Effect of Root Diseases and Nematodes on Yield of Corn in an Irrigated Multiple-Cropping System with Pest Management

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ABSTRACT

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Corn was planted each of 6 yr in an annual multiple-cropping system of turnip-corn-cowpea with four types of soil pest management. Treatments were 1) broadcast soil fumigation with 98% methyl bromide + 2% chloropicrin (MBR-CP) each fall or winter; 2) broadcast soil fumigation with 20% methyl isothiocyanate + 80% chlorinated C_3 hydrocarbons (DD-MENCS) each fall + maximum pest control with nonvolatile nematicides, herbicides, and insecticides; 3) nonvolatile nematicides, herbicides, and insecticides used for an intermediate level of pest control; and 4) one herbicide and cultivation used as needed on each crop for a minimum level of weed control. Root diseases of corn were caused primarily by *Pythium aphanidermatum, P. arrhenomanes, Rhizoctonia solani* AG-4, a sterile white basidiomycete, and *Phoma terrestris.* Soil fumigation reduced root disease severity significantly in 5 of 6 yr and increased grain yield an average of 7.5% (0.94 t/ha). Populations of *Meloidogyne* spp., *Paratrichodorus minor,* and *Pythium* spp. and root disease severity ratings were correlated negatively with yield.

Additional key words: intensive cropping, *Macroposthonia ornata, Zea mays*

Numerous fungi can be isolated from roots of corn in the Georgia coastal plain, and several are known pathogens (11,21,22). Fungi have been associated with seedling decline in sweet corn (26) and changes in mineral concentrations in tissue of field corn (11). Nematodes, weeds, and insects also may reduce growth and yield of corn (9,10). Corn is grown in numerous crop rotations, and with the long growing season in the southeastern United States, it can be used in double or triple cropping with vegetables (9,25).

This research was initiated to determine the influence of different types of pest management using herbicides, nonvolatile nematicides, insecticides, and soil fumigants on populations of soilborne pathogenic fungi, nematodes, and soil insects and on root disease severity in corn in an irrigated multiple-cropping system with vegetables. An economic analysis has been published (2).

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MATERIALS AND METHODS

Corn (*Zea mays* L. 'Pioneer 3369A' or 'Funks G-4507') was planted on Tifton loamy sand (fine loamy, siliceous, Thermic Plinthic Palevdult; 85, 10, and 5% sand, silt, and clay, respectively; 0.5% organic matter) each year from 1975 to 1980 in an annual multiple-cropping sequence of turnip (*Brassica campestris* subsp. *rapifera* (Metzg.) Sinsk.)-corn-cowpea (southern pea) (*Vigna unguiculata* (L.) Walp.). Turnip was planted in February and harvested in late March or early April. Corn was planted 1–8 days later and harvested in early August. Cowpea (Pinkeye Purple Hull, 1975–1978; Worthmore, 1979–1980) was planted 2–7 days after corn harvest and was harvested in October.

Cultural practices. Soil was disc-harrowed and plowed, and beds were prepared with a tractor-driven rototiller before planting turnip. Immediately after turnip was harvested, the soil was disc-harrowed, turned 15–20 cm deep with a moldboard plow, subsoiled 45–60 cm deep, and shaped into beds 1.8 m wide and 10–15 cm high with a tractor-driven rototiller. Nematicide, herbicide, and insecticide treatments were applied (Table 1) and corn was planted. After corn was harvested, the stalks were mowed, the soil was disc-harrowed and plowed, and beds were prepared with a tractor-driven rototiller before planting cowpea.

The experiment was part of a larger split-plot design in strips. Cropping sequences were whole plots replicated twice, and subplots (three 1.8-m beds 7.7 m long) were six replicates of four types of pest management for soil pests:

1. MBR-CP. Between 14 November and 8 February each year, soil was treated with 358.7 kg/ha MBR-CP (98% methyl bromide + 2% chloropicrin) injected broadcast 25 cm deep with chisels 20 cm apart. The soil surface was shaped and sealed with a bed-shaper attachment, and the plots were covered with black polyethylene (152 μm thick) for 48 hr. No other soil pesticides were applied, and weeds were removed by hand in each crop.
2. Maximum. Soil was fumigated between 14 November and 17 December with 376.6 kg/ha DD-MENCS (20% methyl isothiocyanate + 80% chlorinated C_3 hydrocarbons) using the methods described for MBR-CP, except the plots were not covered with plastic. Ethoprop granules (8.96 kg a.i./ha) were broadcast on the soil surface and incorporated 15 cm deep with a tractor-driven rototiller before planting each crop in 1975 and 1976. Nematicides were not applied from 1977 through 1980 because they were not needed. A maximum chemical pest control program with herbicides and insecticides was used on each crop. Insecticides were applied according to a fixed "preventative" schedule whether pest insects were present or not.
3. Intermediate. Pesticide usage was based on crop history and weekly monitoring for pest insects. Ethoprop (8.96 kg/ha) was broadcast before planting each crop from 1975 to 1978 but gave poor nematode control. Therefore, fenamiphos 15G (8.96 kg/ha) was broadcast for nematode control in 1979 and 1980. Herbicides and cultivation were used as needed.
4. Minimum. Pesticide usage was limited and only applied to save the crop. One herbicide and cultivation were used on each crop, and insecticide applications were based on weekly monitoring to save the crop. Nematicides were not used.

Cropping sequence and pest management levels were maintained on the same land unit for the duration of the experiment. Ammonium forms of nitrogen in 10-34-0 or a 32% solution of NH_4NO_3-urea were used to supply nitrogen for turnips and corn; nitrogen was not supplied to southern pea. Soil was maintained at or above pH 6.0. Subplots were separated by 3.3-m weedfree buffer zones, and plant and soil samples were collected from the middle 15 m^2 of each subplot to avoid mixing contaminated soil into the edges of the subplots by tillage practices. Yield was taken on 7.7 m of the center bed. Supplemental irrigation was provided to prevent wilting. From April to July, the plots received 57–77 cm of water as rainfall plus irrigation.

Root disease severity, stalk rot, and foliage and root growth. Corn roots 20–30 cm deep were removed with a shovel 24–41 days after planting in 1976–1979 and 14–16 wk after planting each year. Eight to 20 plants were collected in each subplot, roots washed, and each plant given a root disease index (RDI) using a scale of 1–5, where 1 = <2, 2 = 2–10, 3 = 11–50, and 4 = >50% discoloration and decay; 5 = dead plants. The percentage of plants with stalk rot was determined empirically on the same plants evaluated for root disease by squeezing the stalks by hand in the second internode above the ground. Root growth was rated using an empirical scale of 1–5, where 1 = very poor growth and 5 = excellent growth. Plant height was determined in juvenile plants when root disease data were taken during 1976–1979.

Fungi were isolated from five to 10 root lesions in each subplot in 1976–1979 and from 80 and 50 randomly selected root lesions from four subplots in 1975 and 1980, respectively. Root tissue sections (10–20 mm) were surface-disinfested for 10–15 sec in 0.5% NaOCl, blotted dry on sterile filter paper, and incubated 2–4 days on water agar at 20–30 C. Hyphal tips were transferred to potato-dextrose agar and identified.

Assays of soil fungi. Ten soil cores 2.5 cm in diameter and 15 cm deep were collected and composited within the rows of corn in each subplot 11–13 wk after planting during 1975–1977. Soil was assayed by dilutions (24) on gallic acid medium (3) and modified PCNB medium (16) each year and by soil plates on tannic acid medium (21) and dilutions on OAES medium (19) in 1976 and 1977 for *Pythium* spp., *Fusarium* spp., *Rhizoctonia solani* Kühn and total fungi, respectively. Populations were expressed as colony-forming units (cfu) per gram of oven-dry soil.

Pathogenicity tests. Fungi isolated from root lesions or from soil assays were tested for pathogenicity on corn in a greenhouse. Cultures were grown on 3% cornmeal-sand (w/w) and used to infest heat-treated (65–75 C for 30 min) Dothan loamy sand, 1:300–1:500 (v/v). Randomized complete block designs with three or four replicates were used. Corn plants were rated for root disease severity 4–8 wk after planting (11,22,23,26).

Nematodes. Soil was assayed for plant-parasitic nematodes each month (except January) from 1975 to 1980. Ten cores (2.5 × 15 cm) of soil were collected from each subplot, composited, and thoroughly mixed. A 150-cm^3 sample was processed by the centrifigal-flotation method (4). Twenty plants from each plot were dug; roots were washed and indexed for galls induced by root-knot nematodes, *Meloidogyne* spp. (85% *M. incognita* (Kofoid & White) Chitwood and 15% *M. hapla* Chitwood), 3–6 or 14–16 wk after planting each year except 1980. Data were not taken on eggs or egg masses.

Data from the turnip-corn-cowpea cropping sequence were analyzed as a randomized complete block design with least-squares analysis of variance, correlation, linear regression, and stepwise multiple-regression statistical programs.

Table 1. Pesticides applied to corn grown under four pest-management levels in an annual turnip-corn-cowpea multiple-cropping system (1975–1980)

Pest management level	Chemicals (years)	Rate (kg/ha)
MBR-CP[a]	Methyl bromide (98%) + chloropicrin (2%) (1975–1980)	358.70
	Carbofuran (1978–1980)	2.24
	Methomyl (1976)	0.50
Maximum[b]	Methyl isothiocyanate (20%) + chlorinated C_3 hydrocabons (80%) (1975–1980)	376.60
	Ethoprop (1975–1978)	8.96
	Butylate (1975–1977)	4.48
	Cyanazine (1977–1980)	1.34
	2, 4-D (1976–1980)	0.28
	Pendimethalin (1978–1980)	0.84
	Methomyl (1976)	0.50
	Carbofuran (1978–1980)	2.24
Intermediate[c]	Ethoprop (1976–1978)	8.96
	Butylate (1975–1977)	8.96
	Cyanazine (1977–1980)	1.34
	Paraquat (1977)	0.28
	Pendimethalin (1978–1980)	0.84
	Methomyl (1976)	0.50
	Carbofuran (1978–1980)	2.24
	Fenamiphos (1979–1980)	8.96
Minimum[d]	Butylate (1975–1977)	8.96
	2,4-D (1976–1978)	0.28
	Pendimethalin (1978–1980)	0.84

[a]Soil fumigated with methyl bromide (98%) + chloropicrin (2%) between 14 November and 8 February each fall-winter season before planting turnips. Plots maintained weedfree by hand cultivation.
[b]Soil fumigated with DD-MENCS each fall between 14 November and 17 December. Herbicides, nematicides, and insecticides used on each crop to ensure maximum control of weeds, parasitic nematodes, and insects. Plots maintained weedfree by hand cultivation.
[c]No soil fumigation; nonvolatile nematicides used on each crop. Herbicides and insecticides used only when populations of weeds and insects were estimated to be above threshold levels.
[d]No soil fumigation or nematicides; one herbicide used on each crop.

Table 2. Root disease severity in corn grown under four pest-management levels in an annual turnip-corn-cowpea multiple-cropping system

	Root disease indices[x] (year and days after planting)										
	1975	1976		1977		1978		1979		1980	
Pest management level	104	24	116	26	108	41	110	41	103	102	% CBRR[y]
MBR-CP	2.6 b[z]	1.2 b	2.2 b	1.2 b	2.7 c	1.0 b	2.3 c	1.0 b	2.2 d	2.8	10
Maximum	2.6 b	1.1 b	2.3 b	1.1 b	3.2 b	1.0 b	2.8 b	1.0 b	2.6 c	3.1	23
Intermediate	3.2 a	1.4 a	3.4 a	1.6 a	4.0 a	1.5 ab	4.0 a	1.5 a	2.8 b	3.0	12
Minimum	3.4 a	1.3 a	3.4 a	1.7 a	4.0 a	1.9 a	3.9 a	1.5 a	3.1 a	3.2	27

[x]1 = <2, 2 = 2–10, 3 = 11–50, and 4 = >50% discoloration and decay; 5 = dead plants.
[y]Percentage of plants with reddish brown or black lesions or terminal rot of the large (3–10 mm) crown and brace roots 102 days after planting.
[z]Numbers 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.

RESULTS

Root disease severity and stalk rot. Corn plants 3–6 wk old had little root disease. Soil fumigation with both MBR-CP and DD-MENCS reduced seedling and juvenile plant root discoloration and decay every year compared with the minimum level and in 3 of 4 yr compared with the intermediate level of pest management (Table 2). Fungi most commonly isolated from pink, pinkish-black, and brown lesions on roots of seedling and juvenile plants from 1976 to 1979 were *Trichoderma* spp. (51%); *Fusarium oxysporum* Schlecht. (13%); *R. solani* and binucleate *Rhizoctonia*-like fungi (12%); *Pythium* spp. (primarily *P. aphanidermatum* (Edson) Fitzp.) [60%] and *P. arrhenomanes* Drechs. [25%]) (11%); other *Fusarium* spp. (5%); *Phoma terristris* Hans. (*Pyrenochaeta terristris* (Hans.) Gorenz, Walker, & Larson) (2%); a sterile white basidiomycete (1%); *R. zeae* Voorhees (1%); and a *Phoma* sp. (0.4%). *Rhizoctonia* isolates were identified as *R. solani* AG-4 and *Rhizoctonia*-like CAG-4 in 1976; isolates were not identified to anastomosis groups in other years.

Soil fumigation reduced root disease severity in mature plants during the first 5 yr of the study, but there were no differences among treatments in the last year. In the third, fourth, and fifth years, there was a significantly lower RDI in soil treated with methyl bromide than in soil treated with DD-MENCS and other chemicals (Table 2). Fungi most commonly isolated from lesions on mature plants from 1975 to 1977 were *F. oxysporum* (20%), *Pythium* spp. (primarily *P. aphanidermatum* [90%] and *P. arrhenomanes* [5%]) (20%), *R. solani* and *Rhizoctonia*-like fungi (10%), *P. terristris* (6%), *Trichoderma* spp. (5%), and *F. moniliforme* Sheld. (5%). From selected pink, black, or pinkish-black lesions in 1979 and 1980, *R. solani* and *Rhizoctonia*-like binucleate fungi (38%), *P. terristris* (12%), *Trichoderma* spp. (12%), *Pythium* spp. (10%), and *F. moniliforme* (10%) were isolated most frequently. In 1980, 18% of the plants had crown and brace root rot symptoms, but there were no differences among management levels (Table 2). *R. solani* isolates were identified as AG-4 in 1980 but were not identified to anastomosis groups in other years.

Corn stalk rot averaged 9, 0, 2, and 13% in 1975, 1976, 1977, and 1980, respectively; data were not taken in 1978 and 1979. There were no significant differences among management levels.

Table 3. Populations of *Pythium* spp., *Rhizoctonia solani*, and *Rhizoctonia*-like binucleate fungi in soil under four pest-management levels 11–13 wk after planting corn in an annual turnip-corn-cowpea multiple-cropping system

Pest management level	1975	1976		1977	
	Pythium spp.[x]	*Pythium* spp.	*Rhizoctonia*[y]	*Pythium* spp.	*Rhizoctonia*
MBR-CP	8 b[z]	21	0 b	16 a	7
Maximum	10 b	135	0 b	10 a	23
Intermediate	25 a	20	8 a	44 a	15
Minimum	20 a	27	3 ab	50 b	27

[x] Populations of *Pythium* spp. are expressed as colony-forming units per gram of oven-dry soil.
[y] Populations of *Rhizoctonia solani* plus binucleate *Rhizoctonia*-like fungi are expressed in colony-forming units per 100 g of oven-dry soil.
[z] Numbers in columns 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.

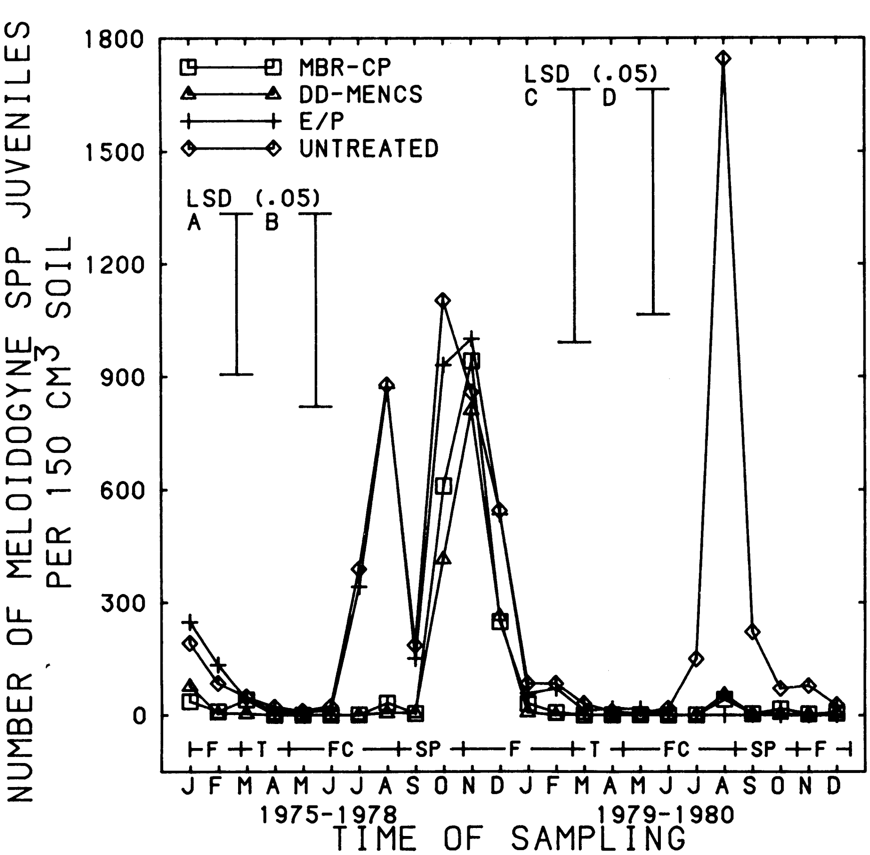

Fig. 1. Effects of four levels of pest management on *Meloidogyne* spp. in a turnip (T)-field corn (FC)-cowpea (SP) intensive cropping system. A and B = LSD 0.05 for different pest-management levels at the same sampling time and for the same pest-management levels at different sampling times, respectively (1975–1978); C and D = LSD 0.05 for different pest management levels at the same sampling time and for the same pest management levels at different sampling times, respectively (1979–1980). F = fallow.

Assays of soil fungi. Populations of unidentified *Pythium* spp. in soil in July were still suppressed in plots that were fumigated the previous fall or winter compared with nonfumigated plots in two of three years (Table 3). Populations of *R. solani* and binucleate *Rhizoctonia*-like fungi were not detected in fumigated soil in 1976 but were in 1977 (Table 3). The *Rhizoctonia* isolates were not identified to anastomosis groups, but six isolates from soil collected in February 1977 and six isolates from the rhizosphere of southern pea in August 1977 caused slight (RDI = 1.7–2.7) root disease in corn in pathogenicity tests.

Populations of other fungi were also variable from year to year. Populations of *F. solani* in the maximum treatment were significantly lower than in the minimum treatment in 1976 and 1977 (av. 560 vs. 1,700 cfu/g of oven-dried soil); the MBR-CP and intermediate treatments did not differ from the other two treatments. Populations of *Trichoderma* spp. and *Penicillum* spp. were lower in the maximum than in the minimum and intermediate treatments. Populations of *Trichoderma* spp. were also lower in the maximum treatment than in the MBR-CP treatment in 1977. There were no differences in populations of *Aspergillus* spp., *Rhizopus* spp., or *Mucor* spp. among treatments.

Nematodes. The most prevalent plant-parasitic nematodes in soil under corn were root-knot, a mixed population of *M. incognita* and *M. hapla*, stubby root (*Paratrichodorus minor* (Colbran) Siddiqi), and ring (*Macroposthonia ornata* (Raski) De Grisse & Loof.

Numbers of nematodes in Figures 1–3 are presented as means for each month across years (1975–1978 and 1979–1980).

Numbers of *Meloidogyne* spp. (second juvenile stage) in untreated plots were near or below detectable levels on turnip and increased to high levels on corn each year (Fig. 1). The application of MBR-CP and DD-MENCS prevented rapid increase of *Meloidogyne* spp. on turnip and corn but not on Pinkeye Purple Hull cowpea. The numbers of *Meloidogyne* spp. in plots of corn treated with ethoprop (1975–1978) did not differ from those in untreated plots; however, numbers of *Meloidogyne* spp. were reduced ($P = 0.05$) in plots of corn treated with fenamiphos (1979–1980).

Numbers of *P. minor* usually were greater on corn in June or July than other sampling dates (Fig. 2). The nematodes increased rapidly after soil fumigation with MBR-CP and DD-MENCS but not with fenamiphos in 1979–1980.

Numbers of *M. ornata* were usually lower in plots treated with MBR-CP and DD-MENCS than those in untreated plots and plots treated with ethoprop (1975–1978) but not in plots treated with fenamiphos (1979–1980) (Fig 3).

In 1977 and 1978, root-gall indices of corn were greater ($P = 0.05$) in the minimum and intermediate levels than in other levels of pest management, but root galls were observed rarely in other years in any treatment.

Pathogenicity tests. The fungi isolated from corn roots in this experiment that caused the most severe root rot in greenhouse pathogenicity tests were a sterile white basidiomycete, *P. aphanidermatum, P. arrhenomanes, R. solani* AG-4, and *Phoma terristris. F. oxysporum, F. moniliforme, Phoma* sp., and *R. zeae* were slightly to mildly virulent, and *F. roseum* 'Equiseti,' other *Fusarium* spp., and the binucleate *Rhizoctonia*-like fungus, CAG-4, were not pathogenic. *Pythium* spp. primarily caused decay of fibrous roots and did not cause discrete lesions or cankers on large crown and brace rots.

Root growth and abnormalities. Relative root growth in juvenile corn plants was consistently greater in the MBR-CP treatment than in other treatments from 1976 to 1978, and root growth (20–30 cm deep) in mature plants was greater in both treatments with soil fumigation than in the intermediate and minimum treatments in 1976 and 1977 (Table 4). In contrast, in 1978, root growth in juvenile plants was poorest in the maximum treatment, and plants in most plots in the maximum treatment had severe club-root distortion of the crown and brace roots and abundant secondary root proliferation, typical of pendimethalin injury. Considerable injury was observed in the intermediate treatment, and some in the minimum treatment, but none in the MBR-CP treatment where pendimethalin was not used. Abnormal secondary root proliferation also was observed in 1979 where pendimethalin was used, but club-shaped distortion of the crown and brace roots was not observed. In the last year of the study, root injury was not observed in mature plants and there were no differences in root growth among treatments.

Foliage growth. Plant height was significantly greater 24–41 days after planting in the MBR-CP treatment than in other treatments each year from 1976 to 1979. Plant height in the maximum treatment was significantly greater than the intermediate treatment in 1976 and 1978 and the minimum treatment in 1978 and 1979; there were no differences among the three treatments in 1977.

Yield. Grain production was significantly greater in soil fumigated with MBR-CP in 1976 and 1978 and DD-MENCS in 1975 and 1976 than in

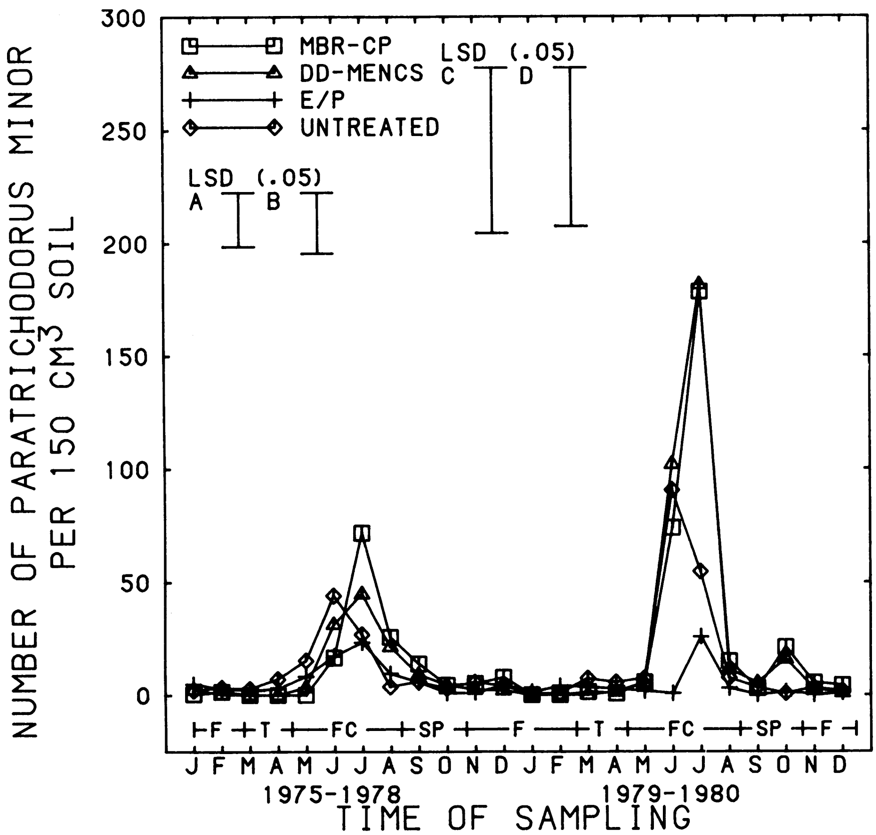

Fig. 2. Effects of four levels of pest management on *Paratrichodorus minor* in a turnip (T)-field corn (FC)-cowpea (SP) intensive cropping system. A and B = LSD 0.05 for different pest-management levels at the same sampling time and for the same pest-management level at different sampling times, respectively (1975–1978); C and D = LSD 0.05 for different pest-management levels at the same sampling time and for the same pest-management levels at different sampling times, respectively (1979–1980). F = fallow.

Table 4. Relative root growth[y] in corn under four pest-management levels in an annual turnip-corn-cowpea multiple-cropping system

Pest management levels	Year and days after planting								
	1976		1977		1978		1979		1980
	24	116	26	108	41	110	41	103	102
MBR-CP	5.0 a[z]	4.8 a	5.0 a	5.0 a	4.0 a	5.0 a	3.7	4.8 a	4.6
Maximum	4.0 bc	4.8 a	4.2 b	4.8 a	2.6 c	4.0 b	3.0	4.0 b	4.5
Intermediate	3.7 c	3.5 b	3.8 b	4.3 b	3.0 bc	4.2 b	3.2	4.5 ab	4.5
Minimum	4.2 b	3.4 b	3.8 b	4.3 b	3.2 b	3.8 b	3.0	4.2 ab	4.5

[y]Root growth: 1 = very poor, 2 = poor, 3 = fair, 4 = good, and 5 = excellent.

[z]Numbers 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.

nonfumigated soil. Both the MBR-CP and maximum treatments were superior to the minimum treatment in 1976–1978 (Table 5). In contrast, there were no differences in yield among treatments during the last 2 yr of the experiment. For the 6 yr, grain yields were increased by an average of 7.5% (0.94 t/ha) by soil fumigation.

Soil insects. Injury caused by soil insects was minimal during 1976, 1977, and 1978, averaging 0.08, 0.04, and zero feeding holes per plant, respectively. Damage was associated with wireworm (Elateridae) recovered from the soil when plant samples were taken. There were no significant ($P = 0.05$) differences among management levels.

Interactions of pest management levels, root diseases, and nematodes. There were highly significant ($P = 0.01$) negative correlations between yield and the following factors measured for the entire 6 yr: populations of stubby root nematodes in April ($r = -0.29$), populations of root knot nematodes in May ($r = -0.29$), and RDI ($r = -0.26$). In contrast, populations of stubby root nematodes in August had a highly significant positive correlation with yield ($r = -0.32$). Relative root growth just before harvest taken during 1976–1979 was highly correlated ($P = 0.01$) with yield ($r = 0.34$). From 1975 to 1977 when data were collected on populations of fungi in soil in July, 44% of the variation in yield was related to populations of ring nematodes and *Pythium* spp. Stepwise multiple regression for 1975–1980 indicated that populations of nematodes from April to August explained a highly significant 23% of the variation in yield.

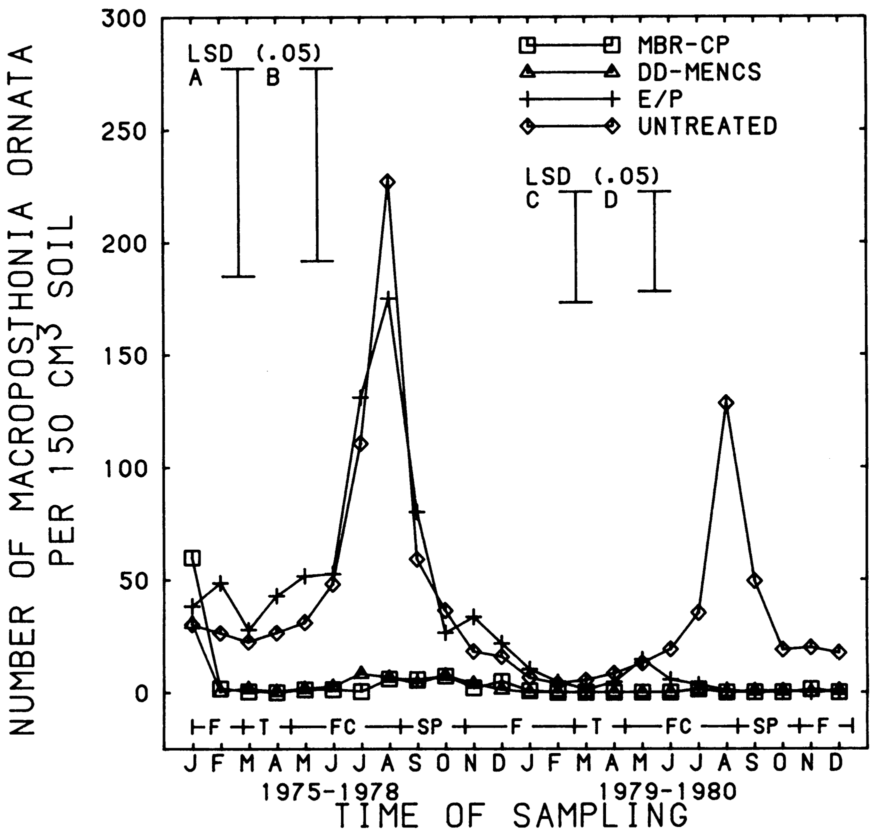

Fig. 3. Effects of four levels of pest management on *Macroposthonia ornata* in a turnip (T)-field corn (FC)-cowpea (SP) intensive cropping system. A and B = LSD 0.05 for different pest-management levels at the same sampling time and for the same pest-management level at different sampling times, respectively (1975–1978); C and D = LSD 0.05 for different pest-management levels at the same sampling time and for the same pest-management levels at different sampling times, respectively (1979–1980). F = fallow.

Table 5. Yield of corn grain grown under four pest-management levels in an annual turnip-corn-cowpea multiple-cropping system

Pest management level	Yield (t/ha)					
	1975	1976	1977	1978	1979	1980
MBR-CP	11.2 b[z]	14.8 a	12.6 a	13.6 a	11.7	11.7
Maximum	12.9 a	14.5 a	12.6 a	12.4 b	11.5	11.6
Intermediate	11.9 b	11.9 c	11.7 ab	12.2 bc	10.4	12.2
Minimum	11.0 b	13.3 b	10.9 b	11.5 c	10.7	11.4

[z]Numbers 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.

From 1975 to 1977, 73% of the variation in the RDI was explained by populations of *Fusarium* spp., ring nematodes, root-knot nematodes, *F. moniliforme*, and *Pythium* spp., in order.

DISCUSSION

Although soil fumigation is not economically feasible for a turnip-corn-southern pea cropping system (2), this study establishes that soilborne pathogens are a significant factor in corn production in the Georgia coastal plain. Soil fumigation reduced populations of *Pythium* spp., *R. solani*, and nematodes; decreased root disease severity consistently; and increased yields in four of six years.

Rotation with soybeans, oats, wheat, and alfalfa increased yield and reduced root and stalk rot of corn (28), but the influence of vegetables on root diseases in corn has received little attention. Sulfur-containing compounds thought to be detrimental to soilborne pathogens are produced by decomposing cruciferous residues (12). Cruciferous residues have been used effectively to reduce diseases induced by *Aphanomyces euteiches* (Drechs.) in greenhouse experiments (15) and to reduce the viability of *R. solani* in soil (13), but the importance of turnip residues in reducing root disease in fields is not known.

Root diseases caused by *Pythium* spp. have been recognized for several decades as important pathogens of corn roots in cold, wet soils (6,17), and *P. aphanidermatum* is a common warm-season pathogen in irrigated multiple cropping in Georgia (24). *Pythium* spp. isolated from corn roots in Georgia caused more severe fibrous root decay than any other fungi (11). Soil temperature ranges during April, May, June, and July 5 cm deep in fallow Tifton loamy sand in the Georgia coastal plain are about 5–37, 15–38, 18–42, and 21–43 C, respectively. In irrigated soils 5 cm under the corn row, temperatures range from 15 to 32 C during May and June. Thus soil temperatures are favorable for infection by cool-season pathogens *P. irregulare* and *P. arrhenomanes* in the spring and for the warm-season pathogen *P. aphanidermatum* in the summer. The cool-season pathogen *P. graminicola* (17) was not isolated during this investigation.

R. solani AG-2 type 2 is widespread in soils of the Georgia coastal plain (21), but the fungus was not isolated from lesions on crown and brace roots in this study. Only *R. solani* AG-4, *R. zeae*, and *Rhizoctonia*-like fungi were isolated, but media selective for *R. solani* were not used for isolations from lesions. *R. solani* AG-2 type 2 is found frequently on corn rotated with peanuts and soybeans, but a turnip-corn-cowpea intensive rotation may not be conducive to the establishment and survival of the pathogen.

P. terristris (1,5), a sterile white basidiomycete (22), *F. oxysporum* (27), *F. moniliforme* (11), *R. zeae* (21), and an unidentified *Phoma* sp. (11) were isolated consistently and are known pathogens of corn. They are associated commonly with root lesions on corn in Georgia, but their role in a corn root disease complex is not known. Greenhouse experiments have demonstrated that all of the pathogens may reduce growth, and several of them may cause leaf symptoms that could be construed as mild Mg or Zn deficiency symptoms (11).

Pesticides may interact with soilborne pathogens and influence root disease severity, and pesticides may have been a factor in root disease severity in this study. Pendimethalin increased root disease severity in corn on Bonifay sand (23), and pendimethalin injury was evident in this test. Ethoprop was used to control nematodes in the maximum level during 1975–1978 and in the intermediate level during 1976–1978. In greenhouse studies with corn, the pesticide decreased foliage weight in soil infested with *P. irregulare* (26) and *P. aphanidermatum* (11) and consistently increased root disease severity in soils infested with *P. aphanidermatum* (D. R. Sumner, *unpublished*). Ethoprop increased root disease severity in snap bean and cowpea in intensive cropping systems (25). In contrast, the pesticide inhibited growth of *R. solani* in culture (18) and decreased root disease severity caused by *R. solani* in cucumber (20).

The increase in nematode population densities on corn was expected. Similar results have been reported on corn in other intensive cropping systems (9). Nematodes reduce yield of corn in soils of the Georgia coastal plain (7,8,10). Yield of corn in our study was lower ($P = 0.05$) in untreated plots than in plots where nematodes and soilborne pathogenic fungi were controlled in all years except 1979 and 1980. As new crop production technology was developed, it was integrated into this pest-management study. Cultural practices such as destruction of crop residues immediately after harvest, clean fallowing from harvest until succeeding crops were planted, crop rotation, planting of poor host crops, and application of pesticides to reduce survival of nematode and soilborne pathogenic fungi reduced inoculum levels for subsequent crops. In addition, optimum irrigation and fertilization may have partially masked damage caused by nematodes and soilborne pathogenic fungi when corn was not grown under biological stress. More was known about optimum fertilization and irrigation methods on corn in 1979 and 1980 than in 1975–1978.

Interactions of nematodes with soilborne pathogenic fungi on corn in soils of the Georgia coastal plain are not known. Root-knot nematodes in combination with *F. moniliforme* reduce corn growth (14), and results of our study suggest that nematodes and other soilborne pathogenic fungi may interact to increase root disease severity and decrease yield.

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