The Impact of Herbicides on the Incidence and Development of *Rhizoctonia solani*-Induced Cotton Seedling Damping-off

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ABSTRACT

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The impact of three pre-plant herbicides, trifluralin, pendimethalin and prometryn, on the incidence and the development of *Rhizoctonia solani*-induced cotton seedling damping-off was investigated in the controlled environmental chamber and in the field. In the controlled environmental chamber experiments, trifluralin, pendimethalin and prometryn were applied to the soil at 1.8, 2.4, and 3.6 $\mu\text{g a.i. g}^{-1}$ soil, respectively (equivalent to the respective recommended field concentrations of 0.7, 0.9, and 1.3 kg a.i. ha^{-1}). In the controlled environmental chamber experiments, where soil was infested at planting, application of prometryn, but not pendimethalin or trifluralin, to the soil caused a significant ($P < 0.05$) increase in damping-off incidence. In controlled environmental chamber experiments where soil was infested after emergence, damping-off increased significantly ($P < 0.05$) in the presence of pendimethalin and prometryn, but not trifluralin. In a field experiment conducted in Safford, Arizona, pre-plant application of pendimethalin or prometryn, but not trifluralin, caused significant ($P < 0.05$) increases in disease incidence. In another field experiment in Tucson, Arizona, a significant ($P < 0.05$) increase in disease incidence was observed in plots treated with prometryn, but not in plots treated with pendimethalin or trifluralin. In both controlled environmental chamber and field experiments, application of selected herbicides had significant effects on disease development as judged by the slope of disease progress curves.

Additional keywords: integrated pest management

Environmental factors play important roles in the incidence and development of plant diseases. Soil factors that can potentially affect the incidence and the development of soilborne plant diseases include moisture, temperature, texture, pH, atmospheric composition, organic matter content, and the presence of agricultural chemicals such as herbicides in the soil (1,2,3,18). Some soil-residing microorganisms, including plant pathogens, are known to be affected by soil-applied herbicides (4,6,8,9,13,15,16,18–22,24,27,28,30,32–36). The effect of herbicides on microorganisms is variable (22); some are highly sensitive, some are insensitive, and others thrive in the presence of herbicides.

Herbicides are known to affect the incidence and severity of plant diseases (2,3,10,11,12,23,25,26,29,31). The cereal cyst disease caused by *Heterodera avenae* (3), take-all of wheat caused by *Gaeumannomyces graminis* var. *tritici* (31), and sugar beet damping-off caused by *Rhizoctonia solani* (2) increased after application

of trifluralin, chlorsulfuron, and cycloate, respectively. Application of trifluralin and dinitramine to field soil also increased cotton seedling damping-off caused by *R. solani* (12,26,29).

In contrast, the incidence of cotton seedling disease caused by *Fusarium oxysporum* f. sp. *vasinfectum* decreased after application of trifluralin, dinitramine, fluometuron, diuron, dalapon, and prometryn to field soil (11), while the incidence of *R. solani*-induced cotton seedling damping-off was not significantly affected by these herbicides (11). Application of EPTC and linuron also decreased the incidence of post-emergence but not pre-emergence cotton seedling damping-off (10).

Herbicides also can induce resistance in some plants. Starratt and Lazarovits (32) showed that the application of dinitroaniline herbicides induced high levels of resistance to *Fusarium oxysporum* f. sp. *lycopersici* in tomato seedlings. Herbicides also may cause changes in crop plants which may influence the outcome of plant-pathogen interactions (2,13,14,28).

The objective of this study was to investigate the impact of 3 widely used pre-plant herbicides—pendimethalin, prometryn, and trifluralin—on the incidence and the development of *R. solani*-induced cotton seedling damping-off. The disease is important on cotton (5), often resulting in a substantial reduction in cotton population.

MATERIALS AND METHODS

Herbicides used. Three herbicides, trifluralin (Treflan; 2,6-dinitro-*N,N*-dipropyl-4-[trifluoromethyl]-benzenamine), pendimethalin (Prowl; *N*-[1-ethylpropyl]-3,4-dimethyl-2,6-dinitrobenzenamine), and prometryn (Caparol; *N,N*-bis[1-methylethyl]-6-[methylthio]-1,3,5-triazine-2,4-diamine) were tested in this study. These herbicides are currently registered for use as pre-emergence herbicides on many crops, including cotton. Trifluralin, pendimethalin, and prometryn were tested at the rate of 1.8, 2.4, and 3.6 $\mu\text{g a.i. g}^{-1}$ soil, respectively (equivalent to the recommended field concentrations of 0.7, 0.9, and 1.3 kg a.i. ha^{-1} , respectively).

Effect of herbicides on the incidence and the development of cotton seedling damping-off for soil infested at planting in controlled environmental chambers.

Field soil (15.1% clay, 33.0% silt, and 51.9% sand) was obtained from the University of Arizona Campus Agricultural Center in Tucson. Trifluralin, pendimethalin, and prometryn were uniformly incorporated into the soil at the rate of 1.8, 2.4, and 3.6 $\mu\text{g a.i. g}^{-1}$ soil, respectively. Each 300-ml pot was filled with 280 g of soil. An isolate of *R. solani* (Anastomosis Group 4) from cotton in Arizona was grown on potato dextrose agar (PDA) for 6 days at 27°C. A plug (1.13 cm^2) from the culture was sliced into 1-mm² sections and was incorporated into the top 2 cm of the soil in each pot. Ten (non-fungicide-treated) cotton seeds, cv. Deltapine 5415, were sown in each pot and pots were placed in 9-cm-diameter saucers in a controlled environmental chamber with a diurnal cycle of 12 h at 30 to 32°C in the light (372 $\mu\text{E m}^{-2} \text{s}^{-1}$) and 12 h at 25 to 27°C in the dark. Pots were arranged in a completely randomized design and were watered from the top with 40 ml of distilled water. This amount of water was sufficient to wet the entire soil column in the pot without any drainage. Pots were subsequently watered by adding about 50 ml of distilled water into each saucer as needed. This method of watering prevented leaching of the herbicides from the soil. The incidence of cotton seedling damping-off was assessed by counting the number of emerged plants in each pot (plant stand) 1, 2, and 3 weeks after sowing. There were eight treatments in each experiment (*R. solani* only, *R. solani* plus pendimethalin, *R. solani* plus prometryn, *R. solani* plus trifluralin, pendimethalin only, prometryn

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only, trifluralin only, none), each with five replicates. One pot with 10 seedlings constituted one experimental unit. The experiment was performed twice.

Effect of herbicides on the incidence and the development of cotton seedling damping-off for soil infested after emergence in controlled environmental chamber. The protocol of this experiment was similar to that described above, except that seedlings in each pot were thinned to 5 seedlings 8 days after sowing and prior to infesting the soil with *R. solani*, using procedures described earlier. The incidence and the development of post-emergence damping-off were assessed by counting the number of dead or dying seedlings in each pot 1, 2, and 3 weeks after infestation. There were eight treatments in each experiment as described above, each with five replicates. One pot with 5 seedlings constituted one experimental unit. The experiment was performed twice.

Field experiments. Two field experiments, with plots arranged in a randomized block design, were established and managed according to the procedures followed by cotton growers in Safford and Tucson, Arizona in April 1996. The soil at the Safford and Tucson experimental sites were loam soils containing 14% clay, 36% silt, and 50% sand; and 15.1% clay, 33.0% silt, and 51.9% sand, respectively. There were four treatments, each with four replicates, in each experiment. Each replicate plot was a 10-m-long section of a bed. Beds were 100 cm apart. Trifluralin, pendimethalin, or

prometryn was sprayed in a 60-cm band on the top of each plot at the recommended field concentration of 0.7, 0.9, and 1.3 kg a.i. ha⁻¹, respectively, using a CO₂-pressurized backpack sprayer. Herbicides were incorporated into the top 5 to 7 cm of soil with a rotomulcher shortly after application. Plots were infested with *R. solani* according to the following procedures: 1 kg barley seeds were wetted with 500 ml water and autoclaved at 15 psi for 60 min. Seeds were inoculated with *R. solani* and incubated at 25°C for 3 weeks. Seeds were air-dried for 24 h, ground with a mill through a 3-mm sieve, and stored in a paper bag at 25 to 27°C in the laboratory. Eight g of the fungal inoculum were mixed with 200 g of the field soil and sprinkled into the furrow of each 10-m-long replicate plot shortly before sowing. Four hundred non-fungicide-treated cotton seeds (cv. Deltapine 5415) were sown in each plot. The number of sown seeds in each plot was higher than the average number sown by most farmers, in order to avoid a very poor stand due to heavy damping-off as a result of high inoculum density. The field was irrigated the following day. The incidence and the development of *R. solani*-induced cotton seedling damping-off were assessed by counting the number of emerged seedlings (stand count) in each plot 15, 25, and 50 days after planting.

Statistical analysis. For each herbicide and each assessment time, the variances in two controlled environmental chamber experiments were tested for homogeneity.

Since the variances were homogeneous and there was no interaction between experiments and treatments, values from the two experiments were pooled. The data for the stand count in pre-emergence inoculation experiments and for mortality in post-emergence inoculation experiments in the controlled environmental chambers were tested by analysis of variances, and means were compared by Duncan's multiple range test using COSTAT (Cohort Software, Berkeley, CA). Data from each field experiment were analyzed separately using analysis of variances and means comparison as described above. Slopes of disease progress curves (change in stand or mortality over time) was determined by regression analysis using COSTAT. Slopes of disease progress curves for different treatments in each experiment were compared using procedures described by Campbell and Madden (7).

RESULTS

Typical *R. solani*-induced damping-off symptoms were observed on all sampled non-emerged and emerged seedlings in both controlled environmental chamber and field experiments. Radicles, roots, and lower stems of all sampled seedlings yielded *R. solani* on PDA. Other cotton seedling pathogens were not recovered.

In controlled environmental chamber experiments where soil was infested before emergence, the stand count in the soil treated with prometryn was significantly ($P < 0.05$) lower by 21.4, 36.2, and 66.7%

Table 1. Stand count (the number of emerged seedlings) in soils treated with each test herbicide and infested with *Rhizoctonia solani* at planting time in controlled environmental chambers

Treatment	1 week after sowing		2 weeks after sowing		3 weeks after sowing		Slope ^z
	Stand ^x	% change ^y	Stand	% change	Stand	% change	
<i>R. solani</i> only	8.9 a	...	7.2 ab	...	6.0 ab	...	-1.35
<i>R. solani</i> + pendimethalin	8.4 a	-5.6	6.3 b	-12.5	5.0 b	-16.7	-1.52
<i>R. solani</i> + prometryn	7.0 b	-21.4	4.6 c	-36.2	2.0 c	-66.7	-2.5*
<i>R. solani</i> + trifluralin	9.4 a	+5.6	8.2 a	+13.9	7.0 a	+16.6	-1.31

^x Stand = the average number of emerged seedlings in one pot or one replicate sown with 10 seeds. Each mean is an average of 10 values obtained in two experiments each with five replicates. Means followed by the same letter in each column are not significantly different according to Duncan's multiple range test ($P > 0.05$).

^y Represents percent change in the plant stand relative the control (*R. solani* only).

^z Slopes of disease development curves (change in plant stand over time). Slopes marked with asterisks are statistically different from that of the control (*R. solani* only) according to the procedures described by Campbell and Madden (7).

Table 2. Mortality (the number of dead or dying seedlings) due to *Rhizoctonia solani*-induced post-emergence damping-off in the presence of each test herbicide in soil infested with *R. solani* after plant emergence in controlled environmental chambers

Treatment	1 week after sowing		2 weeks after sowing		3 weeks after sowing		Slope ^z
	Mortality ^x	% change ^y	Mortality	% change	Mortality	% change	
<i>R. solani</i> only	0.5 b	...	1.2 b	...	2.0 b	...	0.75
<i>R. solani</i> + pendimethalin	1.4 a	+64.3	2.9 a	+58.7	4.6 a	+56.6	1.60*
<i>R. solani</i> + prometryn	1.4 a	+64.3	3.0 a	+60.0	4.0 a	+50.0	1.30*
<i>R. solani</i> + trifluralin	0.8 b	+37.5	1.4 b	+14.3	3.0 b	+33.3	0.83

^x Mortality = the number of dead or dying seedlings among 5 seedlings in one pot. Each mean is an average of 10 values obtained in two experiments each with five replicates. Means followed by the same letter in each column are not significantly different according to Duncan's multiple range test ($P > 0.05$).

^y Represents percent change in mortality relative to the control (*R. solani* only).

^z Slopes of disease development curves (change in mortality over time). Slopes marked with asterisks are statistically different from that of the control (*R. solani* only) according to the procedures described by Campbell and Madden (7).

relative to the control 1, 2, and 3 weeks after sowing, respectively (Table 1). The stand count in soil treated with pendimethalin and trifluralin was not significantly ($P > 0.05$) different from that in the control. In controlled environmental chamber experiments where plants were inoculated after emergence, mortality (the number of dead or dying plants) in soils treated with pendimethalin and prometryn increased significantly ($P < 0.05$) by 64.3, 58.7, and 56.6% and by 64.3, 60.0, and 50.0%, relative to the control 1, 2, and 3 weeks after infestation, respectively (Table 2). Trifluralin did not have a significant ($P > 0.05$) effect on the mortality.

Treatments without *R. solani* averaged 90% seed germination and stand establishment, regardless of the presence or absence of the three test herbicides in controlled environmental chamber experiments.

In field experiments, the stand count in plots treated with pendimethalin and prometryn in the Safford field experiment was significantly ($P < 0.05$) reduced by 29.6, 38.9, and 46.7% and 27.2, 30.2, and 39.1%, relative to the control 15, 25, and 50 days after sowing, respectively (Table 3). The difference in the stand count in plots treated with trifluralin compared to the control in the Safford experiment was not significant ($P > 0.05$). The stand count in plots treated with prometryn in the Tucson field experiment was significantly ($P < 0.05$) reduced by 40.6, 49.5, and 54.4% relative to the control 15, 25, and 50 days after sowing, respectively (Table 4). Pendimethalin and trifluralin did not cause

significant changes in the stand count compared to the control in the Tucson field experiment.

Disease development also was affected by test herbicides in both controlled environmental chamber and field experiments, as judged by the slopes of disease progress curves (Tables 1 to 4). In controlled environmental chamber experiments for soil infested before emergence, only prometryn affected disease development significantly; for soil infested after emergence, only prometryn and pendimethalin affected disease development significantly (Table 1 and 2). In the Safford field experiment, disease development was not affected by any herbicide (Table 3). In the Tucson field experiment, pendimethalin and trifluralin, but not prometryn, affected disease development (Table 4).

DISCUSSION

Results of this study demonstrated that pendimethalin and prometryn, currently in use on cotton, may cause significant increases in the incidence of *R. solani*-induced cotton seedling damping-off in the field. These findings are in agreement with the results of previous studies on the effect of herbicides on the incidence and severity of some plant diseases, including cotton seedling diseases (2,3,10,12,23,25,26,29).

The mechanism of herbicide-mediated change in damping-off incidence reported here is not known. The phenomenon could be due to the effect of herbicides on the plant (20,26,29), on the pathogen (10–12,16,26), on the antagonistic microorganisms (10), and/or on the interactions among

these entities. Herbicide-mediated changes in the plant may occur both at the physical and biochemical levels (2). Herbicides have been reported to cause alterations in growth, lignin-containing substances, β -glucosides (28), wax layers on leaves (13,14), and in the release of nutrients from roots (2,37). Herbicides may also alter plant resistance to pathogens (32).

The direct effect of herbicides on pathogens also has been demonstrated (2,4,10–12,26). Herbicides are reported to increase (12) or decrease the pathogenic activity of *R. solani*. For example, with *R. solani* on sugar beet, cycloate may interfere with the growth of the fungus and at the same time may enhance root exudates. In such cases, the impact of the herbicide on the disease is determined by the balance of stimulatory and inhibitory effects (2). In this study, the growth of *R. solani* in vitro was not significantly affected by any of the three test herbicides (*data not shown*).

Herbicide-mediated alterations in the outcome of plant-pathogen interactions may also be due to the effect of herbicides on naturally occurring microbial antagonists of pathogens (16). Herbicides tested in this study caused a shift in bacterial communities in the cotton rhizosphere, including some biocontrol-active bacteria (15).

The effect of trifluralin and prometryn on cotton seedling damping-off has been variable. For example, prometryn, which increased cotton seedling damping-off in this study, did not change the incidence of this disease in a previous study (11). Trifluralin, which has been reported to

Table 3. Plant stand for soils treated with each test herbicide and infested with *Rhizoctonia solani* inoculum for the Safford field experiment

Treatment	Plant stand						Slope ^z
	15 days		25 days		50 days		
	Stand ^x	% change ^y	Stand	% change	Stand	% change	
<i>R. solani</i> only	166 a	...	126 a	...	105 a	...	–30.55
<i>R. solani</i> + pendimethalin	117 b	–29.6	77 b	–38.9	56 b	–46.7	–30.25
<i>R. solani</i> + prometryn	121 b	–27.2	88 b	–30.2	64 b	–39.1	–28.25
<i>R. solani</i> + trifluralin	163 a	–1.9	132 a	+4.7	112 a	+6.6	–27.85

^x Stand = the number of emerged seedlings in one plot sown with 400 seeds. Each mean is an average of four replicates. Means followed by the same letter in each column are not significantly different according to Duncan's multiple range test ($P > 0.05$).

^y Represents percent change in plant stand relative to the control (*R. solani* only).

^z Slopes of disease development curves (change in plant stand over time).

Table 4. Plant stand for soils treated with each test herbicide and infested with *Rhizoctonia solani* inoculum for the Tucson field experiment

Treatment	Plant stand						Slope ^z
	15 days		25 days		50 days		
	Stand ^x	% change ^y	Stand	% change	Stand	% change	
<i>R. solani</i> only	101 a	...	87 a	...	79 a	...	−10.75
<i>R. solani</i> + pendimethalin	91 a	−9.9	75 ab	−13.8	55 ab	−30.4	−18.13*
<i>R. solani</i> + prometryn	60 b	−40.6	44 b	−49.5	36 b	−54.4	−12.15
<i>R. solani</i> + trifluralin	104 a	+2.9	97 a	+11.4	70 a	−11.4	−28.95*

^x Stand = the number of emerged seedlings in one plot sown with 400 seeds. Each mean is an average of four replicates. Means followed by the same letter in each column are not significantly different according to Duncan's multiple range test ($P > 0.05$).

^y Represents percent change in plant stand relative to the control (*R. solani* only).

^z Slopes of disease development curves (change in plant stand over time). Slopes marked with asterisks are statistically different from that of control (*R. solani* only) according to the procedures described by Campbell and Madden (7).

increase cotton seedling damping-off (12,25,26,29), did not affect the disease in this study or in a previous study by El-Khadem et al. (11). Differential responses may be due to the differences in soil moisture, soil temperature, herbicide concentration, *R. solani* population, cotton cultivars, the composition of rhizosphere microflora, and the rate of herbicide inactivation. The development of tolerance to herbicides by pathogens as a result of long-term herbicide use also can not be ruled out.

Results of the present study provide additional evidence that a pesticide which is being used against a specific pest may encourage the activity of another pest, and support the need for integrated pest management (IPM) strategies for managing pest problems. However, the selection of an ideal pesticide (one which is not harmful to the crop and to non-target beneficial organisms) is difficult because of the number and diversity of pests involved in any crop in a region. For example, in addition to insects and weeds, cotton seedlings are damaged by a number of soilborne pathogens besides *R. solani*. Although *R. solani*-induced cotton seedling damping-off was shown in this study to increase in the presence of pendimethalin and prometryn, it is not known how other soilborne cotton diseases respond to these herbicides. The reported herbicide-fungicide interactions (17,25,29) further complicate the problem. The development of IPM requires a knowledge of the impact of a selected pesticide not only on its intended target, but also on plants, as well as on beneficial and harmful microorganisms and insects.

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