB or metalaxyl treatments. When compared with controls, plants treated with tolclofos-methyl had fewer lesions on fibrous roots and fewer reddish-brown cankers on the hypocotyl, but the same level of collar rot on the stems. Populations of *R. solani* AG-4 in soil, 5 wks after planting, were low and not different among treatments. Populations of *Pythium* spp. were high and variable (15–60 cfu/g of oven-dry soil), but there were no significant differences among treatments. There was a high coefficient of variability (52.2%) and yield of green pods was not different among treatments (Table 3).

In 1986, seven fungicides were tested against two inoculum levels (0 and 448 kg/ha). There were no differences in emergence or numbers of live plants 10–27 days after planting (*data not shown*). Numbers of live plants (average of fungicide treatments) 64 days after planting were significantly less in infested than in noninoculated soil (Table 4). Among fungicide treatments (mean of plants in infested and noninoculated soil), only the tolclofos-methyl treatment had significantly more live plants than the control. There was no interaction among soil and fungicide treatments.

Postemergence damping-off 22 days after planting was significantly greater in infested plots, but there were no significant differences among fungicide treatments, and no interaction between soil and fungicide treatments. There was no significant difference in root and hypocotyl disease severity between soil treatments. Among the fungicide treatments, tolclofos-methyl alone, and combined with metalaxyl, reduced root and hypocotyl disease severity (Table 4).

Average yield of green pods was significantly greater in noninoculated soil than in infested soil (Table 4), but there were no significant differences among fungicide treatments. Numbers of plants with black lesions or fibrous root lesions were not significantly different in soil or fungicide treatments. The percentage of plants with reddish-brown lesions, typical of symptoms caused by *R. solani* AG-4, was significantly greater in infested than in noninoculated soil (25.1 vs. 17.6%), but none of the fungicide treatments reduced the percentage of plants with reddish-brown lesions.

The infestion of soil with *R. solani* AG-4 did not influence the populations of *R. solani* AG-4 recovered on soil plates. Populations of *R. solani* AG-4 were low in all treatments, but tolclofos-methyl, PCNB, and carboxin + metalaxyl reduced populations of the pathogen below detectable levels (Table 4). Very few colonies of *R. solani* AG-2 type 2 were found in the soil, and there were no significant differences among treatments (*data not shown*). *Rhizoctonia*-like binucleate CAG-2, CAG-3, CAG-4, and CAG-5 were occasionally found in soil. Total populations of *Rhizoctonia*-like binucleate fungi were less in noninoculated

Table 3. Postemergence damping-off, plant stand, root and hypocotyl disease severity, populations of *Rhizoctonia solani* AG-4 and *Pythium* spp., and yield in snap bean in soil infested with *Rhizoctonia solani* AG-4 following sweet corn in 1985

Fungicides and kg/ha a.i.		Postemergence damping-off (%)		Plants/7.6 m of row at 22 days	RHDS[x]	*Pythium* spp. (cfu)[y]	*Rhizoctonia solani* AG-4 (cfu)[y]	Yield (kg/ha)
		15 Days	22 Days					
Tolclofos-methyl	0.56	6.5	9.9	79	2.9	39	3.5	4,015
Tolclofos-methyl	1.12	5.6	11.4	79	2.4	47	1.8	4,222
Tolclofos-methyl	1.68	5.6	6.2	82	2.0	60	3.5	3,755
PCNB	1.68	5.9	13.1	73	3.2	44	5.2	2,176
Metalaxyl	0.56	15.6	20.5	63	3.0	15	7.0	2,367
Control		13.8	24.5	66	3.0	20	7.0	4,480
Comparisons of interest[z]								
Tolclofos-methyl, linear		0.01	0.01	0.01	0.01	NS	NS	0.05
Control vs. PCNB		0.05	NS	NS	NS	NS	NS	NS
Control vs. metalaxyl		NS	NS	NS	NS	NS	NS	NS

[x] Root and hypocotyl disease severity 4 wk after planting: 1 = <2, 2 = 2–10, 3 = 11–50, and 4 = >50% discoloration and decay; 5 = dead plant.
[y] Colony-forming units/g or 100 g of oven-dried soil in *Pythium* spp. and *Rhizoctonia solani* AG-4, respectively, 5 wk after planting.
[z] Analysis of variance linear comparisons, tested with the *F* test. $P = 0.05$ or 0.01, NS = no significant difference.

Table 4. Root disease severity, plant stand, populations of *Rhizoctonia solani* AG-4 and related fungi, and yield in snap bean in soil inoculated or noninoculated with *R. solani* AG-4 following sweet corn in 1986

Treatment	Postemergence damping-off at 22 days (%)	Plants/0.9 m of row at 9 wk	RHDS[v]	*Rhizoctonia solani* AG-4 (cfu)[w]	RBN[x] (cfu)	Green pods (kg/ha)
Soil treatment						
Noninoculated	2.8 b[y]	9.4 a	1.6	3.5	2.5 b	1,852 a
Inoculated (448 kg/ha)[z]	6.6 a	6.6 b	1.8	3.3	4.4 a	1,251 b
Fungicide						
Metalaxyl (seed)	6.0	6.4 d	1.8 bc	0.8 bc	5.4	1,082
Oxadixyl (seed)	5.0	8.8 ab	1.6 bcd	6.2 abc	8.5	1,576
Carboxin + metalaxyl (seed)	3.1	8.2 abc	1.7 bc	0.0 c	0.0	1,725
Metalaxyl (soil)	1.4	6.5 cd	1.7 bc	9.2 ab	3.1	1,790
Tolclofos-methyl (soil)	2.3	9.9 a	1.4 cd	0.0 c	4.6	1,721
Metalaxyl + tolclofos-methyl (soil)	0.0	8.8 ab	1.2 d	5.4 abc	1.5	2,010
PCNB (soil)	11.7	8.1 abc	2.2 a	0.0 c	3.1	1,187
Control	8.1	7.4 bcd	2.0 ab	5.4 abc	1.5	1,324

[v] Root and hypocotyl disease severity: 1 = <2, 2 = 2–10, 3 = 11–50, and 4 = >50% discoloration and decay; 5 = dead plant.
[w] Colony-forming units/100 g of oven-dried soil 19 days after planting.
[x] *Rhizoctonia*-like binucleate fungi CAG-2, CAG-3, CAG-4, and CAG-5.
[y] Numbers in columns within soil or fungicide treatments followed by the same letters are not significantly different, according to Duncan's multiple range test ($P = 0.05$). No letters indicates no significant differences. Means are the average of soil treatments across fungicide treatments, and vice versa.
[z] Cornmeal-sand inoculum of *Rhizoctonia solani* AG-4.

Table 5. Yield and postemergence damping-off in different snap bean cultivars grown in soil inoculated with different inoculum densities of *Rhizoctonia solani* AG-4

Cultivars	Green pods (kg/ha)[w]			Postemergence damping-off at 28 days (%)[x]
	High inoculum	Low inoculum	Noninoculated	
R-924	683 c[y]	1,439 ab	1,796 ab	34 ab
Nemasnap	1,016 bc	1,606 a	3,074 a	28 ab
5W-372A	789 c	...[z]	...[z]	25 ab
5W-372B	950 bc	...[z]	...[z]	22 ab
Atlantic	1,824 ab	2,083 a	1,310 b	27 ab
XPB-179	1,181 abc	1,190 ab	1,329 b	12 b
Greencrop	2,365 a	1,424 ab	1,267 b	22 ab
Eagle	909 c	793 b	1,319 b	48 a

[w] Cornmeal-sand inoculum (3% w/w). High (448 kg/ha), low (224 kg/ha), or none.
[x] Data from plots inoculated with a high inoculum level.
[y] Numbers in columns followed by the same letter are not significantly different, according to Duncan's multiple range test ($P = 0.05$).
[z] There was only enough seed of these cultivars to plant plots in the high inoculum level.

Table 6. Postemergence damping-off, plant stand, populations of *Rhizoctonia solani* AG-4 and related fungi, and yield in soil inoculated with different inoculum densities of *R. solani* AG-4[v]

Inoculum density[w]	Postemergence damping-off (%)		Plants/1.5 m of row at 4 wk	*Rhizoctonia solani* AG-4 (cfu)[x]	RBN[y] (cfu)	Green pods (kg/ha)
	13 Days	28 Days				
High	10	27	14.5	6.2	3.3	1,333 b[z]
Low	13	32	14.0	4.9	2.1	1,421 ab
Noninoculated	16	29	13.3	5.7	3.9	1,683 a

[v] Average of eight cultivars.
[w] High (448 kg/ha) and low (224 kg/ha) levels of *Rhizoctonia solani* AG-4 in 3% cornmeal-sand (w/w).
[x] Colony-forming units/100 g of oven-dried soil 19 days after planting.
[y] *Rhizoctonia*-like binucleate fungi CAG-2, CAG-3, CAG-4, and CAG-5.
[z] Numbers followed by the same letter are not significantly different, according to Duncan's multiple range test ($P = 0.05$). No letters indicates no significant differences.

soil than in soil inoculated with *R. solani* AG-4 (Table 4). *R. zeae* was present in soil in low to moderate populations (4–12 cfu/100 g), but there were no significant differences among treatments.

The fungi isolated most frequently from lesions on roots and hypocotyls of snap bean in noninoculated soil were *R. zeae* (47%), total *Rhizoctonia*-like binucleate fungi (18%), *Fusarium* spp. (16%), *R. solani* AG-4 (15%), AG-2 type 2 (1%), and *Pythium* spp. (1%). Fungi isolated most frequently from snap bean sown in infested soil were *R. zeae* (43%), total *Rhizoctonia*-like binucleate fungi (29%), *R. solani* AG-4 (18%), *Fusarium* spp. (4%), *R. solani* AG-2 type 2 (3%), and *Pythium* spp. (3%). Other fungi isolated rarely were a sterile white basidiomycete, pink basidiomycetes, *Trichoderma* spp., *M. phaseolina*, and *Curvularia* spp.

Yields of the different cultivars were significantly different with different inoculum densities of *R. solani* AG-4 (Table 5). With the high inoculum density (448 kg/ha), Greencrop had the highest yield and R-924, 5W-372A, and Eagle had the lowest yield. With the low inoculum density, Atlantic had the highest yield, Nemasnap had the second highest, and Eagle had the lowest. In the noninoculated treatment, Nemasnap yield was significantly higher than all cultivars, except R-924.

The percentage of postemergence damping-off was significantly different 28 days after planting in the high inoculum density treatment. XPB-189 had significantly less postemergence damping-off than Eagle, but was not different from the other cultivars.

R. solani AG-4, CAG-2, CAG-3, *M. phaseolina*, and *F. solani* were the fungi isolated most frequently from roots and hypocotyls of dead and dying plants. *R. solani* AG-4 was isolated from all cultivars, but was isolated more frequently from plants grown in soil infested with *R. solani* AG-4 than in noninoculated soil. In contrast, *F. solani*, *M. phaseolina*, and the binucleate fungi were isolated at random in soil treatments.

There were no significant differences among soil treatments in the percentage of postemergence damping-off or plant stand, but yields were reduced 20% in soil infested with a high inoculum density of *R. solani* AG-4 compared with noninoculated soil (Table 6). Populations of *R. solani* AG-4 and *Rhizoctonia*-like binucleate fungi in soil were low and not different among the different soil treatments. Soil under cultivar 5W-372A had significantly greater populations of *R. solani* AG-4, AG-2 type 2, and

binucleate *Rhizoctonia*-like fungi in soil infested with a high inoculum density than most other cultivars (12, 6, and 12 cfu/100 g of soil, respectively). Populations in soil under other cultivars were usually not significantly different from Eagle.

DISCUSSION

This research indicates that both *R. solani* AG-4 and AG-2T2 may cause yield loss in double-crop snap bean following corn in soil infested artificially following conservation tillage. Yield differences among inoculum levels of *R. solani* AG-2T2 were inconsistent over 3 years of testing in snap bean planted no-till following field corn. The yield of green pods was 67% less in infested than in noninoculated soil in the first year, but there were no differences in other years, even though the preceding crop of corn had symptoms of crown and brace root rot each year. The pathogen survived in soil or infested corn debris and infested snap bean each year, but other soilborne pathogenic fungi were isolated more frequently during the last 2 years of the study than *R. solani* AG-2T2.

Crown and brace root rot has been isolated and identified from corn roots in 17 counties in the Georgia coastal plain. The pathogen, *R. solani* AG-2T2, is widely distributed and has been isolated from snap bean seedlings with symptoms of root and hypocotyl rot following corn in naturally infested fields (23). The pathogen is difficult to detect in soil, but it survived 3 years in microplots in a corn-peanut rotation (17). In the coastal plain, corn is rotated frequently with peanut, and the pathogen may survive in soil in colonized peanut pods and debris (1,17).

Corn in rotation with snap bean reduced hypocotyl rot in Delaware (8), and both green corn residues and corn stover reduced hypocotyl rot in greenhouse tests (5,9). However, the addition of nitrogen to corn debris for fertilization of snap bean may influence the inoculum potential of *R. solani* propagules (5,12,26). In previous research, starter fertilizer increased root disease severity in spring snap bean in the coastal plain, but yield of green pods was not reduced (23).

Isolates of *R. solani* AG-4 have been associated consistently with increased root and hypocotyl rot and reduced plant stand with disk harrowing or subsoiling tillage treatments in previous studies (23,24). However, this research is the first documentation in the Georgia coastal plain of reduced yield in conservation tillage induced by a low inoculum density (3–7 cfu/100 g of oven-dry soil) of *R. solani* AG-4. In our tests following sweet corn, yield of green pods was 20–30% less in plots infested artificially with low levels of *R. solani* AG-4, compared with noninoculated plots. Thus, growers could sustain substantial losses in conservation tillage following corn, especially if the inoculum density of *R. solani* AG-4 was increased to moderate to high levels (10–20 cfu/100 g of soil) by a susceptible host (peanut, soybean, other vegetables) planted ahead of corn. Even though corn is not a host of *R. solani* AG-4, there is ample evidence to indicate that the pathogen can survive saprophytically in soil or debris during corn culture (22,23). The pathogen does not cause preemergence damping-off or root diseases in young corn, but roots and stalks of corn are colonized as the plants mature. The fungus is isolated commonly from decaying stalks and roots of corn in the southeastern U.S. (20,21,25). Corn in Georgia also is a host to a sterile white basidiomycete that causes root and hypocotyl diseases in snap bean (2,3,18).

The snap bean cultivars grown in Georgia are susceptible to both *R. solani* AG-2T2 and AG-4 (14). Some inbred lines are resistant to *R. solani* AG-4, but resistance to *R. solani* AG-2T2 has not been demonstrated (14). Because *P. myriotylum*, *P. aphanidermatum* (Edson) Fitzp., and *M. phaseolina* may cause disease in fall snap bean following corn (13,22,23), multiple disease resistance would be highly desirable in snap bean in conservation tillage. The soil fungicides PCNB and metalaxyl were beneficial in reducing root disease severity from *R. solani* and *Pythium* spp., respectively, but more efficacious fungicides or biocontrol agents are needed to control root and hypocotyl pathogens in snap bean. Until yield of green pods in conservation tillage is comparable to yield with conventional tillage, conservation tillage is unlikely to be accepted by growers.

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