Interactions of Tillage and Soil Fertility with Root Diseases in Snap Bean and Lima Bean in Irrigated Multiple-Cropping Systems

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ABSTRACT

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Snap bean or lima bean was planted each August following corn in a multiple-cropping system for 6 yr. Root and hypocotyl disease severity and postemergence damping-off (caused primarily by *Rhizoctonia solani* AG-4, *Fusarium solani*, a sterile white basidiomycete, and *Pythium* spp.) were greater in fall snap bean than in lima bean and in subsoiled or disked than in plowed treatments. In one year of three, postemergence damping-off was increased in snap bean by applying nitrogen broadcast preplant compared with applying it through overhead irrigation. Plowing reduced populations of *R. solani* AG-4 and *Rhizoctonia*-like fungi compared with disking but increased or had no effect on populations of *Pythium* spp. In spring snap bean, root disease severity was greater in single rows than in twin rows and with starter fertilizer than without. Subsoiling increased the number of plants with reddish brown sunken cankers on the hypocotyls compared with plowing. Numbers of *Meloidogyne incognita* juveniles in the soil and root-gall indices were greater in fall lima bean than in snap bean. In most tests, numbers of *M. incognita* juveniles and root-gall indices were not affected by tillage methods or fertilization treatments. Yield of snap bean was greater in the spring than in the fall.

In the southeastern United States, vegetables are commonly double-cropped or triple-cropped with other vegetables or agronomic crops (30). Snap bean (*Phaseolus vulgaris* L.), lima bean (*P. lunatus* L.), and cowpea (southern pea) (*Vigna unguiculata* (L.) Walp) are grown widely in multiple-cropping systems in Georgia as spring and fall crops. Soilborne pathogens (31), nematodes (11,24), and soil insects (4) must be controlled to increase production efficiency and produce profitable yields.

Tillage practices influence distribution and survival of soilborne pathogens (7,14,30), soil compaction, and plant growth (3,25). Both snap bean and lima bean are susceptible to *Rhizoctonia solani* Kühn anastomosis group (AG) 4 (27) and AG-2 type 2 (27,28), *Pythium* spp. (31), a sterile white basidiomycete (1,9,29), *Sclerotium rolfsii* Sacc. (31), and nematodes (11,24,31,33,34), pathogens that are ubiquitious in soils in the Georgia coastal plain. Soil fertility may influence pathogenesis and severity of root disease (5,17,26), but the effect of the interaction of tillage and soil fertility on severity of root disease on snap bean and lima bean has not been studied. Plant residues may influence root disease severity in snap bean (26). Corn was beneficial in reducing Rhizoctonia hypocotyl rot in snap bean in Delaware (18) and in reducing populations of total *F. solani* (both pathogenic and saprophytic isolates) and *Pythium* spp. compared with peanut in Georgia (31).

This study was initiated to determine the influence of tillage and fertilization practices on root diseases and nematodes in the production of spring and fall snap bean and fall lima bean in irrigated multiple-cropping systems following corn or winter rye.

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MATERIALS AND METHODS

Fall crops. A double crop of corn/snap bean (1978–1980) or corn/lima bean (1981–1983) was grown under solid-set overhead sprinkler irrigation on Bonifay sand (loamy, siliceous, thermic, gross arenic, plinthic, paleudult). The corn/snap bean double crop was in a 2-yr rotation with a squash/soybean double crop, and the corn/lima bean double crop was in a 2-yr rotation with a peanut monocrop. Also, rye was planted in the winters of 1979 and 1981 and in 1982 following peanut. Two separate experiments were conducted simultaneously so that each crop sequence was planted each year. A split-plot experiment with a randomized complete block design was used. Three tillage practices were whole plots 48.7 × 24.4 m. Subplots were moldboard-plowed (25–30 cm deep), disk-harrowed (10–15 cm deep), or subsoiled (40 cm deep) under the row just before planting each crop. Subplots of snap bean and lima bean were irrigation and fertilization treatments.

Each year, corn was planted in March or April and harvested in August. Snap bean (BBL47 or Eagle) was planted in late August and harvested in October, lima bean (Nemagreen, Bridgeton, or Maffei-15) was planted in early August and harvested in early November. No yield was taken in 1979 in snap bean because of foliage and pod diseases and in 1981 in lima bean because of severe injury from root-knot nematodes.

Fertilization of snap bean and lima bean was based on soil samples taken after corn was harvested according to crop specificity. All snap bean plots received broadcast preplant fertilizer applications of 22, 63, and 149 kg/ha of nitrogen, phosphorus, and potassium, respectively. Ammonium nitrate, ammoniated polyphosphate, and sulfate of magnesia fertilizers were used.

Nitrogen fertilization (urea ammonium nitrate) treatments on snap bean were as follows: 1) conventional—broadcast preplant (45 kg/ha) and side-dressed (45 kg/ha) 3 wk after planting, totaling 90 kg/ha; 2) applied through overhead irrigation water at 11, 22, 34, 12 and 11 kg/ha 2, 3, 4, 5, and 6 wk after planting, respectively, totaling 90 kg/ha; 3) applied in overhead irrigation water at 14, 28, 42, 14, and 14 kg/ha 2, 3, 4, 5, and 6 wk after planting, respectively, totaling 112 kg/ha; and 4) side-dressed 3 wk after planting (45 kg/ha) and 15 kg/ha per application in overhead irrigation water 4, 5, and 6 wk after planting (45 kg/ha) totaling 90 kg/ha in 1980. In 1978 and 1979, plots were not side-dressed, and nitrogen totaled 67 kg/ha in five applications of 9, 17, 25, 8, and 8 kg/ha 2, 3, 4, 5, and 6 wk after planting, respectively.

Nematicides were applied with overhead sprinkler irrigation before planting snap bean in 1979 and 1980 and lima bean in 1982 and 1983. Ethoprop (6.72 kg/ha) was applied in 1979, and fenamiphos (6.72 kg/ha) was applied in 2.5 cm of water in 1980 and in 1.25 cm of water in 1982 and 1983.

Herbicides used from 1978 to 1980 were DCPA (8.96 kg/ha), metolachlor (1.68 kg/ha), and EPTC (3.36 kg/ha).

Metolachlor (2.24 kg/ha) was used each year on lima bean. Herbicides were applied with 0.6–1.2 cm of water through overhead sprinklers.

Chloroneb was applied as an in-furrow spray (1.68 kg/ha in 93.5 L of water) when planting snap bean in 1979 and 1980 for root disease control. Mancozeb (1.8 kg/ha) and chlorothalonil (1.8 kg/ha) were used to prevent foliar diseases, and malathion (1.7 kg/ha) and dicofol (0.6 kg/ha) were used to control foliar insects and mites.

All lima bean plots received broadcast preplant applications of nitrogen, phosphorus, and potassium at 28, 24, and 70 kg/ha, respectively, in 1981. In 1982 and 1983, potassium and phosphorus were not used and nitrogen at 56 kg/ha was side-dressed at planting.

Nitrogen fertilization treatments on lima bean were as follows: 1) side-dressed 3 wk after planting, totaling 50 kg/ha; 2) applied through overhead irrigation water in equal amounts of 17 kg/ha 3, 4, and 5 wk after planting, totaling 51 kg/ha; 3) side-dressed 3 wk after planting (34 kg/ha) and 17 kg/ha in a single application in overhead irrigation water 5 wk after planting, totaling 51 kg/ha; and 4) side-dressed 3 wk after planting (34 kg/ha) and 17 kg/ha in two applications 4 and 5 wk after planting, totaling 68 kg/ha.

Spring snap bean. In 1980, Eagle snap bean was planted on 2 April on Bonifay sand under center-pivot irrigation following tomato/lima bean/rye in 1979. The experimental area was disked in March before treatments were established in a split-split-split plot experiment with a randomized complete block design. Tillage practices (moldboard plow vs. subsoil plant) were whole plots, row spacings (single rows 91 cm apart vs. twin rows 25 cm apart, 86 cm from center to center of the twin rows) were subplots, preplant fertilizers (phosphorus at 57 kg/ha and potassium at 114 kg/ha, broadcast vs. banded) were sub-subplots, and starter fertilizers (none vs. nitrogen at 22 kg/ha and phosphorus at 38 kg/ha) at planting were sub-sub-subplots. The starter fertilizer was dribbled on top of the band with a hose. Additional fertilizer of sulfur and potassium at 74 kg/ha each and magnesium at 37 kg/ha was broadcast on the experimental area after tillage practices were established and before planting. Fenamiphos (6.7 kg/ha), EPTC (3.4 kg/ha), and bentazon (1.1 kg/ha) were applied through the center pivot for nematode and weed control. Snap beans were irrigated according to pan evaporation (23). Additional nitrogen was applied weekly as a 30% solution through the irrigation water at 11, 33, 22, 11, and 11 kg/ha 2, 3, 4, 5, and 6 wk after planting, respectively.

Snap bean yields were determined by hand-harvesting pods from a single row 3.05 m long (2.8 m^2) when 15–30% of the pods were 9.5 mm in diameter. Plants were removed from plots, counted, and weighed. Pods were removed, weighed, and a 500-g sample was graded by pod diameter (sieve size). Crop value, as reflected by pod diameter, was calculated each season from prevailing prices.

Root disease severity. Plants were counted about 1, 2, and 3 wk after planting and the percentage of postemergence damping-off was computed. Root and hypocotyl disease severity was determined 2–3 wk after planting by digging all plants in six 30-cm sections of row in each subplot. A disease severity rating of 1–5 was used for each plant, where 1 = <2, 2 = 2–10, 3 = 11–50, and 4 = >50% discoloration and decay; 5 = dead or dying plant. Other data taken in one or more years were the percentage of hypocotyls with one or more reddish brown cankers (indicative of infection with *R. solani* or *Rhizoctonia*-like fungi), with superficial white mycelium, or with gray-black streaks. The number of plants without epicotyls, or with other deformities, was recorded.

Fungi were isolated from root or hypocotyl lesions from 10 plants in each subplot in 1978 and from selected plants in other years. Tissues were surface-disinfested 15–30 sec in 0.5% NaOCl or 70% ethanol and incubated on water agar. Hyphal tips were transferred to potato-dextrose agar (PDA) and identified.

Populations of soil fungi. Ten cores of soil (15 cm deep, 1.5 cm in diameter) were taken in the row 10–23 days after planting in five of the seven experiments. Soil was assayed for *Pythium* spp. with dilutions on gallic acid (6) or PAR (12) media, for *F. solani* and *Fusarium* spp. on modified PCNB medium (20), and for total soil fungi on OAES medium (32). A multiple-pellet soil sampler (8) was used to assay *R. solani* and binucleate *Rhizoctonia*-like fungi on tannic acid-benomyl (TAB) medium (28). Ten or more colonies of *Pythium* spp. were selected at random from soil dilutions on PAR at each sampling (1981–1983) and identified. Hyphal tips of *R. solani* and *Rhizoctonia*-like fungi were transferred directly from TAB, after 24 hr of incubation at 26 C, to PDA and PDYC (28). Cultures were stained for number of nuclei per cell and paired with known tester isolates for identification of anastomosis groups (28).

Nematodes. Soil was assayed for plant-parasitic nematodes 6 wk after planting. Twenty cores of soil (2.5 × 15 cm deep) were collected from each plot and mixed thoroughly. A 150-cm^3 sample was processed by the centrifugal-flotation method (10).

Forty plants were selected at random from each plot and indexed for galls in May (spring tests) and September and November (fall tests). Galling on individual plants was rated on a scale of 1–5, where 1 = no galls, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% of the roots galled.

RESULTS

Disease severity. Root and hypocotyl disease severity (RHDS) and postemergence damping-off were greater in fall snap bean than in lima bean and in disk-harrowed and subsoiled than in moldboard-plowed treatments (Tables 1–3). Fertilization and irrigation treatments did not influence RHDS significantly, but postemergence damping-off was greater with conventional application of nitrogen in snap bean than with fertigation in 1979 (Table 2). Plants per

Table 1. Root disease severity and damping-off in fall crops of snap bean and lima bean with different tillage practices (1978–1983)

Crop	RHDI[v]	Damping-off[w] (%)	Plants per meter[w]	*Meloidogyne incognita*[x]	Root-gall index[y]	Green pods (t/ha)
Snap bean	2.4 a[z]	9.6 a	15.2	34 b	1.6 b	5.13
Lima bean	2.2 b	4.7 b	13.7	171 a	2.2 a	4.85
Tillage						
Disk-harrow	2.4 a	8.2 a	13.5 b	97	1.8	4.49 b
Moldboard plow	2.1 b	5.0 b	14.8 a	85	2.1	5.68 a
Subsoil (in-row)	2.3 a	8.1 a	15.1 a	124	2.0	4.73 b

[v] Root and hypocotyl disease index: 1 = <2, 2 = 2–10, 3 = 11–50, and 4 = >50% discoloration and decay; 5 = dead or dying plant. Means of all subplots for 6 yr.

[w] Plants were counted and percentage damping-off computed 10–25 days after planting.

[x] Juveniles per 150 cm^3 of soil 6 wk after planting.

[y] Root gall index: 1 = no galls, 2 = 1–25, 3 = 26–50, 4 = 51–75, and 5 = 76–100% of the roots galled.

[z] Numbers in columns not followed by the same letter within crop or tillage treatments differ significantly according to Duncan's multiple range test (P = 0.05). No letters indicates no significant differences.

meter of row 2–3 wk after planting were greater in moldboard-plowed and subsoiled plots than in disk-harrowed plots. RHDS was slight to moderate in most plots. Postemergence damping-off occasionally was 25–50% in disk-harrowed and subsoiled plots but rarely greater than 10% in moldboard-plowed plots.

The fungi isolated most frequently from lesions on roots and hypocotyls of snap bean (1978–1980) were *F. solani* (22%) *R. solani* AG-4 (18%), the sterile white basidiomycete (5%), a binucleate *Rhizoctonia*-like fungus, CAG-2 (4%), *Pythium* spp. (primarily *P. myriotylum* Drechs.) (3%), and *R. solani* AG-2 (1%). Those isolated most frequently from lima bean (1981–1983) were *R. solani* AG-4 (45%), *F. solani* (7%), CAG-2 (6%), *F. oxysporum* (5%), the sterile white basidiomycete (2%), *Pythium* spp. (1%), and *Macrophomina phaseolina* (Tassi) Goid. (1%). In 1982, *R. solani* AG-4 was isolated from 10 of 11 reddish brown lesions on lima bean pods in contact with the soil. *R. solani* AG-4 was isolated most frequently from reddish brown, sunken lesions on hypocotyls, whereas *R. solani* AG-4 and *F. solani* were both isolated frequently from reddish brown lesions on taproots and fibrous roots. *P. myriotylum* was most commonly isolated from hypocotyls with grayish black lesions or streaks 2–10 cm long on the hypocotyls ascending into the lower stems. Hypocotyl lesions with 2–4 mm of superficial, external white mycelium usually yielded cultures of the sterile white basidiomycete, *R. solani* AG-4 or AG-2, or binucleate *Rhizoctonia*-like fungi. Reddish brown cankers and white mycelium on hypocotyls were more frequent in subsoiled and disked plots than in moldboard-plowed plots, but differences were only significant in 1980 and 1982. The percentage of hypocotyls with reddish brown cankers averaged 15, 27, and 37 in moldboard-plowed, subsoiled, and disk-harrowed plots, respectively, in 1980–1983.

Root disease severity of spring 1980 snap bean was slight to moderate and was not influenced by tillage practice or methods of applying preplant fertilizer. However, root disease severity was greater in single rows than in twin rows and with starter fertilizer than without (Table 4). More plants had reddish brown sunken cankers on hypocotyls in subsoiled than in moldboard-plowed plots (Table 4), but row spacing and fertilizer treatments did not influence the incidence of cankers. Isolations were made from hypocotyls of 120 plants selected at random from each tillage treatment. *R. solani* AG-4, *F. solani*, binucleate *Rhizoctonia*-like fungi (unidentified), the sterile white basidiomycete, and *P. irregulare* were isolated from 43, 12, 10, 6, and 5% of the plants in the moldboard-plowed plots and from 26, 15, 9, 0, and 4% of the plants in the subsoiled plots, respectively. *P. aphanidermatum* and *P. myriotylum* were not isolated from spring snap bean.

Populations of soil fungi. In August, following corn, populations of *R. solani* AG-4 and binucleate *Rhizoctonia*-like fungi at planting were usually lower in moldboard-plowed than in disked plots, but differences were only significant in 1982. Plots with in-row subsoiling were intermediate and not different from the other tillage treatments. When all years (except for no data in 1979) were combined, there were significantly greater populations of *R. solani* and binucleate *Rhizoctonia*-like fungi in disked plots than in moldboard-plowed plots, whereas subsoiled plots were intermediate (13, 6, and 12 cfu/100 g of soil, respectively). *R. solani* AG-4 cultures were identified to anastomosis group in 1981–1983 and averaged 4, 1, and 1 cfu/100 g of soil in disked, moldboard-plowed, and subsoiled plots, respectively. The most common binucleate *Rhizoctonia*-like fungus identified was CAG-2. Populations of CAG-2 averaged 2.0 and 0.2 cfu/100 g of soil in 1982 and 1983, respectively, and there were no differences among treatments. The sterile white basidiomycete was detected only in 1982 (an average of 1 cfu/100 g of soil), and there were no differences in populations among treatments. Populations of *Pythium* spp. were usually not different among tillage treatments, except for lower populations in disked plots than in moldboard-plowed and subsoiled plots in August 1982 (11, 18, and 19 cfu/g of soil, respectively). Each year from 1981 through 1983, 10 colonies from soil dilutions on PAR in September were transferred to oatmeal-cholesterol agar; 40–70% of the colonies were identified as *P. aphanidermatum*, none to 30% were *P. irregulare*, and about 30% of the colonies were unidentified *Pythium* spp.

In April, following rye, populations of *Pythium* spp. were greater in subsoiled than in moldboard-plowed plots and in broadcast-fertilizer than in banded-fertilizer plots. Also, populations of *F. solani*, total *Fusarium* spp., and total fungi were greater in subsoiled than in moldboard-plowed plots (Table 5). Populations of *R. solani*, binucleate *Rhizoctonia*-like fungi, *Trichoderma*

Table 2. Root and hypocotyl disease severity, postemergence damping-off, and plant stand in snap bean with different tillage and fertilization treatments following corn

	RHDI[x]			Postemergence damping-off (%)[y]			Plants/3 m of row[y]		
Tillage	**1978**	**1979**	**1980**	**1978**	**1979**	**1980**	**1978**	**1979**	**1980**
Moldboard plow	1.9	2.8	2.0 b[z]	4 b	9	2	40 ab	35	41
Subsoil (in-row)	1.7	3.1	2.5 a	6 b	16	8	45 a	31	39
Disk-harrow	1.8	3.0	2.5 a	15 a	15	5	33 b	32	36
Nitrogen application									
Conventional	1.7	3.0	2.3	5	21 a	5	39 ab	29 b	30 b
Fertigation (high)	1.9	3.0	2.3	8	12 b	5	36 b	31 a	42 a
Fertigation (medium)	1.9	2.9	2.4	11	9 b	5	42 a	36 a	42 a
Fertigation (low)	1.7	2.9	2.3	8	11 b	5	41 ab	34 a	40 a

[x] Root and hypocotyl disease index: 1 = <2, 2 = 2–10, 3 = 11–50, and 4 = >50% discoloration and decay; 5 = dead or dying plant.
[y] Plants were counted and percentage damping-off computed 10–25 days after planting.
[z] Numbers in columns not followed by the same letter within tillage or nitrogen application treatments differ significantly according to Duncan's multiple range test ($P = 0.05$). No letters indicates no significant differences.

Table 3. Root and hypocotyl disease severity, postemergence damping-off, plant stand, and insect injury in fall lima bean following corn

	1981			1982			1983			
Tillage	**RHDI[w]**	**PEDO[x] (%)**	**Plants per meter**	**RHDI**	**PEDO (%)**	**Plants per meter**	**RHDI**	**PEDO (%)**	**Plants per meter**	**LCB[y] (%)**
Moldboard plow	2.15	4 b[z]	11	2.25 b	2	14	1.58	5	8 a	4 b
Subsoil (in-row)	2.31	12 a	10	2.59 a	3	13	1.74	9	6 ab	8 a
Disk-harrow	2.24	9 a	10	2.80 a	2	13	1.99	10	5 b	10 a

[w] Root and hypocotyl disease index: 1 = <2, 2 = 2–10, 3 = 11–50, and 4 = >50% discoloration and decay; 5 = dead or dying plant.
[x] Postemergence damping-off 11–22 days after planting.
[y] Lesser cornstalk borer injury 25 days after planting.
[z] Numbers in columns not followed by the same letter differ significantly according to Duncan's multiple range test ($P = 0.05$). No letters indicates no significant differences.

spp., *Aspergillus* spp., *Penicillium* spp., *Paecilomyces* spp., *Cladosporium* spp., *Helminthosporium* spp., *Rhizopus* spp., *Zyghorhynchus* spp., and *Neocosmospora vasinfecta* Smith were not different among treatments.

Insects. There was little insect injury on roots, hypocotyls, and stems of snap bean and moderate injury on lima bean only in 1983. The lesser cornstalk borer (*Elasmopalpaus lignosellus* Zeller) caused moderate injury in 1983 and reduced stand. There were significantly more plants damaged in disked and subsoiled plots than in moldboard-plowed plots (Table 3).

Nematodes. Numbers of *Meloidogyne incognita* (Kofoid & White) Chitwood, race 1, juveniles in the soil 6 wk after planting and root-gall indices after harvest were greater in fall snap bean than in lima bean (Table 1) but were not affected by fertilization treatments. In 1980, but not in 1978 or 1979, numbers of *M. incognita* and root-gall indices on fall snap bean at harvest were greater in subsoiled plots than those in disked or plowed plots (Table 6). Numbers of *M. incognita* and root-gall indices on lima bean were not affected by tillage methods in 1981 or 1982 but were respectively greater in disked and subsoiled plots than in other tillage treatments in 1983 (Table 6). Numbers of *M. incognita* juveniles in the soil and root-gall indices of spring snap bean were low and not affected by tillage methods or fertilization treatments.

Root growth. In 1978, soil cores in 10-cm increments were removed 40 cm deep under the row and 23 cm to the side of the row in snap bean, and roots were separated from soil by wet-sieving. Dry root weights (mg/cm^3 of soil) were greater under the row in moldboard-plowed plots than in disked or subsoiled plots 20–30 and 30–40 cm deep, whereas root weights 0–10 and 10–20 cm deep were greatest in disked plots. Root weights in subsoiled plots were always intermediate between moldboard-plowed and disked plots. Away-from-the-row root weights were greater in disked and subsoiled plots than in moldboard-plowed plots 0–10 cm deep, but moldboard-plowed plots had greater root weights than other tillage plots 20–30 and 30–40 cm deep. Root weights were similar in all tillage treatments 10–20 cm deep.

Yield. In fall snap bean, yield of green pods was consistently greater in moldboard-plowed plots than in subsoiled or disked plots. However, yields were much greater in a spring crop of snap bean (Table 4) than in the fall crops (Table 1) with both moldboard-plowed and subsoiled treatments. In the spring crop, the rye residues were disked before the tillage treatments for planting were established, and plant residues on the soil surface were negligible. In contrast, cornstalk debris on the soil surface and volunteer corn were abundant in fall

Table 4. Influence of tillage practices, plant spacing, and soil fertility on root disease severity and yield in spring snap bean grown under center-pivot irrigation

Tillage	RHDI[w]	Hypocotyls with reddish brown cankers (%)	Height (cm)	Pod weight (t/ha)
Moldboard plow	2.26	30 b[x]	14.5	16.4
Subsoil (in-row)	2.34	48 a	15.1	15.4
Spacing[y]				
Single rows	2.41 a	42	14.7	15.6
Twin rows	2.18 b	36	15.0	16.3
Preplant fertilizer				
Broadcast	2.29	38	15.2	15.8
Banded	2.31	39	14.4	16.0
Starter fertilizer[z]				
Yes	2.38 a	39	15.5 a	16.5
No	2.21 b	38	14.2 b	15.3

[w] Root and hypocotyl disease index: 1 = <2, 2 = 2–10, 3 = 11–50, and 4 = >50% discoloration and decay; 5 = dead or dying plant. All root disease data and heights were taken 22–27 days after planting.
[x] Numbers in columns not followed by the same letter within tillage, spacing, or starter fertilizer treatments differ significantly according to Duncan's multiple range test ($P = 0.05$). No letters indicates no significant differences.
[y] Single rows were 91 cm apart, twin rows were 25 cm apart with centers of the twin rows 91 cm apart.
[z] Liquid nitrogen and phosphorus (22.4 and 152.3 kg/ha, respectively) dribbled on top of the seed at planting.

Table 5. Populations of soil fungi in a crop of spring snap bean grown under different tillage and fertilization practices[w]

Tillage[x]	*Rhizoctonia solani* AG-4 and *Rhizoctonia*-like fungi[y]	*Pythium* spp.	*Fusarium solani*	Total *Fusarium* spp.	Total fungi
Moldboard plow	6.3	70 b[z]	1,800 b	3,580 b	328,000 b
Subsoil	4.4	209 a	3,080 a	6,920 a	521,000 a
Preplant fertilizer					
Broadcast	5.5	163 a	2,810	5,160	431,000
Band	4.2	116 b	2,370	5,330	418,000
Starter fertilizer					
Yes	6.6	155	2,580	5,340	423,000
No	4.1	124	2,290	5,150	426,000

[w] Snap bean was planted 2 April 1980 following lima bean (1979) and winter rye (1979–1980).
[x] After winter rye, the experimental area was disked before tillage treatments were established for snap bean.
[y] Populations of *R. solani* AG-4 and *Rhizoctonia*-like fungi are cfu/100 g of soil. Populations for all other fungi are cfu/g of soil.
[z] Numbers within columns not followed by the same letter within tillage or preplant fertilizer treatments differ significantly according to Duncan's multiple range test. No letters indicates no significant differences.

Table 6. Populations of *Meloidogyne incognita* juveniles and root-gall indices in snap bean (1978–1980) and lima bean (1981–1983) grown under different tillage treatments following corn

	Meloidogyne incognita[x]						Root-gall index[y]					
Tillage	1978	1979	1980	1981	1982	1983	1978	1979	1980	1981	1982	1983
Moldboard plow	55	13	21 b[z]	36	613	11 b	2.2	1.4	1.5 b	1.7	2.9	2.0 b
Subsoil (in-row)	46	9	68 a	16	294	76 ab	2.1	1.3	2.1 a	1.5	3.2	2.4 a
Disk-harrow	83	8	3 b	27	338	124 a	2.0	1.2	1.6 b	1.4	2.4	1.8 b

[x] Number of juveniles per 150 cm^3 of soil 6 wk after planting.
[y] 1 = No galls, 2 = 1–25, 3 = 26–50, 4 = 51–75, and 5 = 76–100% of the roots galled.
[z] Numbers in columns not followed by the same letter differ significantly according to Duncan's multiple range test ($P = 0.05$). No letters indicates no significant differences.

crops of snap bean. In the fall crops, plant growth was less than in the spring crop, and pods were near the ground. Harvesting by machine would have been very difficult in disked and subsoiled plots because of corn debris. Pod quality was lower in fall crops because of pod deformities and lesions caused by soilborne and foliar pathogens. Powdery mildew (*Erysiphe polygoni* DC. ex Mérat), rust (*Uromyces phaseoli* (Reben) Wint.), and Cercospora leaf spot (*Cercospora* spp.) were identified on fall snap bean in one or more years, and the fall snap bean in 1979 was not harvested because pods were unacceptable for fresh market.

Lima bean yields were greater in moldboard-plowed than in disked and subsoiled plots in 1982 and 1983. The crop was not harvested in 1981 because of injury by root-knot nematodes. Nitrogen application method and irrigation treatments did not influence plant population, growth, or yield.

Interactions. Stepwise regression analysis each year indicated that populations of *Pythium* spp., *R. solani* AG-4, total *R. solani* and binucleate *Rhizoctonia*-like fungi, and nematodes and root disease severity, root gall indices, postemergence damping-off, and insect injury all contributed to yield decreases. However, only 9–21% of the variation in yield could be explained by these factors (R^2 = 0.09, 0.12, 0.18, and 0.21 in 1978, 1980, 1982, and 1983, respectively). For the 6 yr (only four with yield), yield was correlated negatively with root disease severity ($r = -0.45$), root gall indices ($r = -0.50$, data for 2 yr), insect injury to hypocotyls ($r = -0.31$, data for 1 yr), and postemergence damping-off ($r = -0.34$) but not with populations of *R. solani* and *Pythium* spp. in soil.

DISCUSSION

Yields of fall snap bean and lima bean following corn were increased consistently by moldboard plowing compared with disking and subsoiling, but yields were low in all treatments compared with spring snap bean. Some of the factors causing poor yield in fall crops were root diseases, nematodes, and the lesser cornstalk borer. In Tennessee, yields of snap bean and lima bean were usually higher with conventional tillage (moldboard plowing and disking) than with nontillage or disk tillage, but no data were taken on root diseases (19). In Maryland, moldboard plowing reduced the severity of root disease caused by *R. solani* and *Pythium* spp. and increased pod weights in snap bean (14). Inoculum densities of *Pythium* spp. and *R. solani* were less in moldboard-plowed than in disked soils (14,15). In our study, moldboard plowing reduced populations of *R. solani* AG-4 and *Rhizoctonia*-like fungi consistently but not populations of *Pythium* spp. or nematodes. In 1982, disking significantly reduced populations of *Pythium* spp. compared with moldboard plowing and subsoiling under the row. However, oospores of *P. myriotylum* cannot be detected in soil assays (17), and the influence of plowing on the inoculum density of *P. myriotylum* is unknown.

In other tests at the Coastal Plain Station, moldboard plowing reduced root disease slightly in southern pea grown in Tifton loamy sand, but yield increases with plowing and subsoiling over disking were caused primarily by a reduction in soil strength leading to greater root growth, plant growth, and nutrient use efficiency (25). The beneficial effect of moldboard plowing for root disease control is probably greatest where a high inoculum potential of *R. solani* exists.

Corn in rotation with snap bean reduced hypocotyl rot in Delaware (18) and corn stover reduced hypocotyl rot in greenhouse tests (5,26). However, the effect of mature plant residues may be nullified by additional nitrogen, and green plant residues may increase root disease severity (22,26). Colonization of plant residues in soil by *R. solani* was increased by NH_4-N but not NO_3-N (21), and increasing the nutrient supply increased inoculum potential of *R. solani* (16). In our experiments, preplant broadcast nitrogen reduced plant stand compared with application through irrigation water in fall snap bean in two of three years, but application method did not affect root and hypocotyl disease severity, numbers of nematodes in the soil, or root-gall indices. Starter fertilizer in spring snap bean increased root and hypocotyl disease severity slightly, but yield was not influenced. In August, the corn residues were mature but still contained some green tissues, and volunteer corn provided additional green tissue. Thus, the mixture of green and mature corn residues probably would not have the beneficial affect of corn stover in reducing the inoculum potential of *R. solani*. Also, peanut in the rotation may have increased the inoculum potential of *R. solani* and the sterile white basidiomycete (2).

Soil assays have been developed to determine the root rot potential of fields for snap bean (13). We found that populations of *R. solani* were related to hypocotyl rot and damping-off but populations of *Pythium* spp. were not. More research needs to be done on assaying *Pythium* spp. and specific anastomosis groups of *R. solani* and *Rhizoctonia*-like fungi before soil assays can be related to bean root rot potential in Georgia.

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