# Herbicide, Planting Date, and Root Disease Interactions in Corn

DONALD R. SUMNER, Associate Professor, Department of Plant Pathology, University of Georgia, and CLYDE C. DOWLER, Research Agronomist, USDA, ARS, Coastal Plain Experiment Station, Tifton, GA 31793

**ABSTRACT**

Sumner, D. R., and Dowler, C. C. 1983. Herbicide, planting date, and root disease interactions in corn. Plant Disease 67:513-517.

The interaction of herbicides and root disease of corn caused by *Rhizoctonia solani* AG-2 type 2 and *R. zeae* was studied in tests in a greenhouse and environmental chambers. In a greenhouse test with *R. solani* AG-2 type 2, root disease severity increased and root and shoot development were restricted in soil treated with pendimethalin and metolachlor. Alachlor, cyanazine, and cyanazine plus atrazine caused variable effects, and butylate and atrazine did not influence root disease severity or plant growth. Plant height was decreased significantly by X and 2X rates of the herbicides in uninfested soil but only by the X rate in infested soil. In environmental chambers, pendimethalin and metolachlor increased root disease severity and reduced plant height at night-day temperatures of 9–20, 15–25, and 21–32 C in untreated or heat-treated Dothan loamy sand. In soil infested with *R. solani* or *R. zeae*, pendimethalin caused more swollen club-shaped root enlargements at temperatures of 12–25 C than at 8–21 and 20–32 C. In field tests in Bonifay sand, root disease severity increased in soil treated with pendimethalin in corn planted on 3 March but not in corn planted on 21 February, 17 and 25 March, or 4 April. Grain yield was lower in soil treated with pendimethalin in the 3 March planting, and in soil treated with pendimethalin, metolachlor, and butylate in the 25 March planting. The herbicides did not increase root disease severity or decrease yield at any planting date on Tifton loamy sand. There were more enlarged roots in pendimethalin-treated plots in the first two plantings than in the last three plantings. In early plantings of corn when soil temperatures are 5–18 C, severe root injury and increased root disease severity may occur in sand and loamy sand soils treated with pendimethalin.

Herbicides interact with soilborne pathogens to influence root disease severity in many crops (2,7). In intensive cropping systems on sandy loam soils in the Georgia coastal plain, treatment with DCPA increased root disease severity and decreased yield of leafy greens in turnip (15), but treatment with trifluralin had irregular effects on root disease severity in snap bean and southern pea compared with cultivation without herbicides (16).

A root disease of corn caused by *Rhizoctonia solani* Kühn anastomosis group 2 (AG-2) was reported recently in the Georgia coastal plain (14). A less severe root disease of corn was caused by *R. zeae* Voorhees, a fungus widely distributed in soils of the Georgia coastal plain. The influence of cultural practices on the disease has not been studied but we have observed herbicide injury in plants with root disease symptoms. Pendimethalin, metolachlor, alachlor, atrazine, cyanazine, and butylate are herbicides used commonly in Georgia, and pendimethalin (13) and metolachlor (10) may cause injury in corn. In Michigan (9), root rot of corn induced by *Fusarium roseum* f. sp. *cerealis* 'Culmorum' was more severe in soil treated with atrazine. In contrast, atrazine decreased injury by *Diplodia maydis* and *Gibberella zeae*, and alachlor decreased injury by *D. maydis* in Missouri (6). Atrazine inhibited growth of *R. solani* in culture (11), but the influence of herbicides on Rhizoctonia root rot of corn is unknown. This research was begun to determine whether herbicides could interact with *R. solani* AG-2 and *R. zeae* to affect root disease severity in corn. A preliminary report on the influence of planting date on the activity of pendimethalin, metolachlor, and butylate in the Georgia coastal plain has been published (4).

This research was supported by state, Hatch, and Mellon Foundation funds allocated to the Georgia Agricultural Experiment Station. No endorsements are implied herein.

Accepted for publication 4 October 1982.

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be hereby marked "*advertisement*" in accordance with 18 U.S.C. § 1734 solely to indicate this fact.



## MATERIALS AND METHODS

**Greenhouse test.** Bonifay sand (93, 3, and 4% sand, silt, and clay, respectively) soil was heated in an oven to 55–60 C for 30 min. Heat-treated soil was separately infested 1:120 or 1:300 with cultures of *R. solani* (AG-2 type 2 or AG-4) grown on 3% cornmeal-sand (w/w) for 2–3 wk.

Soils were infested and fertilized by blending with 19, 38, and 57 μg/kg NPK for 5 min in a concrete mixer. Herbicides used (mg a.i./kg of soil, comparable to kg/ha) were pendimethalin 1.12 and 2.24, metolachlor 1.68 and 3.36, alachlor 2.24 and 4.48, cyanazine 1.12 and 2.24, butylate plus an inert herbicide safener 3.36 and 6.72, atrazine 2.24 and 4.48, and atrazine plus cyanazine 1.12 + 1.12 and 2.24 + 2.24.

Soil (2.5 kg, 1,800 ml) was placed into 16-cm-diameter black plastic cans, five corn kernels (Funks G-4507) were planted 3 cm deep, and solutions of all herbicides except butylate were atomized on the soil surface. Butylate was mixed with soil separately and placed in a layer 7.5 cm deep over untreated soil before planting. A split-plot experiment in a randomized complete block design was used. Whole plots were three replicates of infested or uninfested soil and subplots were herbicide treatments, one can per treatment. Plants were grown 4 wk in a greenhouse at night-day soil temperature ranges of 15 ± 2 to 26 ± 4 C and air temperatures of 21 ± 3 to 27 ± 6 C, then rated for root disease severity (RDS) with an index of 1–5 where 1 = <2, 2 = 2–10, 3 = 11–50, 4 = >50% discoloration and decay, and 5 = dead plants.

Plants were considered deformed if leaves were chlorotic, necrotic, gnarled or twisted, or if the internodes were telescoped and the leaves did not unfurl. The percentage of plants showing any foliage deformity was calculated in each treatment.

**Environmental chamber tests.** In the first experiment, Funks G-4507 was planted in 16-cm plastic cans and grown in three environmental chambers for 4 wk in naturally infested or heat-treated Bonifay sand treated with pendimethalin (1.12 mg/kg), or metolachlor (1.68 mg/kg), or untreated. A factorial experiment with three replicates of three plants per treatment was used. Night-day temperatures were 9–20 C for 2 wk, then 15–25 C for 2 wk, 15–25 or 21–32 C. A 12-hr day of 13,000 lux was provided with Sylvania Growlux and incandescent light bulbs. In a second test in environmental chambers, heat-treated Dothan loamy sand (85, 11, and 4% sand, silt, and clay, respectively) was infested separately with *R. solani* AG-2 type 2 or *R. zeae* or uninfested. Whole plots were two replicates of each of 13 isolates of *R. zeae*, two isolates of *R. solani*, and uninfested soil. Subplots were 10-cm pots, three seeds per pot, treated with pendimethalin (1.12 mg/kg) or untreated. Corn was grown 12–17 days at night-day temperatures of 8 ± 1 to 21 ± 1, 12 ± 4 to 25 ± 3, or 20 ± 1 to 32 ± 1 C, and root disease severity, foliage deformities, and green foliage weight were determined.

**Field tests.** Experiments were done in naturally infested fields in two locations, Tifton loamy sand and Bonifay sand following soybean and vegetable crops, respectively. A split-plot experiment in a randomized complete block design was used. Soils were turned with a moldboard plow and fertilizer broadcast and incorporated 10–15 cm deep with a tractor-driven rototiller. Plots were subsoiled 45 cm deep under the row to reduce subsoil compaction, which can be a limiting factor to root penetration in soils in the Georgia coastal plain.

Whole plots were four replicates of planting dates: 21 February, 3 March, 17 March, 25 March, and 4 April. Subplots were herbicide treatments: pendimethalin, metolachlor, and butylate at 1.12, 1.68, and 4.48 kg/ha, respectively, and a hand-weeded control. Butylate was incorporated with the rototiller and the other herbicides were sprayed on the soil surface. Each subplot was four rows 91 cm apart and 4.6 or 7.6 m long. Corn seeds (Funks G-4507) were planted 15 cm apart and 3 cm deep. Experiments in both locations were grown under overhead sprinkler irrigation. Subplots for the first three planting dates were cultivated for additional weed control. Minimum and maximum soil temperatures 2.5 cm deep were recorded daily at each location from 17 February to 26 April.

Plants were rated for root disease severity and relative root growth when they were 7–10 wk old. Root growth was rated on an empirical scale of 1–5 where 1 = very poor growth and 5 = excellent growth without regard to root discoloration. Ten plants per subplot were evaluated in each of the last four plantings, but only one to seven plants per subplot were evaluated in the first planting because a severe freeze (−9 C) killed most of the plants on 3 March.

One root or hypocotyl (subcrown internode) tissue section (5–10 mm) was removed from each of five plants in each subplot of two replicates at each location in the second and third plantings to determine what fungi were involved in the root disease complex. Discolored tissues from seminal roots were washed 30–60 min in cool (15–25 C) running tap water and edges of large (5–20 mm) lesions were surface-disinfected 10–15 sec in 0.5% NaOCl. All tissues were blotted dry on sterile filter paper and incubated on water agar for 2–3 days. Hyphal tips were transferred to potato-dextrose agar and identified.

**Table 1.** Root disease severity, root weight, and height of corn grown in heat-treated soil infested with *Rhizoctonia solani* or uninfested and treated with herbicides in a greenhouse

| | RDI[x] | | Dry root wt (mg) | | Height (cm) | |
|---|---|---|---|---|---|---|
| Herbicide[w] | Infested soil[y] | Uninfested soil | Infested soil | Uninfested soil | Infested soil | Uninfested soil |
| Pendimethalin | 4.8 a A[z] | 3.8 a A | 88 b A | 392 b A | 2 b A | 17 b A |
| Metolachlor | 3.7 ab A | 3.7 a A | 410 b A | 480 b A | 24 a A | 8 b A |
| Alachlor | 4.5 a A | 2.6 ab B | 230 b A | 598 b A | 13 ab A | 17 b A |
| Cyanazine (C) | 4.2 ab A | 1.7 b B | 148 b A | 463 b A | 18 ab A | 42 a B |
| Butylate | 3.9 ab A | 1.7 b B | 572 a A | 1,025 a B | 24 a A | 52 a B |
| Atrazine (A) | 3.5 ab A | 1.7 b B | 500 ab A | 672 ab A | 28 a A | 54 a B |
| C + A | 3.0 b A | 1.8 b A | 332 b A | 563 b A | 23 a A | 42 a B |
| None | 3.8 ab A | 1.8 b B | 450 a A | 1,250 a B | 30 a A | 58 a B |
| LSD 0.05 | 1.25 | | 370 | | 18 | |

[w]Herbicides were applied at X and 2X rates according to manufacturers' recommendations. There were no significant differences in root disease severity or root weight between rates with any of the herbicides.

[x]RDI = Root disease index: 1 = <2, 2 = 2–10, 3 = 11-50, 4 = >50% discoloration or decay, and 5 = dead plants.

[y]Numbers in columns followed by the same lowercase letter or pairs of numbers (for RDI, dry root weight, and height) in rows followed by the same capital letter are not significantly different according to Duncan's multiple range test, $P = 0.05$.

[z]Average of two replicates in Bonifay sand and Dothan loamy sand soil infested with *R. solani* AG-2 and one replicate in soil infested with AG-4.

**Table 2.** Influence of herbicide dosage on root disease severity, root weight, and height of 26-day-old corn grown in soil infested with *Rhizoctonia solani* or uninfested in a greenhouse

| | RDI[x] | | Dry root wt (g) | | Height (cm) | |
|---|---|---|---|---|---|---|
| Herbicide dosage[w] | Infested soil[y] | Uninfested soil | Infested soil | Uninfested soil | Infested soil | Uninfested soil |
| 0 | 3.8 a A[z] | 1.8 a B | 0.45 a A | 1.25 a B | 30 a A | 58 a B |
| X | 4.2 a A | 2.3 a B | 0.28 a A | 0.61 b A | 15 b A | 36 b B |
| 2X | 3.7 a A | 2.5 a B | 0.37 a A | 0.59 b A | 23 ab A | 31 b A |
| LSD 0.05 | 1.1 | | 0.33 | | 14.7 | |

[w]Based on manufacturers' recommended rates. Each dosage is the average of pendimethalin, metolachlor, alachlor, cyanazine, butylate, atrazine, and cyanazine + atrazine treatments.

[x]RDI = Root disease index: 1 = <2, 2 = 2–10, 3 = 11-50, 4 = >50% discoloration or decay, and 5 = dead plants.

[y]Average of two replicates in Bonifay sand and Dothan loamy sand soil infested with *R. solani* AG-2 and one replicate in soil infested with AG-4.

[z]Numbers in columns followed by the same lowercase letter or in pairs of numbers in rows (infested soil, uninfested soil) followed by the same capital letter are not significantly different according to Duncan's multiple range test, $P = 0.05$.

## RESULTS

**Greenhouse Test.** In soil infested with *R. solani*, the number of plants was reduced by metolachlor, cyanazine, butylate, and atrazine at X rates and by pendimethalin and alachlor at 2X rates. In contrast, butylate increased stand at the 2X rate.

Root disease severity in infested soil ranged from moderate in the cyanazine plus atrazine treatment to severe in the alachlor and pendimethalin treatments. Only pendimethalin, metolachlor, and cyanazine plus atrazine caused as much root injury in uninfested soil as in infested soil (Table 1). Root weight was greater in uninfested than in infested soil, but the herbicide treatments had the same effects on root growth in both soils. Only the pendimethalin treatment restricted shoot development in both infested and uninfested soil (Table 1).

There was no difference between the X and the 2X rates of the herbicides on root disease severity and root weight. In contrast, height was decreased significantly by both the X and 2X rates in uninfested soil but only by the X rate in infested soil, indicating that higher rates of herbicides were more detrimental to the host than to the pathogen. In infested soil, the height of plants grown in the 2X treatments was not significantly different from that of plants in soil not treated with herbicides (Table 2).

Pendimethalin treatments caused swollen tips on crown and lateral roots in many plants in uninfested soil. Roots were so severely rotted in infested soil that swollen roots were not visible. In the 2X treatment, primary roots were also swollen in uninfested soil. Deformed roots were not considered diseased unless they were discolored or decayed. Metolachlor and alachlor treatments caused foliage deformation but did not cause visual root injury.

**Environmental chamber tests.** Temperature differences did not influence root disease severity or height of plants in heat-treated or untreated Dothan loamy sand from the field. Pendimethalin and metolachlor significantly increased root disease severity and the percentage of dead plants and reduced height at all three temperature ranges compared with soil with no herbicides (Table 3). Metolachlor caused more plant injury than pendimethalin. There was a temperature treatment interaction on the percentage of plants with deformed foliage. Two weeks after planting, there were no differences among treatments and very little injury at the temperature range of 21–32 C, but both herbicides caused injury at 15–25 and 9–20 C and metolachlor caused severe deformation. After 4 wk, there was no observable interaction and only metolachlor caused injury (Table 4). In deformed plants, the leaves did not unfurl until plants were 3–5 cm tall and sometimes not at all. Leaves were wrinkled, twisted, and gnarled as they unfurled and were sometimes chlorotic or necrotic, especially in the metolachlor treatment. Surviving plants were stunted but frequently resumed normal growth 3–4 wk after planting. In many plants, pendimethalin caused swollen club-shaped or 'bowling-pin' shaped enlargements on the tips of lateral and crown roots in the top 3–5 cm of soil. No enlargments were observed on primary roots.

In soil infested with *R. solani* AG-2 type 2 or *R. zeae*, pendimethalin did not increase root disease severity or reduce foliage weights at any temperature range. The number of plants with swollen roots in soil treated with pendimethalin, however, was greater at soil temperatures of 12 ± 4 to 25 ± 3C than at either 8 ± 1 to 21 ± 1 C or 20 ± 1 to 32 ± 1 C. *R. solani* AG-2 type 2 was equally virulent at all ranges of temperature, but the virulence of *R. zeae* increased as temperature increased (Table 5).

**Field tests.** The average minimum and maximum soil temperatures for 2 wk after planting ranged from 5 and 18 C in the first planting to 13 and 30 C in the last planting in Tifton loamy sand and were similar in Bonifay sand. When RDS was determined, plants in 21 February and 3, 17, and 25 March plantings were 40–60 cm tall in the six- to eight-leaf stage and plants in the 4 April planting were 1.6–2.5 m tall in the pretassel to tasseling stage. Root disease severity was significantly lower in the 17 and 25 March plantings than in the other plantings in both tests. Pendimethalin increased root disease severity in the 3 March planting on Bonifay sand but not in the other plantings (Table 6). Yields were lowered by the pendimethalin treatment in the 3 March planting and by all herbicide treatments in the 25 March planting. In Tifton loamy sand, herbicide treatments did not influence root disease severity or yield (Table 7). Root growth of 7- to 10-wk-old plants was progressively greater from the 25 February through the 17 March planting, but there were no

**Table 3.** Influence of herbicides on disease severity and growth of 4-wk-old corn in Bonifay sand in environmental chambers[x]

| Treatment | RDI[y] | Height (cm) | Dead plants (%) |
|---|---|---|---|
| Control | 1.1 a[z] | 62 a | 0 c |
| Pendimethalin | 1.9 b | 51 b | 22 b |
| Metolachlor | 2.7 c | 23 c | 46 a |

[x]Data are the average of corn grown at night-day temperatures of 21–32, 15–25, and 9–20 C in field soil and heat-treated soil. Temperature and soil differences were not significant.
[y]RDI = Root disease index: 1 = <2, 2 = 2–10, 3 = 11–50, 4 = >50% discoloration or decay, and 5 = dead plants.
[z]Numbers followed by different letters are significantly different according to Duncan's multiple range test, $P = 0.05$.

**Table 4.** Influence of temperature ranges and herbicides on percentage of corn plants with deformed foliage in Bonifay sand in environmental chambers

| | Temperature range[y] | | | | | |
|---|---|---|---|---|---|---|
| | 2 Wk | | | 4 Wk | | |
| Treatment | High | Medium | Low | High | Medium | Low |
| Control | 4 | 0 c[z] | 5 c | 0 b | 0 b | 0 b |
| Pendimethalin | 0 | 27 b | 50 b | 0 b | 0 b | 8 b |
| Metolachlor | 15 | 83 a | 75 a | 15 a | 8 a | 33 a |

[y]High, medium, and low were night-day temperature ranges of 21–32, 15–25, and 9–20 C, respectively. The low temperature range was raised to 15–25 C 12 days after planting.
[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 difference.

**Table 5.** Root disease severity, root injury, and foliage weight in corn seedlings grown in environmental chambers at various temperature ranges in infested or uninfested soil treated with pendimethalin or untreated

| | RDI[x] | | | Number of plants with swollen roots | | | Foliage green wt (g) | | |
|---|---|---|---|---|---|---|---|---|---|
| Treatment | 8–21 C | 12–25 C | 20–32 C | 8–21 C | 12–25 C | 20–32 C | 8–21 C | 12–25 C | 20–32 C |
| Herbicide | | | | | | | | | |
| Pendimethalin | 1.7 a A[y] | 1.9 a A | 1.8 a A | 1.30 a B | 2.17 a A | 1.34 a B | 1.39 a A | 2.32 a B | 3.73 a C |
| None | 1.8 a A | 1.8 a A | 1.8 a A | 0 a A | 0 b A | 0.15 b A | 1.50 a A | 2.45 a B | 3.98 a C |
| Fungus[z] | | | | | | | | | |
| RS-AG2-2 | 2.6 a A | 2.7 a A | 2.2 a A | 1.12 a A | 0.75 a A | 1.50 a A | 1.48 a A | 1.94 b A | 3.25 b B |
| RZ-RBF | 1.6 a A | 1.7 b A | 2.0 a A | 0.44 ab A | 1.12 a A | 0.38 b A | 1.44 a A | 2.12 b B | 3.75 b C |
| RZ-WM | 1.8 b B | 2.1 b AB | 2.5 a A | 0.69 ab AB | 1.39 a A | 0.50 b B | 1.59 a A | 2.18 b A | 3.74 b B |
| SBR | 1.6 b A | 1.3 c A | 1.4 b A | 1.00 a A | 1.40 a A | 1.35 a A | 1.70 a A | 2.42 b B | 3.92 b C |
| None | 1.1 c A | 1.6 bc A | 1.0 b A | 0 b A | 0.75 a A | 0 b A | 1.00 a A | 3.25 a B | 4.62 a C |

[x]RDI = Root disease index: 1 = <2, 2 = 2–10, 3 = 11–50, 4 = >50% discoloration or decay, and 5 = dead plants.
[y]Numbers in columns of herbicide or fungus treatments followed by the same lowercase letter and groups of three numbers in rows (RDI, plants with swollen roots, and green weight) followed by the same capital letter are not different according to Duncan's multiple range test, $P = 0.05$.
[z]RS-AG2-2 = *Rhizoctonia solani* AG-2 type 2; RZ-RBF = *R. zeae*, reddish brown isolates with plectenchymatous mycelium; RZ-WM = *R. zeae*, tan to pale orange isolates with floccose mycelium; SBR = unidentified soil basidiomycete with brick-red sclerotia.

**Table 6.** Effects of date of planting and herbicide treatments on root disease severity and yield in corn grown in Bonifay sand

| | Date of planting | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 21 February[x] | 3 March | | 17 March | | 25 March | | 4 April | |
| Herbicide | RDI[y] | RDI | Yield (kg/ha) | RDI | Yield (kg/ha) | RDI | Yield (kg/ha) | RDI | Yield (kg/ha) |
| Pendimethalin | 2.0 a[z] | 2.0 a | 6,710 b | 1.2 | 10,602 | 1.1 | 5,586 b | 1.3 b | 10,376 |
| Metolachlor | 1.4 c | 1.8 ab | 9,271 a | 1.2 | 10,652 | 1.3 | 5,907 b | 1.7 a | 10,156 |
| Butylate | 1.6 bc | 1.7 ab | 8,330 a | 1.3 | 11,167 | 1.2 | 5,285 b | 1.6 ab | 11,054 |
| None | 1.8 ab | 1.6 b | 9,397 a | 1.3 | 10,740 | 1.2 | 7,457 a | 1.5 ab | 10,351 |

[x] Yields were not taken in the 21 February planting because of a hard freeze (−9 C) on 3 March that killed most of the plants.

[y] Root disease index: 1 = <2, 2 = 2–10, 3 = 11–50, 4 = >50% discoloration and decay, and 5 = dead plants.

[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.

**Table 7.** Effects of date of planting and herbicide treatments on root disease severity and yield in corn grown on Tifton loamy sand

| | Date of planting | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 21 February[a] | 3 March | | 17 March | | 25 March | | 4 April | |
| Herbicide | RDI[b] | RDI | Yield (kg/ha) | RDI | Yield (kg/ha) | RDI | Yield (kg/ha) | RDI | Yield (kg/ha) |
| Pendimethalin | 2.2[c] | 1.8 | 3,195 | 1.4 | 7,018 | 1.7 | 5,166 | 1.7 | 4,513 |
| Metolachlor | 2.0 | 1.8 | 5,298 | 1.1 | 6,057 | 1.0 | 5,260 | 1.9 | 3,803 |
| Butylate | 2.0 | 1.8 | 4,306 | 1.3 | 4,394 | 1.0 | 4,042 | 2.0 | 3,766 |
| None | 2.2 | 1.8 | 4,162 | 1.2 | 5,568 | 1.1 | 4,363 | 1.9 | 2,687 |

[a] Yields were not taken in the 21 February planting because of a hard freeze (−9 C) on 3 March that killed most of the plants.

[b] Root disease index: 1 = <2, 2 = 2–10, 3 = 11–50, 4 = >50% discoloration and decay, and 5 = dead plants.

[c] 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.

differences among the 17 and 25 March and 4 April plantings. Pendimethalin treatments reduced root growth in the 25 February, 3 March, and 4 April planting in Bonifay sand and in the 3 March planting on Tifton loamy sand. Metolachlor and butylate treatments did not influence root growth. More roots were enlarged and deformed in pendimethalin treatments in the 25 February and 3 March plantings than in later plantings, but there were club-shaped enlargements on roots of some plants in every planting in both soils. Metolachlor and butylate treatments did not affect visual root morphology.

*Trichoderma* spp. and *F. oxysporum* were isolated more frequently than other fungi from roots and hypocotyls in the 3 and 17 March plantings in all treatments in both soils (55 and 23%, respectively). *R. solani* and *R. zeae* were isolated infrequently (4 and 3%, respectively) from root lesions in Tifton loamy sand but not in Bonifay sand. *R. solani* AG-2 type 2 was isolated from reddish brown lesions on brace and crown roots of plants in one plot treated with pendimethalin in the 17 March planting on Tifton loamy sand. The pathogen was primarily isolated from lesions on roots in the top 15 cm of soil but once from a lesion on a root more than 15 cm deep.

A stepwise multiple regression analysis after fixed effects of location, date of planting, and herbicide treatments were removed indicated that residual yield differences were related to root growth but not to root disease severity ($R^2$ = 0.45). Root growth differences were related to location but root disease severity was independent of fixed effects.

There was a significant negative correlation of root disease severity with both height ($r = -0.18$) and root growth ($r = -0.36$), of the number of plants with hypocotyl lesions with both height ($r = -0.27$) and yield ($r = 0.28$), and of the number of plants with swollen club-shaped roots with root growth ($r = -0.31$). There was a significant positive correlation of yield with both root growth ($r = 0.4$) and height ($r = 0.48$) and root disease severity with days to midtassel ($r = 0.33$) and midsilk ($r = 0.36$).

## DISCUSSION

Our research indicates that pendimethalin can cause severe root injury, increase root disease severity, and decrease yield in early plantings of corn when soil temperatures range from 5 to 18 C. The root injury we observed in tests in fields, environmental chambers, and the greenhouse were similar to symptoms described previously for dinitroanaline injury (3,5,12). Others found that pendimethalin phytotoxicity to corn roots and foliage increased with increasing temperatures and was greater at 20–22 C (13). We observed club-shaped root enlargements at all temperatures (9–31 C) in controlled-temperature tests, with the greatest injury at temperatures of 12 ± 4 to 25 ± 3 C. Foliage injury did not occur when minimum soil temperatures were above 21 C. Root disease severity caused by *R. solani* AG-2 type 2 was greatest in soil treated with pendimethalin, indicating that the herbicide may predispose corn roots to the pathogen. In contrast, the herbicide reduced damping-off of tomato caused by *Pythium* spp. in Sudan and no phytotoxicity was reported (1).

Metolachlor and butylate did not increase root disease severity or cause root or foliage injury in field tests. In controlled-temperature tests, alachlor and metolachlor caused severe foliage injury. Chloroacetamide herbicides are primarily absorbed by shoots rather than roots, and this may explain the severe foliage deformation in our tests (8,10).

Populations of *R. solani* AG-2 were apparently low (<5.0 propagules/100 g soil) in the field tests because the pathogen was rarely isolated. Nevertheless, the pathogen was isolated primarily from roots of plants treated with pendimethalin, and crown and brace root rot typical of infections by *R. solani* AG-2 type 2 (14) was most frequently observed in pendimethalin treatments. In greenhouse and environmental chamber tests, foliage and root injury were always greatest in pendimethalin treatments. Thus, it is evident that pendimethalin has the potential to increase root disease severity in field corn in the Georgia coastal plain, especially in early plantings in fields with moderate to high populations (10–20 propagules/100 g soil) of *R. solani* AG-2.

## LITERATURE CITED


1. Abdalla, M. H., and Manci, S. F. 1979. Interaction between a *Pythium* and the herbicide 'Stomp.' Trans. Br. Mycol. Soc. 72:213-218.
2. Altman, J., and Campbell, C. L. 1977. Effect of herbicides on plant diseases. Annu. Rev. Phytopathol. 15:361-385.
3. Ashton, F. M., and Crafts, A. S. 1973. Dinitroanilines. Pages 221-235 in: Mode of Action of Herbicides. John Wiley & Sons, New York.
4. Dowler, C. 1981. Influence of corn planting date on activity of selected herbicides. (Abstr.) Proc. South. Weed Sci. Soc. 34:42.
5. Hacskaylo, J., and Amato, V. A. 1968. Effect of trifluralin on roots of corn and cotton. Weed Sci. 16:513-515.
6. Houseworth, L. D., and Tweedy, B. G. 1972. Effect of herbicides on soilborne pathogens. (Abstr.) Phytopathology 62:765.
7. Katan, J., and Eshel, Y. 1973. Interactions between herbicides and plant pathogens. Residue Rev. 45:145-177.
8. Narsaiah, D. B., and Harvey, R. G. 1977. Alachlor placement in the soil as related to phytotoxicity to maize (*Zea mays* L.) seedlings. Weed Res. 17:163-168.
9. Percich, J. A., and Lockwood, J. L. 1975. Influence of atrazine on the severity of Fusarium root rot in pea and corn. Phytopathology 65:154-159.
10. Pillai, P., Davis, D. E., and Truelove, B. 1979. Effects of metolachlor on germination, growth, leucine uptake, and protein synthesis. Weed Sci. 27:634-637.
11. Rodriguez-Kabana, R., Curl, E. A., and Funderburk, H. H., Jr. 1966. Effect of four herbicides on growth of *Rhizoctonia solani*. Phytopathology 56:1332-1333.

12. Schultz, D. R., Funderburk, H. H., Jr., and Negi, N. S. 1968. Effect of trifluralin on growth, morphology, and nucleic acid synthesis. Plant Physiol. 43:265-273.
13. Schwartz, T. K., and Alley, H. P. 1979. Factors affecting the activity and movement of pendimethalin. Weed Abstr. 28:367.
14. Sumner, D. R., and Bell, D. K. 1982. Root diseases of corn caused by *Rhizoctonia solani* and *Rhizoctonia zeae*. Phytopathology 72:86-91.
15. Sumner, D. R., Glaze, N. C., Dowler, C. C., and Johnson, A. W. 1979. Herbicide treatments and root diseases of turnip in intensive cropping systems. Plant Dis. Rep. 63:801-805.
16. Sumner, D. R., Johnson, A. W., Glaze, N. C., and Dowler, C. C. 1978. Root diseases of snapbean and southern pea in intensive cropping systems. Phytopathology 68:955-961.