Interaction of Fungicides, Herbicides, and Planting Date with Seedling Disease of Cotton Caused by *Rhizoctonia solani* AG-4

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ABSTRACT

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In field experiments with seedling disease of cotton (*Gossypium* spp.) caused by *Rhizoctonia solani* anastomosis group (AG)-4 in Egypt and in Georgia, recommended rates of the herbicides norflurazon, pendimethalin, fluometuron, prometryn, fomesafen, and oxyfluorfen significantly affected the efficacy of the fungicides tolclofos-methyl, pencycuron, carboxin, flutolanil, metalaxyl, and chloroneb on the basis of percentage of plant stand 7–42 days after planting. Also, the efficacy of three experimental combinations of fungicides and two fungicide combinations sold commercially (copper oxyquinolate + carboxin and pentachloronitrobenzene + metalaxyl) was reduced. All herbicides caused visible damage to cotton plants in Tifton loamy sand soil in Georgia but not in the silty loam soil in Egypt. The most rapid recovery from herbicide damage and the least reduction in efficacy of fungicides were observed with herbicide norflurazon. In Georgia, the efficacy of fungicides was evaluated with no herbicides for four planting dates between 29 March and 2 May. Planting on 12 and 19 April did not affect the efficacy of the fungicides chloroneb, flutolanil, pencycuron, tolclofos-methyl, metalaxyl, or pentachloronitrobenzene, but it significantly reduced the percentage of stand with carboxin. Efficacy of all fungicides was reduced by delaying planting until 2 May (in warm, wet soil, 21–28 C) or planting early (29 March) in cool, wet soil (14–24 C).

Rhizoctonia solani Kühn anastomosis group (AG)-4 (teleomorph: *Thanatephorus cucumeris* (A. B. Frank) Donk) is one of the most important pathogens in cotton (*Gossypium* spp.) wherever the crop is grown. The pathogen usually attacks cottonseed or seedlings during germination and initial establishment of plants in the soil (5,41) and is considered to be a major factor affecting cotton stands in Egypt. An estimated 4–7% of the cotton fields in the Nile Delta are replanted each year because of seedling diseases caused by *R. solani, Pythium* spp., *Sclerotium rolfsii* Sacc., and *Fusarium* spp. Seed treatments with one or more protectant and systemic fungicides are the main recommendation for reducing disease and avoiding replanting, particularly if the weather is wet and cool during planting, or if the field has a history of diseases (1,4,24,25).

The efficacy of fungicides is extremely variable among cotton regions with different weather and even within fields of the same region with different dates of planting (8,14,24). The reaction of *R. solani* to many fungicides varies among isolates (6,36,40) or anastomosis groups (17,38). Furthermore, fungicidal derivatives (carboxin and several of its analogues) have variable activities against *R. solani* of cotton in vitro (16). Dry and warm weather at planting followed by cool weather after planting reduced the improvement of cotton stand with soil fungicides in Tennessee (7); with different soil treatments, however, delaying planting until soils were warmer did not reduce seedling disease of cotton in California (10).

Herbicides are widely used in cotton fields, and they and fungicides may act simultaneously in the same field environment and may interact and affect the control of disease, weeds, or both (11-13, 19-21). Herbicides affected the activity of some fungicides in vitro and in greenhouse tests (26,30,43). Objectives of this research were to study the interaction of fungicides with herbicides that are commonly used in cotton fields naturally infested with *R. solani* and to investigate the effect of planting date on the efficacy of some recommended seed-treatment fungicides.

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MATERIALS AND METHODS

Fungicides and herbicides were applied as formulated products (except for experimental fungicides) at the rates recommended for cottonseed treatment or for the soil type. The protectant fungicides tolclofos-methyl, pencycuron, and pentachloronitrobenzene (PCNB); the systemic fungicides carboxin, flutolanil, metalaxyl, and chloroneb; and two fungicide combinations (copper oxyquinolate + carboxin and PCNB + metalaxyl) were applied to cottonseed at 3 g a.i./kg with an electric rotary seed mixer and Triton B-1956 (5 ml/150 g of seed) as a spreader-sticker. The herbicides prometryn, fluometuron, oxyfluorfen, pendimethalin, fomesafen, and norflurazon were applied in a water solution (according to manufacturers' recommendations) just after planting and before watering with a hand pump sprayer at 1.67, 1.67, 0.41, 1.1, 0.42, and 1.1 kg a.i./ha, respectively. Preplant incorporation into soil is an alternative method of application, but it was not used in these experiments.

The experiments were performed over two seasons (1990 and 1991) in the greenhouse in both countries to evaluate the efficacy of fungicides. Field experiments to investigate the interaction of fungicides with herbicides were carried out in naturally infested soil at two locations for one season (1990) in Egypt and at two sites in the other season (1991) at the Coastal Plain Experiment Station, Tifton, Georgia.

Greenhouse and field experiments in Egypt. In 1990, four fungicides (tolclofos-methyl, pencycuron, carboxin, and copper oxyquinolate + carboxin) recommended as seed treatments were tested in the greenhouse to evaluate their efficacy against a highly virulent isolate of *R. solani* (morphologically similar to AG-4) obtained from a diseased cotton seedling from Menofia governorate. The isolate was grown for 14 days at 25 C on sterilized sorghum grain and then used to infest the silty loam soil of Giza Research Station (steam-autoclaved for

2 hr at 121 C) at 0.05% (w/w). Cotton seed of the Egyptian cultivar Giza 75 (*G. barbadense* L.) were used. The treatments were arranged in a completely randomized design in four replicates, with three rows of 50 seed per replicate in 10 holes 2–3 cm deep. Five seeds were planted per hole by a method similar to that used by farmers in Egypt. Soil temperature during the experiment ranged from 22 to 26 C. Percent stand was recorded 10, 20, 30, and 40 days after planting (DAP).

The same fungicides were tested for efficacy in fields of alluvial silty loam naturally infested with *R. solani* at two locations in the Nile Delta (Menofia and Dakahlia governorates) separately or in the presence of four different herbicides recommended as preemergence treatments (pendimethalin, oxyfluorfen, fluometuron, and prometryn). Cotton seed of Giza 75 (78 kg/ha, recommended to produce 78,000 plants per hectare) were planted on 30 March and 27 April in Menofia and Dakahlia, respectively. The Menofia experiment was planted following 2 yr of fallow, but the Dakahlia experiment was delayed to allow harvesting of the precrop (carrot, *Daucus carota* L. subsp. *sativus* (Hoffm.) Arcang.). At Dakahlia the experiment was furrow-irrigated immediately after planting, but at Menofia irrigation was inadvertently delayed, because water for furrow irrigation was unavailable until 3 days after planting and herbicide application. The experimental design was a split–split plot, with fungicides as whole plots, herbicides as subplots, and dates of collecting stand counts as sub-subplots. Each replicate was three rows, spaced 60 cm apart and 4.5 m long, with 200 seeds in holes 20–25 cm apart (10 seeds per hole), 2–3 cm deep. Data were recorded as percent stand at 10-day intervals until 40 DAP.

Greenhouse and field experiments in Georgia. In the second season (1991), seed of the American cultivar Delta-Pine 90 (*G. hirsutum* L.) were treated with five recommended fungicides (flutolanil, tolclofos-methyl, pencycuron, carboxin, or PCNB) to evaluate their efficacy as seed treatments against the pathogen *R. solani* AG-4 in the greenhouse. A highly virulent isolate obtained from soil in a cotton field was grown for 14 days on cornmeal–sand (3:100, w/w) medium at 25 C. Tifton loamy sand soil (fine-loamy, siliceous, thermic, plinthic kandiudults) was treated with aerated steam at 65 C for 2 hr, mixed with fertilizer (N, P_2O_5, and K_2O, each at 38 μg per gram of soil) and infested with 0.4% cornmeal–sand (v/v). A total of 20 cottonseeds were planted 2–5 cm deep in five holes (four seeds per hole) in 16-cm-diameter plastic pots. A split-plot design with five replicates was used, with fungicides as whole plots and date of stand counts as subplots.

The effect of six herbicides (prometryn, fluometuron, oxyfluorfen, pendimethalin, fomesafen, or norflurazon) on the efficacy of six protectant or systemic fungicides and on three fungicide combinations was studied in two separate experiments in a cotton field (in which peanut was the previous crop) in Tifton loamy sand soil on the Coastal Plain Experiment Station in Georgia. The peanut crop was moderately infected with Rhizoctonia limb blight induced by *R. solani* AG-4. In the first experiment, acid-delinted seed of the cultivar Delta-Pine 90 were treated 4 days before planting with a fungicide, either tolclofos-methyl, pencycuron, carboxin, PCNB, flutolanil, or chloroneb. In the second experiment in the field, seeds pretreated with experimental fungicide or biocontrol combinations (carboxin-thiram + metalaxyl at 6.4 + 0.45 ml/kg, Mon [experimental fungicide] 24,000 + metalaxyl + thiram at 19.2 + 0.45 + 1.75 ml/kg, Colorcon opradry type F + the biocontrol agent *Trichoderma harzianum* Ritai; 2–3% + 25–50 μg/g, respectively) and untreated seeds of the same cultivar were used. Both experiments were conducted in a split–split-plot design with four replications. Whole plots were herbicides, subplots were fungicides, and sub-subplots were date of recording each of the six weekly stand counts. Experiments were irrigated with overhead sprinklers (1.2 cm) immediately after planting and as needed to prevent drought stress.

Effect of planting date on the efficacy of fungicides. The experiment was conducted in a naturally infested field of Tifton loamy sand at the Coastal Plain Experiment Station during the planting season of 1991. The previous crop was peanut in 1990. The test was designed in a split–split-plot in time. Whole plots were date of planting (29 March, 12 April, 19 April, and 2 May) in four blocks, but planting dates were not randomized. Subplots were two rows (3.5 m long) of acid-delinted Delta-Pine 90 seed treated with the recommended dosage (3 g a.i./kg) of seven fungicides (tolclofos-methyl, pencycuron, carboxin, metalaxyl, flutolanil, chloroneb, and PCNB + metalaxyl) and an untreated control. The fungicide treatments were randomized among the planting dates in the first block, and the same design was used in the other blocks; consequently, there was no replication. Sub-subplots were dates of six weekly stand counts. Dates of planting represented the range of recommended times for planting cotton in Georgia (April and May) and the northern region of the Nile Delta in Egypt (March and April).

In all field experiments conducted in Tifton, Georgia, seed-bed preparation and fertilization were completed in late March 1991. Soils were moldboard-plowed 20–25 cm deep, and a 10-10-10 N-P-K fertilizer with micronutrients (Ca, Mg, S, B, Zn, and Cl) was broadcast at 558.5 kg/ha 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 limit root penetration in Coastal Plain soils of Georgia (3). Soil was not treated with any herbicides or soil fungicides for 10 mo before planting. Each row was planted with 100 seeds, 5 seeds per hole, 2–3 cm deep and 15-cm apart. Rows were 50 cm apart, and replicates were separated by an unplanted row. Meteorological data (rainfall, soil temperatures at different depths, and air temperature) were recorded daily from 15 March until 13 June, when experiments were terminated.

In Egypt, soil was disk-harrowed 20–25 cm deep before planting. Soil fertility was adequate for seedling establishment, and no fertilizer was applied before planting. No herbicides were used during the previous 2 yr. Planting methods were similar to those used in Georgia.

Statistical analysis. All data were analyzed by SAS analysis of variance (PROC-ANOVA) or general linear model procedures when data were missing (35). The appropriate model for each design was used to analyze data from each experiment. The Waller-Duncan mean separation test was used to separate means at the 5% level of significance (k ratio = 100). The t test was used to compare betas (slope from linear models) when the F test was significant ($P = 0.05$). The word *significant* is used throughout the manuscript to indicate $P = 0.05$.

RESULTS

Efficacy of fungicides in the greenhouse. In the greenhouse in Egypt in 1990 (Fig. 1A), all tested fungicides significantly increased the percentage of standing plants through the 40 days of the experiment. There were no significant differences among fungicides in emergence 10 DAP. Tolclofos-methyl and pencycuron (81 and 82% stand, respectively) were more efficacious against *R. solani* AG-4, and they protected standing plants longer, than carboxin and copper oxyquinolate + carboxin (63 and 58% stand, respectively). All fungicides were better than the untreated control (9% stand) (Fig. 1A).

In a similar experiment in 1991 in Tifton, Georgia, PCNB was the only treatment that increased emergence significantly 7 DAP (84%), compared with 63% in the control treatment (Fig. 1B). At 4 wk after sowing, plant stands from seed treated with flutolanil, PCNB, and pencycuron were still greater (64, 56, and 51%) compared with tolclofos-methyl (32%), carboxin (31%), and the untreated control (19%), respectively (Fig. 1B).

Efficacy of fungicides in fields. All fungicides showed a trend in disease control similar to the greenhouse experiment evaluated at 40 DAP. The percent stand with tolclofos-methyl and pencycuron was 62 and 53% at 10 DAP and 48 and 47% at 40 DAP, respectively, compared with 41% (10 DAP) and 26% (40 DAP) in the untreated control. Two other fungicides (carboxin and copper oxyquinolate + carboxin) also increased stand to 37 and 39%, respectively, at 40 DAP (Fig. 1C). *R. solani* was frequently isolated (50–60%) from diseased seedlings collected from the untreated control in the experiment at Menofia.

The descending order of the efficacy of the four fungicides (shown as percentage of stand) at Dakahlia (Fig. 1D) was almost the same as in the Menofia and greenhouse experiments; however, the untreated control had a higher percentage of standing plants than any of the fungicide treatments. The plant stand with tolclofos-methyl and pencycuron was the same (71%) at 10 DAP and 54% and 66% at 40 DAP, respectively. Plant stands with the other two fungicides were 47% (carboxin) and 48% (copper oxyquinolate + carboxin) at 40 DAP. Fungi isolated from diseased seedlings from the control treatment were *Pythium* spp., *R. solani* (AG not determined, but morphologically similar to AG-4), and *S. rolfsii*.

Effect of planting date on the efficacy of fungicides in the field. In Georgia, there was significant interaction between fungicide treatments and weeks of recording data and between planting dates and week of recording data through the six weekly intervals (Table 1). The interactions for week × fungicide × planting date and week × week × fungicide × planting date were not significant. However, there was a significant interaction centered at 3.5 wk (planting date × fungicide). Testing the hypotheses using Type I mean square for replicates × planting date × fungicide as an error term showed that planting date was the most significant variable (Table 1).

At the first planting date (29 March), the fungicides metalaxyl, PCNB, and carboxin significantly increased plant stand compared with the untreated control, but at the last planting date (2 May) flutolanil was the only fungicide that significantly increased stand compared with the untreated control (Table 2).

The relationship between date of planting and development of cotton seedling disease (on the basis of plant stand), using means of fungicide treatments through six weekly intervals, gave downward trends at the first and fourth dates of planting significantly different from those of the second and third dates of planting (Fig. 2).

The weather conditions in Georgia through the first 15 days after the first planting date were 21–24 C average soil surface temperature, 20–24 C average soil temperature at a depth of 5 cm, 3.7 cm of rainfall, and 38–90% relative humidity. The weather was cooler than during the first 15 days after the other planting dates. During the 2 wk after planting, the average soil temperature increased as planting was delayed, which was similar to the average of the previous 5 yr at the Coastal Plain Station. The last planting date had the most rainfall (9.5 cm) and warmest soil temperature at a depth of 5 cm (av. 24–25 C).

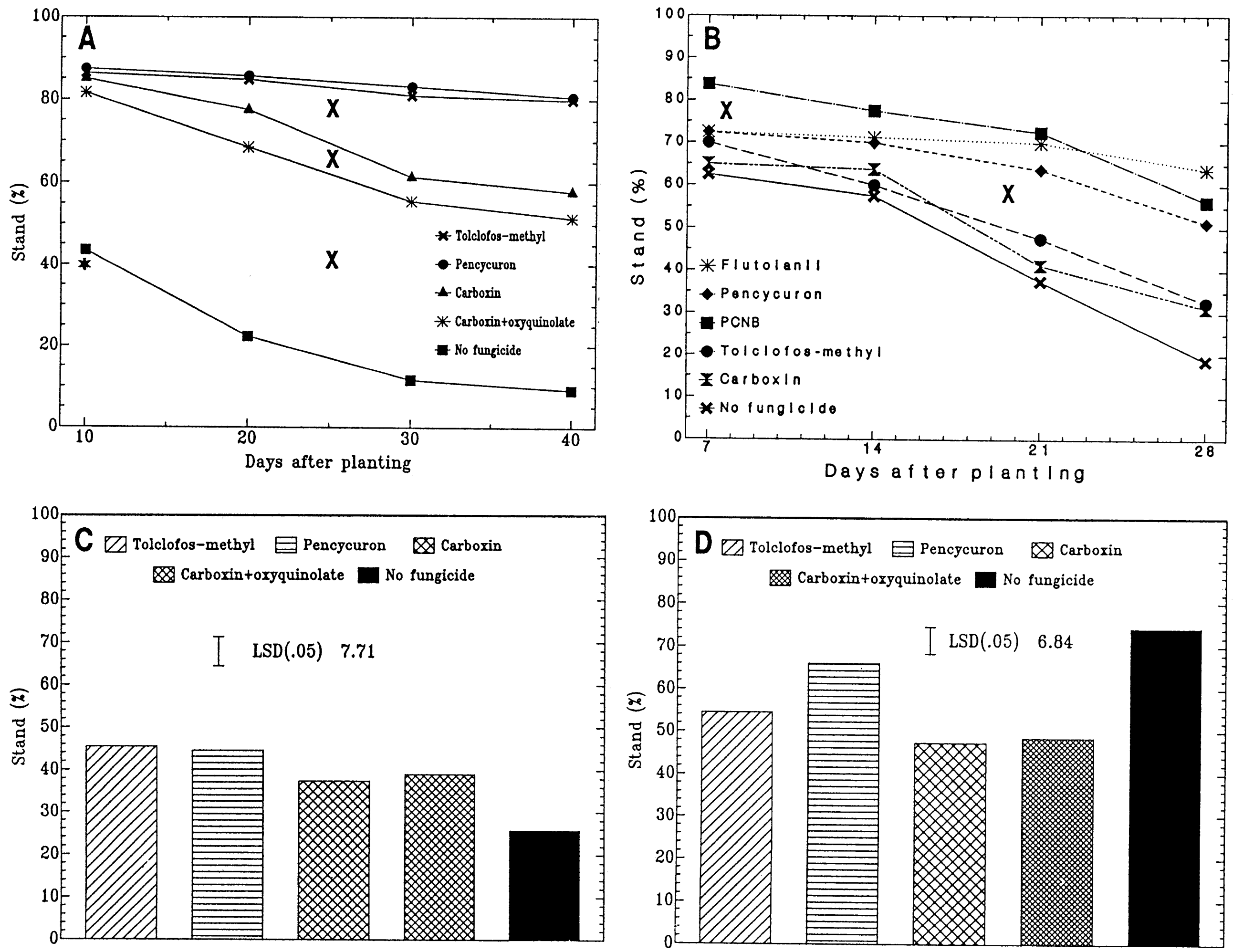


Fig. 1. Efficacy of fungicides against cotton seedling disease in a greenhouse in Egypt in 1990 (**A**) and in Georgia in 1991 (**B**). Asterisk in (**A**) indicates significant difference from lines without asterisks. Treatments above an X are significantly different from treatments below an X. Treatments that appear together with no intervening X are not different. Plant stand 40 days after planting in fields in Menofia (**C**) and Dakahlia (**D**), Egypt, in 1990.

Table 1. Interaction between planting date and seed treatments with fungicides on plant stand in cotton in Georgia

Test[z] Source of variation	df	*F* value	*P*>*F*
ANOVA			
Planting date	3	3,491.42	0.0001
Fungicides	7	405.04	0.0001
Planting date × fungicides	21	108.98	0.0001
Replicates × planting date × fungicides	88	55.31	0.0001
Week (of recording data)	1	240.12	0.0001
Week × week	1	11.62	0.0007
Week × planting date	3	25.72	0.0001
Week × fungicides	7	5.00	0.0001
Week × planting date × fungicides	21	1.43	0.0991
Week × week × planting date	3	8.55	0.0001
Week × week × fungicides	7	0.82	0.5749
Week × week × planting date × fungicides	21	0.99	0.4733
Hypothesis			
Planting date	3	63.33	0.0001
Fungicides	7	7.35	0.0001
Planting date × fungicides	21	1.98	0.148

[z]ANOVA = analysis of variance using general linear models procedure; hypothesis = testing of hypotheses using Type I mean square for replicates × planting date × fungicides as an error term.

Table 2. Effect of planting date and efficacy of fungicides on plant stand in cotton fields in Georgia[x]

Fungicide	Planting date 29 March	12 April	19 April	2 May
Chloroneb	(25.6)[y] b[z]	59.2 a	71.1 a	(17.9) b
Flutolanil	(16.5) c	59.3 a	58.6 a	40.7 b
Pencycuron	(4.7) c	(51.4) a	(37.5) ab	(31.0) b
Tolclofos-methyl	(25.7) b	70.1 a	64.3 a	(31.9) b
Metalaxyl	31.1 c	(52.6) a	49.5 ab	(34.9) bc
PCNB	28.9 b	69.8 a	55.9 a	(29.8) b
Carboxin	34.1 bc	63.8 a	42.0 b	(24.0) c
Control	(11.5) b	(40.7) a	(25.0) b	(21.1) b

[x]Efficacy of fungicides was based on percent stand at six weekly intervals of recording data centered at 3.5 wk.
[y]Means within a column in parentheses are not significantly different from the control ($P = 0.05$) according to Waller-Duncan mean separation test (LSD = 15.18).
[z]Means within a row followed by the same letter are not significantly different ($P = 0.05$) according to Waller-Duncan mean separation test (LSD = 15.18).

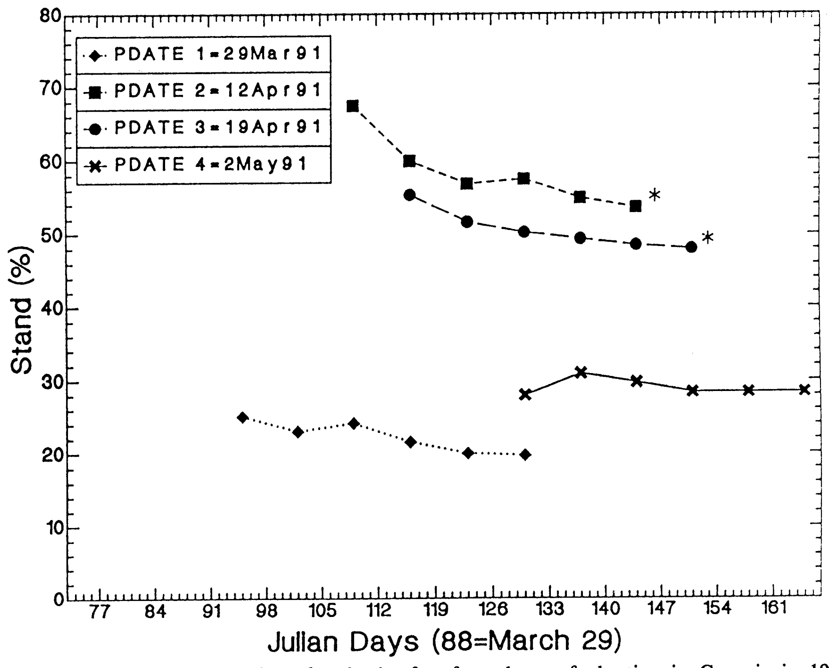


Fig. 2. Stand of cotton seedlings for 6 wk after four dates of planting in Georgia in 1991. Means of six fungicide treatments and a control; tests of significance at $P = 0.05$. Asterisk indicates significant difference from lines without an asterisk.

Effect of herbicides on the efficacy of fungicides. There was a significant fungicide–herbicide interaction each time data was recorded at 10 through 40 days after planting at Menofia, but only at 40 DAP at Dakahlia. The numbers of plants present at 10 and 40 DAP were used as parameters of the interaction between herbicides and fungicides on the efficacy of fungicides. At the Menofia field in 1990, the fungicide tolclofos-methyl followed by pencycuron and copper oxyquinolate + carboxin resulted in an increased percent emergence compared with no fungicide and carboxin treatments in plots with no herbicides (Table 3). The herbicides pendimethalin, prometryn, fluometuron, and oxyfluorfen also increased emergence when herbicides were tested separately with no fungicides.

Efficacy of the fungicides tolclofos-methyl, carboxin + oxyquinolate, and pencycuron, which gave the best stand in the no-herbicide treatment 10 DAP (Table 3), was reduced significantly by herbicides, except for pencycuron with the herbicides oxyfluorfen and prometryn. On the other hand, only the herbicide oxyfluorfen showed a significant effect on the efficacy of carboxin, in which the percentage of stand was increased to 48% compared with 40% in the no-herbicide control. The effect of herbicides on the efficacy of fungicides was generally similar at both 10 and 40 DAP in the Menofia experiment (Table 3). In the other experiment in Dakahlia, only oxyfluorfen had a significant influence on the fungicide treatments tolclofos-methyl and carboxin + oxyquinolate. The opposite was true with the fungicides pencycuron and carboxin. The efficacy of the fungicide carboxin was increased significantly; however, the efficacy of pencycuron was reduced with all herbicide treatments except oxyfluorfen. In contrast, the significant differences among fungicides with no herbicide treatment was eliminated by herbicide treatments except prometryn and oxyfluorfen. Data from the experiment in Dakahlia are not presented for 10 DAP, because there was a high percentage of uniform emergence (average 80%). The most unusual occurrence at the second location (Table 3) was the higher percentage of standing plants from seed not treated with fungicides compared with seed treated with fungicides. There were no visual symptoms of herbicide damage on cotton plants in either experiment conducted in Egypt.

In the 1991 season in Georgia, there were significant interactions of herbicides × fungicides × time. In control plots with no herbicides, seed treated with chloroneb produced 47% emergence at 7 DAP, plant stand increased to 72% 7 days later, and there was 67% stand at the end of the experiment (42 DAP) (Fig. 3A). Emergence with the fungicides carboxin and PCNB was 48 and 49% at 7 DAP, and plant stands were 51 and 48%, respectively, at 42 DAP. The other three fungicides, flutolanil followed by tolclofos-methyl and pencycuron, gave lower increases in the percentages of standing plants at 42 DAP compared with the control (35, 28, 29, and 26%, respectively) (Fig. 3A). The herbicide norflurazon increased plant stand significantly at 42 DAP to 45%, and the herbicide oxyfluorfen significantly decreased cotton stand to 1% compared with 26% for the untreated control in plots with no fungicides. The other herbicides had no significant effects on plant stands (Fig. 3B).

The same visual symptoms of herbicidal damage to cotton plants were observed in the field as in greenhouse experiments: stunting with thickened leathery leaves with pendimethalin, pruning of the main and lateral roots and dry wilted leaves by fluometuron, abnormal growth characterized by yellowing of foliage by prometryn, dry brown patches on the stem with burned spots or edges of leaves by oxyfluorfen, white discoloration in leaves and rose patches on the stem by norflurazon, and severe discoloration and abnormal growth of foliage and roots by fomesafen. Cotton plants showed a rapid recovery from damage caused by norflurazon (3 wk after planting) compared with fluometuron and prometryn (4 wk after planting) or pendimethalin (5 wk). No recovery from the damage of the other herbicides was observed at the end of the experiments at 42 DAP.

Consequently, the efficacy of the fungicides was significantly affected by all herbicides. The combination of the herbicide norflurazon, which had the least visible effect on plant stand and growth, with the fungicides tolclofos-methyl, pencycuron, and flutolanil reduced plant stand compared with the control (Fig. 3C). Norflurazon did not reduce the effectiveness of the fungicides carboxin, chloroneb, or PCNB. The interaction between norflurazon and fungicides showed that herbicides could influence the efficacy of fungicides, even when visible effects on cotton plants were minimal. Statistically, the interaction between herbicides and fungicides was caused primarily by the herbicides. The efficacy of the fungicides chloroneb, carboxin, PCNB, tolclofos-methyl and flutolanil was reduced significantly by all herbicides except norflurazon compared with no herbicide treatment. The same trend was true for the fungicide pencycuron, except for a significant increase of plant stand with the herbicide fluometuron (44%) compared with norflurazon (32%) and no herbicide treatment (30%); other herbicides reduced plant stand to less than 20%.

In the other 1991 field experiment in Georgia with three different experimental combinations of fungicides, the combination of Mon 24,000 + metalaxyl + thiram and the combination of carboxin-thiram + metalaxyl showed the highest efficacy at 42 DAP (64 and 59%, respectively) compared with 48% in the untreated control and 40% stand with the combination of Colorcon opradry type F + the biocontrol agent *T. harzianum*, when no herbicides were used (Fig. 3D). The fungicide combination of carboxin-thiram + metalaxyl in plots not treated with any herbicide gave the best stand over the 6-wk period compared with herbicide treatments (except prometryn) with the same fungicide combination (Fig. 3E). A similar trend occurred with the fungicide combination Mon 24,000 + metalaxyl + thiram, except there was no significant effect by the herbicides fluometuron or prometryn. In this experiment, all the herbicides significantly decreased cotton stand at 42 DAP in plots not treated with fungicides.

DISCUSSION

The biological interaction between herbicides and fungicides or between fungicides and soilborne pathogens is apparently controlled by many factors, including weather, date of planting, location, and soil type. The main goal of these experiments was to investigate some aspects that could cause or influence the variability of the efficacy of some fungicides recommended for control of cotton seedling disease. Variation in fungicidal efficacy has been a pronounced complaint by cotton growers in Egypt within the last decade. This research was conducted with the most commonly applied fungicides recommended as seed treatments in cotton fields. The fungicides were carefully selected according to their mode of action to cover all three types of commercial fungicides: protectants, systemics, and combinations of both. Our results emphasize the possible effect of herbicides and date of planting on the fungicidal activity against *R. solani* AG-4.

The untreated control in Dakahlia had a greater plant stand than any of the fungicide treatments, possibly because fungicides that controlled *R. solani* increased infection by other pathogenic soilborne microorganisms. The cotton stand in Menofia was low in general because of early planting, delayed irrigation, planting after 2 yr in fallow, and poor fertility of the plots. In Georgia,

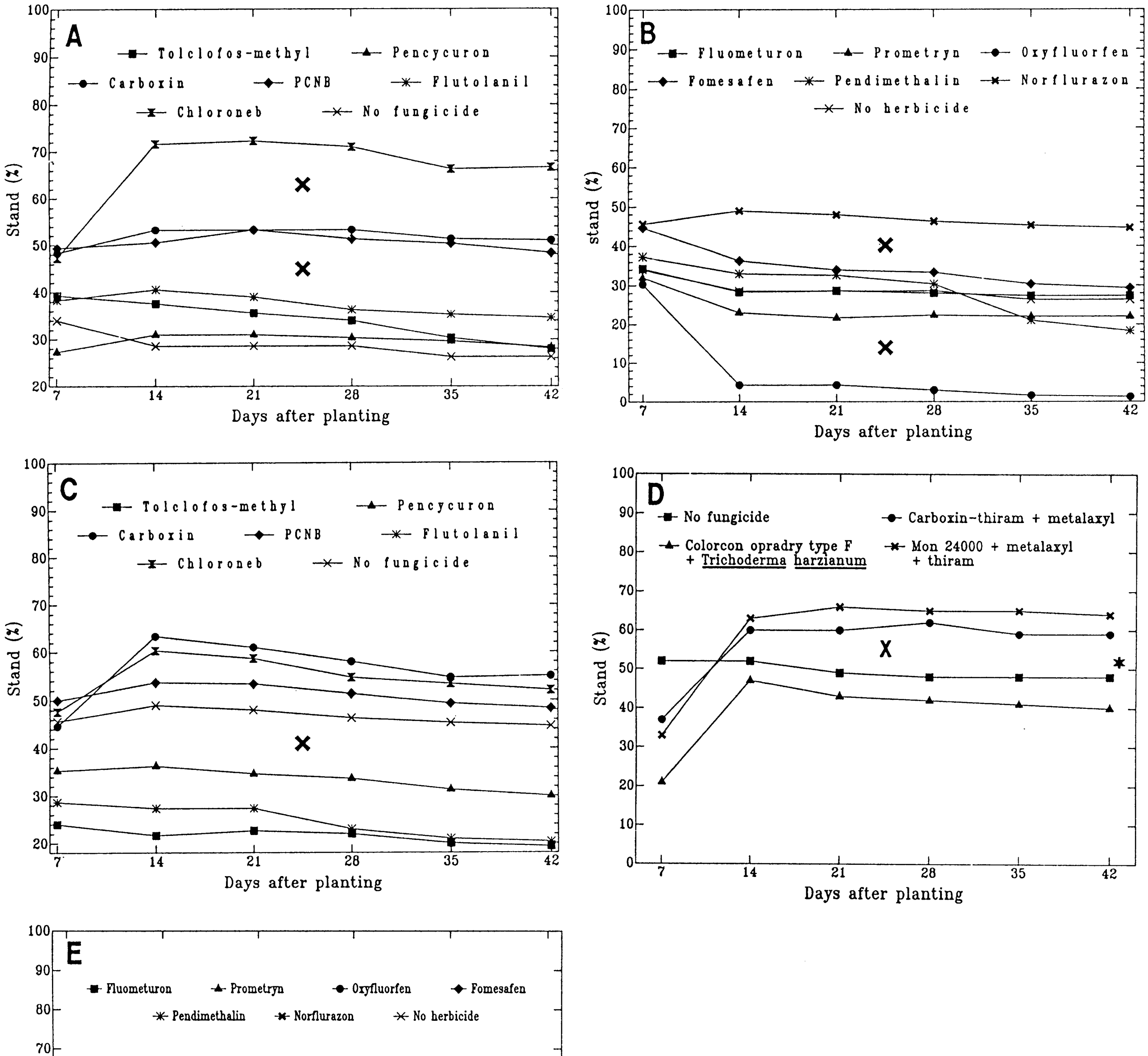
Table 3. Interaction between herbicides and fungicides on stand of cotton in fields in Egypt in 1990[y]

			% Plant Stand				
			Herbicides				
Stand	DAP[z]	Fungicides	None	Fluometuron	Pendimethalin	Prometryn	Oxyfluorfen
Menofia	10	None	(40.7) c	45.5 a	48.0 a	46.2 abc	45.5 c
		Carboxin (CN)	(40.0) c	(42.5) a	(36.8) b	(42.3) c	48.0 bc
		CN + oxyquinolate	(49.5) b	43.8 a	39.8 b	44.0 bc	44.0 c
		Pencycuron	(53.2) b	44.7 a	46.5 a	(50.7) a	(52.8) a
		Tolclofos-methyl	61.7 a	43.5 a	47.0 a	48.0 ab	51.5 ab
LSD = 4.69 ($P = 0.05$)							
Menofia	40	None	(25.7) c	35.5 a	(32.7) a	38.1 ab	38.5 a
		Carboxin (CN)	(37.3) b	(37.0) a	(35.3) a	(31.5) b	(37.3) a
		CN + oxyquinolate	(39.0) ab	(32.5) a	(35.0) a	(34.7) ab	29.5 b
		Pencycuron	(44.6) ab	35.0 a	34.5 a	(36.9) ab	(37.0) ab
		Tolclofos-methyl	(45.5) a	37.3 a	36.5 a	(41.8) a	(40.6) a
LSD = 7.66 ($P = 0.05$)							
Dakahlia	40	None	(74.3) a	81.9 a	(73.5) a	(72.5) a	82.7 a
		Carboxin (CN)	(47.4) d	58.6 b	61.2 b	56.9 b	(53.1) c
		CN + oxyquinolate	(48.5) d	(49.5) c	(55.3) c	(41.9) c	59.8 c
		Pencycuron	(66.0) b	53.8 c	51.3 c	54.3 b	(64.8) b
		Tolclofos-methyl	(54.5) c	(50.3) c	(50.6) c	(55.4) b	63.8 b
LSD = 6.8 ($P = 0.05$)							

[y] In each group, means within a row in parentheses or within a column followed by the same letters are not significantly different (P = 0.05) according to Waller-Duncan separation test (LSD = 4.69, 7.66, and 6.8, respectively).
[z] Days after planting.

all fungicides except pencycuron increased cotton stand significantly in the field when planting was conducted in favorable weather conditions (12 or 19 April). Our research confirms the range of variable reactions of pencycuron when evaluated under greenhouse and field conditions (6,21,38). There are several reports in the literature of carboxin and other carboxamide derivatives giving moderate to good control against *R. solani* in both greenhouse and field-grown cotton (1,4,9,16). The high efficacy of tolclofos-methyl against *R. solani*, as shown in the first season in Egypt, was previously reported (22,30); however, the weak effectiveness shown by tolclofos-methyl in the second season may be because of resistance to the fungicide, which could exist in some pathogenic isolates of *R. solani* in fields (40). Our results confirm the importance of field evaluation of any fungicide before it is recommended for application in fields of any region.

Temperature and moisture are two of the most critical factors that influence the efficacy of fungicides on cotton seedling disease (8,34). That is why fungicides were evaluated in the second season in Georgia with different planting dates encompassing different conditions of soil temperature and moisture. Planting date affected the stand of cotton plants in all treatments, but the second date of planting had the highest plant stand. At the first planting date, only carboxin followed by metalaxyl and PCNB treatments increased percent stand compared with the untreated control. Efficacy of these three fungicides was reported against *Pythium* spp. and



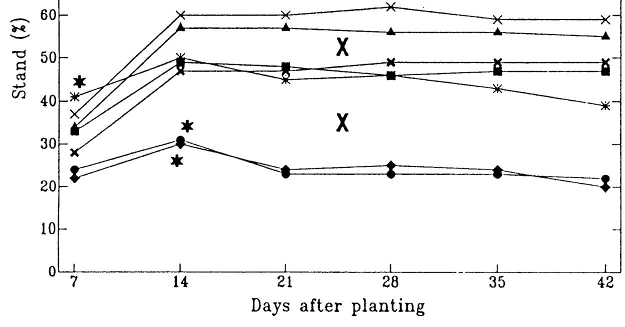


Fig. 3. The interaction of soil fungicide and herbicide treatments on plant stand in Georgia in 1991. **(A)** Fungicides with no herbicides. **(B)** Herbicides with no fungicides. **(C)** Fungicides with norflurazon. **(D)** Combinations of seed treatments with fungicides or a biocontrol agent with no herbicide. **(E)** Carboxin-thiram + metalaxyl seed treatment with herbicides. Treatments above an X are significantly different from treatments below an X ($P = 0.05$). Treatments that appear together with no intervening X are not different. Asterisk indicates significant difference from lines without asterisks.

R. solani in vitro (6,21,22). However, in research on snap bean in Georgia, only PCNB and carboxin (without metalaxyl) controlled *R. solani* (39).

Pythium root rot may significantly reduce vegetative growth of young cotton plants when the early portion of the growing season is cool and moist (23,32,33). We isolated *Pythium* spp. from seedlings frequently in the first planting date, but infrequently thereafter. This may explain why other fungicides failed to increase cotton stands at the first planting date where weather conditions were more favorable for *Pythium* spp. than other pathogenic microorganisms. As soil temperature increased and moisture was adequate in the second planting date, all of the fungicides except pencycuron and metalaxyl increased cotton stand significantly compared with the control. For unknown reasons, the pencycuron treatment did not differ significantly from the control treatment at any planting date. Metalaxyl probably did not increase stand significantly in the second date of planting, because weather conditions became more favorable for *R. solani* than for *Pythium* spp., and metalaxyl is ineffective against *R. solani*. Following the third planting date, soil temperatures were reasonably warm, but soil moisture was greater than field capacity for 1 wk after planting, because of frequent rainfall. These conditions were favorable for both *R. solani* and *Pythium* spp., and all fungicides (except pencycuron) increased plant stand significantly. However, carboxin and metalaxyl followed by PCNB were the least effective treatments. After the fourth planting date (2 May), there was excess rainfall, and soil temperatures were usually 22–26 C. Thus, growing conditions were unfavorable for host plants, and the interaction of high soil moisture with a complex of soilborne pathogens may have created a complex fungal invasion (*R. solani, Pythium* spp., *Fusarium* spp., and *S. rolfsii*) that was only restricted by flutolanil, which provides systemic control of basidiomycetes. These results partially agree with published reports that delayed planting and a combination of soil fungicide treatments improve plant stand and cotton yield (25,34). Our results suggest that soil moisture is a major factor that can influence pathogen behavior and affect the fungicidal efficacy against cotton seedling disease. High amounts of rainfall or excessive watering at the seedling stage may leach fungicides from the soil or change their efficacy. Furthermore, soil moisture reduces soil temperature. Combining fungicides may be vital to effective disease control in such instances.

The efficacy of fungicides (systemic, protectant, or combinations of both) was extremely affected by herbicides applied in this investigation. In Egypt, the percentage of stand was usually reduced when both herbicides and fungicides were applied. In Georgia, cotton stand was significantly affected by fungicides, herbicides, or by herbicide–fungicide combinations and date of stand count. Herbicides contributed more to the interaction effect than did fungicides.

The nontarget effect of herbicides on soilborne pathogens and disease severity has been reviewed (2,15,31). Four possible mechanisms were suggested to explain how plant disease could be affected by herbicides. They were direct effects on the growth of the pathogen, its virulence or the susceptibility of the host plant, and an indirect effect on the microorganisms antagonistic to the pathogen (18). The possible effects of herbicides on the host plant were reported as indirect effects on the physical structure, biochemical defenses or root exudation, and direct injury to the plant (29). Such possible effects of herbicides on the host plant, the causal organism, and other microorganisms could influence the fungicidal efficacy against *R. solani* (19,26,27,30).

The results of these experiments and the observed visual symptoms of herbicidal damage on cotton plants suggest that the preponderant interaction between herbicides and fungicides was caused by direct or indirect damage to the host plant by herbicides. These damage symptoms were observed in the second season in sandy loam soil in Georgia but were not observed in the previous experiments in the silty loamy soil in Egypt. The persistence and leachability of preemergence herbicides in cotton fields are greatly influenced by soil texture, chemical composition, organic matter, pH, moisture, and temperature (28,37,42). Apparently, the effect of chemical composition or temperature had no influence in this research, because the herbicides and temperatures were similar in both seasons. Organic matter, soil pH, moisture, and soil texture were the main factors that varied between the two seasons. Also, the Egyptian cotton cultivar may be more tolerant to herbicides than the American cultivar. In our opinion, irrigation systems played a major part in the variation between seasons. The overhead sprinkler irrigation system used in Georgia may not have allowed leaching of the herbicides and may have kept them concentrated for a longer time near the soil surface. The furrow irrigation system used in Egypt may lead to a quicker dilution of the herbicides and, consequently, may prevent visible damage of herbicides to cotton plants.

This investigation shows that interactions of fungicides with planting date or with herbicides are of great significance in control of root and hypocotyl diseases caused by *R. solani* AG-4 in cotton. Seed treatment with a fungicide may not provide adequate disease control in cool, wet weather in fields with a history of severe disease. Also, fungicidal efficacy could be affected by some of the preemergence herbicides. Therefore, in evaluating or recommending fungicides for controlling *R. solani* in cotton, consideration should be given to the type, rate, and mode of action of herbicides likely to be applied to the soil and to the weather conditions at planting.

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In the article "Maize White Line Mosaic Virus Transmission to Maize Seedlings in Hydroponic Culture" by Raymond Louie, J. J. Abt, and J. K. Knoke (pages 1069–1073), the cloth used in the hydroponic culture system was polyester, not nylon.