Management of Leaf Spot Diseases of Peanut with Prothioconazole Applied Alone or in Combination with Tebuconazole or Trifloxystrobin

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ABSTRACT

Field experiments were conducted in Tifton and Plains, GA in 2001–2007 to determine the efficacy of prothioconazole on early leaf spot (*Cercospora arachidicola*) and late leaf spot (*Cercosporidium personatum*) of peanut (*Arachis hypogaea*). In five of six experiments, application of one or both rates (0.18 and 0.20 kg ai/ha) of prothioconazole in sprays 3–6 (chlorothalonil at 1.26 kg ai/ha in sprays 1, 2, and 7) provided leaf spot control superior to tebuconazole (0.23 kg ai/ha) in a similar regime, and superior to chlorothalonil at 1.26 kg ai/ha applied full season (seven times) in four of six experiments. In a similar series of six experiments, application of 0.085 kg ai/ha of prothioconazole + 0.17 kg ai/ha of tebuconazole provided better leaf spot control than tebuconazole (0.23 kg ai/ha) applied in regimes similar to those described above. Leaf spot control with prothioconazole + tebuconazole was similar to chlorothalonil applied at 1.26 kg ai/ha full season in five of eight experiments, but was less effective in the remaining three experiments. Fungicide effects on yield were inconsistent, but in all experiments, yield response with either rate of prothioconazole was similar to or greater than that obtained with 0.23 kg ai/ha tebuconazole on the same schedule. In a third series of four experiments, full-season (seven sprays) application of mixtures of prothioconazole at 0.063 kg ai/ha with trifloxystrobin at 0.063 kg ai/ha gave similar or better leaf spot control than chlorothalonil full season.

Key Words: triazolinthione fungicides, sterol biosynthesis inhibitors, *Cercosporidium personatum*, *Cercospora arachidicola*.

Management of early leaf spot, caused by *Cercospora arachidicola* S. Hori, and late leaf spot, caused by *Cercosporidium personatum* (Berk. & M. A. Curtis) Deighton, of peanut (*Arachis hypogaea* L.) is essential for peanut production in most areas of the world. In the southeastern U.S., control of these diseases is heavily reliant upon multiple fungicide applications. Fungicides are also important for management of stem rot (*Sclerotium rolfsii* Sacc.) and Rhizoctonia limb rot (*Rhizoctonia solani* Kühn), and application regimes used in most fields include one or more fungicides that provide some control of these soilborne diseases as well as the leaf spot diseases. Sterol biosynthesis inhibitor (SBI) fungicide, tebuconazole, and the strobilurin fungicides azoxystrobin, pyraclostrobin, and fluoxastrobin are the fungicides currently used to manage both leaf spot and soilborne diseases, while chlorothalonil is used exclusively to control foliar diseases. All of these fungicides are recommended for use in spray regimes utilizing two or more fungicides, and most are recommended for application every 14 days beginning approximately 30 days after planting.

Prothioconazole is an SBI in the new triazolinthione class of fungicides (Dutzmann and Suty-Heinze, 2004) that has shown activity against *C. arachidicola* and *C. personatum* as well as *S. rolfsii* and *R. solani* (Musson *et al*., 2006). In addition, this fungicide provides suppression of Cylindrocladium black rot, caused by (*Cylindrocladium parasiticum* Crous, Wingfield, & Alfeas) (Brenneman and Young, 2007; Musson *et al.*, 2006), another extremely destructive disease of peanut in some areas of the southeastern U.S. Therefore, prothioconazole may have potential for use in peanut fields where control of multiple diseases is desired.

The effects of prothioconazole on leaf spot diseases is of special interest because of populations of both leaf spot pathogens have displayed reduced sensitivity to tebuconazole, and noticeable reductions in efficacy of that fungicide. The purpose of this work was to characterize the effects of prothioconazole applied alone or in combination with tebuconazole or trifloxystrobin on leaf spot diseases of peanut. Of particular interest was the comparison of prothioconazole or mixtures of prothioconazole with tebuconazole or trifloxystrobin to chlorothalonil and tebuconazole. Two sets of experiments focused on application regimes analogous to those typically used currently with tebuconazole where control of soilborne diseases is a major objective. The other set of experiments was

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directed toward use of full-season applications of prothioconazole and tebuconazole alone and in combination with the strobilurin fungicide trifloxystrobin, with rates similar to those of the pre-mix combination of trifloxystrobin and tebuconazole (Absolute 500, Bayer CropScience, Research Triangle Park, NC).

Materials and Methods

Efficacy of Prothioconazole and Prothioconazole + Tebuconazole.

A series of six field experiments were conducted in 2001–2003 to determine the effects of prothioconazole applied alone in a four spray block regime on leaf spot diseases of peanut, and one experiment was conducted in 2007 to determine the effects of full-season applications of prothioconazole on leaf spot diseases. A second series of eight field experiments were conducted in 2005–2007 to determine the effects of mixtures of prothioconazole and tebuconazole on leaf spot diseases in similar four spray block regimes. Four experiments conducted in Tifton 2007 are designated as experiments A, B, C, and D.

Peanut seeds (18 seed/m of row) were planted in fields of Tifton sandy loam at the Coastal Plain Experiment Station, Lang Farm, Tifton, GA on 28 May 2001, 27 May 2002, 28 May 2003, 25 May 2005, 18 May 2006, 25 May 2007 (the full-season prothioconazole experiment and experiments A and B), and 7 June 2007 (experiments C and D), and in fields of Faceville sandy loam at the Southwest Georgia Branch Station, Plains, GA on 14 May 2001, 7 May 2002, 16 May 2003, 16 May 2006, and 8 May 2007. The cultivar Georgia Green was used in all experiments in 2001–2005 except in 2002 at Tifton where AT-201 was planted. In 2006, cultivars Carver and Georgia-02C were used in Tifton and Plains, respectively. In 2007, Carver was used in experiments A, B, and D, and Georgia Green was used in experiment C at Tifton. All fields except those used for experiments A, C, and D in 2007 had been planted to cotton (*Gossypium hirsutum* L.) the previous year but had been planted to peanut two years prior. Experiments A, C, and D had been planted to various vegetable crops the previous several years, and had not been planted to peanut in at least 5 years. Except for the Tifton experiment in 2005, all plots received aldicarb (Temik 15 G, Bayer CropScience, Research Triangle Park, NC) (0.75–1.0 kg ai/ha) in-furrow at planting. No insecticide was applied at planting in the Tifton experiment in 2005. At Tifton, row spacing was a uniform 0.91 m (1.83 m bed). At Plains, rows were 0.71 m apart within the bed and 0.91 m between rows in adjacent beds (1.63 m bed). Plots were 7.6–12.2 m long and 1.8 m wide. In 2003 and before, plots were separated by two non-sprayed border rows. In 2004 and thereafter, plots were bordered by two non-treated rows on one side, and a plot with another randomly assigned treatment on the other. Blocks were separated by 2.4 m fallow alleys. The experimental design was a randomized complete block with four replications in all trials.

In all experiments in 2001–2003, treatments consisted of i) nontreated control, ii) 0.18, and iii) 0.20 kg ai/ha of prothioconazole (JAU 6746 480 SC, Bayer CropScience, Research Triangle Park, NC) applied in the third through the sixth sprays of a seven spray regime, with chlorothalonil (Bravo Weather Stik 720 F, Syngenta Crop Protection, Greensboro, NC) applied at 1.26 kg ai/ha in the first, second and seventh sprays; v) 1.26 kg ai/ha of chlorothalonil in all seven sprays; and vi) 0.23 kg ai/ha of tebuconazole (Folicur 3.6 F, Bayer CropScience, Research Triangle Park, NC) applied the third through the sixth sprays of a seven spray regime, with chlorothalonil applied at 1.26 kg ai/ha in the first, second and seventh sprays. In 2007, treatments in the full-season prothioconazole experiment included i) nontreated control, ii) 1.26 kg ai/ha of chlorothalonil, iii) 0.23 kg ai/ha of tebuconazole, and iv) 0.20 kg ai/ha of prothioconazole. All fungicide treatments included seven applications.

In 2005–2007, treatments in all of the prothioconazole + tebuconazole tank mix experiments except experiment B at Tifton and the Plains experiment in 2007 included i) nontreated control; ii) chlorothalonil, 1.26 kg ai/ha applied in all seven sprays; iii) a mixture of prothioconazole, 0.085 kg ai/ha with tebuconazole 0.17 kg ai/ha applied in the third through the sixth sprays of a seven spray regime, with chlorothalonil applied at 1.26 kg ai/ha in the first, second and seventh sprays; and iv) 0.23 kg ai/ha of tebuconazole applied the third through the sixth sprays of a seven spray regime, with chlorothalonil applied at 1.26 kg ai/ha in the first, second and seventh sprays. In 2007, treatments in experiment B at Tifton and Plains were similar, except the tebuconazole treatment was not included. Both experiments in 2006 and experiment A in 2007 had an additional treatment of prothioconazole 0.12 kg ai/ha and tebuconazole 0.23 kg ai/ha applied in sprays 3–6 with chlorothalonil applied in sprays 1, 2 and 6. In 2005, the fungicide mixture treatments were applied as tank mix combinations of prothioconazole (JAU 6746 480 SC) with tebuconazole (Folicur 3.6 F), whereas in

2006 and 2007, the mixtures were applied as a premix formulation of the two fungicides (Provost 433, Bayer CropScience, Research Triangle Park, NC).

Efficacy of Prothioconazole + Trifloxystrobin Mixtures.

Field experiments were conducted in Tifton, GA in 2002–2005 to determine the efficacy of low rates of prothioconazole applied alone and in tank-mix combinations with trifloxystrobin on leaf spot diseases of peanut. Planting dates were 27 May 2002, 28 May 2003, 28 May 2004, and 23 May 2005. Seeding rate, plot structure, and field history were as previously described. Cultivars used were Georgia Green in 2002 and 2003 and Carver in 2004 and 2005. Three sterol biosynthesis inhibitor (SBI) treatments (no fungicide, tebuconazole, and prothioconazole) were arranged factorially with and without trifloxystrobin. Specific treatments included i) 0.063 kg ai/ha of prothioconazole; ii) 0.063 kg ai/ha of tebuconazole; iii) 0.063 kg ai/ha of trifloxystrobin (Flint 50 WDG, Syngenta Crop Protection, Greensboro, NC); iv) tank mix combination of 0.063 kg ai/ha of prothioconazole and 0.063 kg ai/ha of trifloxystrobin; v) tank mix combination of 0.063 kg ai/ha of tebuconazole and 0.063 kg ai/ha of trifloxystrobin; vi)1.26 kg ai/ha of chlorothalonil; and vii) nontreated control. The tank mix combination of tebuconazole and trifloxystrobin contains approximately the same rate of those active ingredients as the labeled application rate of pre-mix formulation Absolute 500. A randomized complete block design with four replications was used in all four experiments.

General Methodology.

All fungicides were applied at approximately 14-day intervals, with initial application 35–45 days after planting. Fungicide applications in all experiments were made using a multiple-boom tractor-mounted CO_2-propellant sprayer. Each boom was equipped with three D3-23 hollow-cone spray nozzles per row. Fungicides were applied in 114 L of water/ha at a pressure of 345 kPa. Leaf spot was assessed for each plot by use of the Florida 1–10 scale where 1 = no leaf spot, and 10 = plants completely defoliated and dead because of leaf spot (Chiteka *et al.*, 1988). Values of 1 through 4 on the scale reflect increasing incidence of leaflets with spots, and occurrence of spots in lower versus upper canopy of the plots. Values 4 through 10 reflect increasing levels of defoliation (Chiteka *et al.*, 1988). For the purposes of this paper, this rating of the combination of disease severity on existing leaves and level of defoliation will be referred to as leaf spot intensity. Leaf spot intensity was rated several times during the season in each experiment. Final ratings were made immediately prior to digging and inverting the peanut plants which was 123–140 days after planting (DAP) on Georgia Green, AT-201 and Carver cultivars, and 140-150 DAP on Georgia-02C. Subsequent indications of leaf spot intensity in this paper refer to the final intensity rating.

Loci of stem rot were counted immediately after plants were inverted for each plot except the nontreated plots in all experiments and the plots at Plains in 2001 and 2003. A locus represented 31 cm or less of linear row with one or more plants infected (Rodriguez-Kabana *et al.*, 1975). Incidence of stem rot was calculated as the percentage of 31 cm row sections with symptoms of stem rot and/or signs of the pathogen. At Plains in 2001 and 2003, severe infestations of Cylindrocladium black rot prevented rating of the plots for stem rot and in 2003 prevented taking yield. In those experiments, the percentage of the row length showing symptoms of wilting or death of plants caused by *C. parasiticum* was determined for each plot immediately prior to the plots being inverted.

After plants were inverted they were allowed to dry in the wind-row for 3–7 days, and pods were harvested mechanically. Pods were dried to 10% w/w moisture, and yields (kg/ha) were determined for each plot for treatment comparisons.

Final leaf spot intensity ratings, incidence of stem rot or Cylindrocladium black rot (CBR), and pod yield were used for treatment comparisons. Data were subjected to analysis of variance (Steel and Torrie, 1980). Fisher's protected least significant differences were calculated for mean separations (Steel and Torrie, 1980). In the trifloxystrobin tank mix experiments, factorial analysis was conducted for leaf spot intensity and yield for the sterol inhibitors with and without trifloxystrobin. In addition, Dunnett's minimum significant differences (Steel and Torrie, 1980) were calculated to compare all other treatments to the full-season chlorothalonil treatment that was included as a standard. All subsequent reference to significant effects of factors, interactions or differences among means indicates significance at $P \leq 0.05$ unless otherwise stated.

Results

Severity of leaf spot epidemics varied across the experiments and ranged from moderate to extremely heavy. Both early and late leaf spot were observed in all experiments. Early leaf spot was the predominant foliar disease during much of the season in all experiments at Plains and in all

Table 1. Effect of prothioconazole, tebuconazole and chlorothalonil on final leaf spot intensity and peanut pod yield, Tifton and Plains, GA, 2001–2003.

			Leaf spot intensity[a]						Pod yield				
			Tifton			Plains			Tifton			Plains	
Fungicide	Rate	Sequence[b]	2001	2002	2003	2001	2002	2003	2001	2002	2003	2001	2002
	kg ai/ha								kg/ha				
Nontreated	–	–	8.2	8.1	9.4	8.0	8.1	5.7	3211	1366	2543	3634	3488
Chlorothalonil	1.26	1–7	3.4	4.4	6.3	3.5	2.4	2.5	4318	1609	4664	4512	6521
Chlorothalonil &	1.26	1,2,7	3.9	5.1	6.1	3.1	3.7	3.0	4496	1740	5347	5196	6334
tebuconazole	0.23	3–6											
Chlorothalonil &	1.26	1,2,7	2.9	3.8	2.3	1.1	2.1	2.1	4439	2130	5731	5732	5708
prothioconazole	0.18	3–6											
Chlorothalonil &	1.26	1,2,7	2.6	3.5	2.6	1.3	1.6	1.6	5098	1837	5197	5480	6911
prothioconazole	0.20	3–6											
LSD (P = 0.05)			0.8	1.1	0.5	0.8	0.6	1.3	950	658	746	1386	2006

[a]Leaf spot intensity was assessed shortly before plot inversion using the Florida 1–10 scale (Chiteka *et al.*,1988).

[b]Sequence numbers indicate the chronological order of application of fungicides at approximately 14 day intervals in a regime that included a total of seven sprays.

experiments at Tifton through 2003. At Tifton, late leaf spot became prevalent late in the season in 2003, and was the predominant foliar disease in the plots in 2004–2007.

Efficacy of Prothioconazole.

Significant interactions of year × treatment and location × treatment effects for final leaf spot intensity ratings and yield for experiments conducted in 2001–2003 were noted. Therefore, each experiment was analyzed independently. All treatments resulted in lower leaf spot intensity than the nontreated plots in all experiments (Table 1). When applied on the same schedule, both prothioconazole treatments had final leaf spot intensity ratings that were lower than tebuconazole in all experiments except Plains in 2003. One or both of the prothioconazole treatments had final leaf spot intensity ratings lower than those for chlorothalonil full season in both locations in 2001, at Plains in 2002, and at Tifton in 2003 (Table 1). Final leaf spot intensity ratings were similar for chlorothalonil full season and the tebuconazole block treatments in all experiments except Plains in 2002 when leaf spot ratings were higher for the tebuconazole block treatment (Table 1).

In 2007, all fungicide treatments had final leaf spot intensity ratings lower than those of the nontreated control (Table 2). Leaf spot intensity was higher for tebuconazole than for either chlorothalonil or prothioconazole, which had the lowest leaf spot rating (Table 2).

Incidence of stem rot was low in all experiments. Highest incidence in any treatment at Tifton was 6.0% in 2001 and 7.0 % in 2002, and no differences among treatments ($P > 0.05$) were seen (Data not shown). At Tifton in 2003, stem rot incidence was 11.3, 3.4, 5.2 and 5.6% (LSD = 5.4) for the chlorothalonil, tebuconazole, and low and high rates of the prothioconazole + tebuconazole, respectively. Although stem rot incidence was not evaluated at Plains in 2001 or 2003, disease incidence in 2002 was 9.0% or lower for all

Table 2. Effect of full-season applications of prothioconazole, tebuconazole and chlorothalonil on final leaf spot intensity and peanut pod yield, Tifton, GA, 2007.

Fungicide	Rate	Sequence[b]	Leaf spot intensity	Pod yield
	kg ai/ha			kg/ha
Nontreated	–	–	9.6	3166
Chlorothalonil	1.26	1–7	5.3	6071
Tebuconazole	0.23	1–7	8.0	5887
Prothioconazole	0.20	1–7	3.8	6712
LSD (P = 0.05)			0.8	1401

[a]Leaf spot intensity was assessed shortly before plot inversion using the Florida 1–10 scale (Chiteka *et al.*,1988).

[b]Sequence numbers indicate the chronological order of application of fungicides at approximately 14 day intervals in a regime that included a total of seven sprays.

treatments with no differences among treatments (P > 0.05) (Data not shown). In 2007, incidence of stem rot at Tifton was 5.8% or lower in all treatments, and no differences occurred among treatments (P > 0.05) (Data not shown). At Plains in 2001, CBR incidence ranged from 18% for chlorothalonil full season to 11% in the highest rate of prothioconazole, and in 2003, 70% or more of the plants in all treatments. No differences (P >0.05) in CBR incidence were noted among fungicide treatments in either experiment (Data not shown).

Due to the severe epidemic of Cylindrocladium black rot at Plains in 2003, yields are not reported. Yields were greater for tebuconazole and both prothioconazole treatments than for the nontreated plots in all other experiments except Tifton in 2002, when 0.18 kg ai/ha prothioconazole yielded greater than the nontreated control (Table 1). Yields did not differ among the chlorothalonil, tebuconazole or prothioconazole treatments except in 2003 when yields of plots treated with 0.18 kg ai/ha of prothioconazole were greater than those of chlorothalonil full season (Table 1). In 2007, all three fungicide treatments had yields that were greater than that of the nontreated control, but there were no other differences among treatments (Table 2).

Efficacy of Prothioconazole + Tebuconazole Mixtures.

Since treatments were not identical among the years and locations, each experiment was analyzed independently. In all experiments except A and D in 2007, final leaf spot intensity ratings were lower for all fungicide treatments than for the nontreated control (Table 3). Final leaf spot intensity ratings for the tebuconazole block treatment did not differ from those of the nontreated control in experiments A or D in 2007. Leaf spot intensity ratings were higher in the tebuconazole block treatments than in any other treatment except the nontreated control in all experiments where that treatment was included (Table 3). Leaf spot ratings for the two rates of prothioconazole + tebuconazole were similar to those of chlorothalonil full season in all experiments in 2005 and 2006, and in experiment C and at Plains in 2007. However, leaf spot ratings were higher for the prothioconazole + tebuconazole treatments than chlorothalonil full season in experiments A, B and D in 2007. Leaf spot intensity ratings were similar for the two rates of prothioconazole + tebuconazole in both 2006 experiments and in experiment A in 2007.

Stem rot ratings were low in all three experiments in 2005 and 2006, with incidence ≤ 3.4% in 2005, ≤ 6.6% at Tifton, and ≤ 4.2 % at Plains in 2006. No differences (P > 0.05) in stem rot incidence among treatments were seen in any of the three experiments (Data not shown). In 2007, in experiment A, incidence of stem rot was 25.4, 20.7, 10.1 and 7.2 % (LSD = 8.0) for the chlorothalonil, tebuconazole and low and high rates of prothioconazole + tebuconazole, respectively. In experiment B, stem rot incidence was 24.5 and 13.5% (LSD = 8.0) for the chlorothalonil and prothioconazole + tebuconazole treatments, respectively. In experiment C, incidence

Table 3. Effect of prothioconazole and tebuconazole mixtures on final leaf spot intensity, Tifton and Plains, GA, 2005–2007.

			Leaf spot intensity[a]							
			Tifton						Plains	
Treatment	Rate	Sequence[b]	2005	2006	2007A	2007B	2007C	2007D	2006	2007
	kg ai/ha									
Nontreated		–	8.8	9.7	9.6	9.2	8.7	9.8	6.8	7.7
Chlorothalonil	1.26	1–7	5.4	5.1	5.6	4.3	4.6	5.4	2.6	2.3
Chlorothalonil &	1.26	1,2,7	6.4	6.6	9.2	–[d]	6.2	9.1	4.2	–[d]
tebuconazole	0.23	3–6								
Chlorothalonil &	1.26	1,2,7	5.3	5.0	8.4	5.6	4.9	7.1	2.3	1.6
prothioconazole +	0.085	3–6								
tebuconazole[c]	0.17	3–6								
Chlorothalonil &	1.26	1,2,7	–	4.5	8.1	–[d]	–[d]	–[d]	2.1	–[d]
prothioconazole +	0.11	3–6								
tebuconazole[c]	0.23	3–6								
LSD (P = 0.05)			0.9	0.8	0.6	1.0	1.1	1.2	0.6	0.7

[a]Leaf spot intensity was assessed shortly before plot inversion using the Florida 1–10 scale (Chiteka *et al.*,1988).

[b]Sequence numbers indicate the chronological order of application of fungicides at approximately 14 day intervals in a regime that included a total of seven sprays.

[c]Prothioconazole + tebuconazole treatments were applied as a tank mix of separate formulations in 2005, and as a single pre-mix formulation in 2006 and 2007.

[d]Treatment not included in this experiment.

of stem rot was 4.3% or lower, with no differences ($P > 0.05$) among treatments (Data not shown). Incidence of stem rot was 4.6 and 4.2% ($P > 0.05$) for the chlorothalonil and prothioconazole + tebuconazole treatments in experiment D, but severe leaf spot damage precluded evaluation of stem rot in the tebuconazole treatment.

In 2005, no fungicide treatment had yield greater than that of the nontreated control (Table 4). In 2006, all fungicide treatments had yields greater than that of the nontreated control at Tifton, and yields did not differ among the fungicide treatments (Table 4). At Plains in 2006, only 0.085 kg of prothioconazole + 0.17 kg of tebuconazole had yields greater than that of the nontreated control. In 2007, yields were highly variable in Experiments A and B, and differences among treatments were few. All fungicide treatments in experiments A, C, and D had yields greater than the nontreated controls, but only the prothioconazole + tebuconazole treatment had yield greater than the nontreated control in Experiment B (Table 4). In Experiment A, the high rate of prothioconazole + tebuconazole had yields that were greater than those of chlorothalonil full season (Table 4). In the remaining experiments, yield for chlorothalonil full season and prothioconazole + tebuconazole treatments were similar.

Prothioconazole + Trifloxystrobin Tank Mix Experiments.

Since significant year × treatment interactions for final leaf spot intensity ratings and yield were found, experiments were analyzed within each year. Significant SBI × trifloxystrobin interactions for final leaf spot intensity ratings in all four years were also noted. Within plots treated with 0.063 kg ai/ha of the SBI fungicides alone, final leaf spot intensity ratings were lower for prothioconazole than tebuconazole in all four experiments (Table 5). In 2002 and 2004, leaf spot ratings with 0.063 kg ai/ha of tebuconazole alone and nontreated plots were similar. Combinations of prothioconazole or tebuconazole with trifloxystrobin resulted in lower final leaf spot intensity ratings than trifloxystrobin alone in 2003, 2004, and 2005. In only 2003, the combination of prothioconazole with trifloxystrobin resulted in leaf spot ratings lower than tebuconazole + trifloxsystrobin tank-mixture (Table 5). Leaf spot ratings for tebuconazole applied alone were higher than those in plots treated with chlorothalonil in all experiments (Table 5). Prothioconazole applied alone had leaf spot ratings similar to those for chlorothalonil in 2002, and lower than those of the chlorothalonil treatment in 2003 (Table 5). However, leaf spot ratings were higher for prothioconazole treatments than for the chlorothalonil standard in 2004 and 2005.

Leaf spot ratings for the prothioconazole and trifloxystrobin mixture treatments were similar to those for chlorothalonil in all experiments except in 2003, when both prothioconazole and trifloxystrobin mixtures and tebuconazole and trifloxystrobin mixtures had lower leaf spot ratings than chlorothalonil (Table 5).

Table 4. Effect of prothioconazole and tebuconazole mixtures on peanut pod yield, Tifton and Plains, GA, 2005–2007.

			Yield (kg/ha)							
			Tifton						Plains	
Treatment		Sequence[a]	2005	2006	2007A	2007B	2007C	2007D	2006	2007
	kg ai/ha									
Nontreated		–	2644	2683	2002	4500	3153	1907	5342	5343
Chlorothalonil	1.26	1–7	3418	4570	3780	6028	4823	4699	5570	6505
Chlorothalonil &	1.26	1,2,7	3684	4423	3370	–[d]	5395	3683	5740	–[d]
tebuconazole	0.23	3–6								
Chlorothalonil &	1.26	1,2,7	3343	5189	4410	6583	5247	4821	6147	6175
prothioconazole +	0.085	3–6								
tebuconazole[b]	0.17	3–6								
Chlorothalonil &	1.26	1,2,7	3343	5091	5293	–[d]	–[d]	–[d]	5806	–[d]
prothioconazole +	0.11	3–6								
tebuconazole[b]	0.23	3–6								
LSD ($P = 0.05$)			ns[c]	954	1327	1902	581	952	748	914

[a]Sequence numbers indicate the chronological order of application of fungicides at approximately 14 day intervals in a regime that included a total of seven sprays.

[b]Prothioconazole + tebuconazole treatments were applied as a tank mix of separate formulations in 2005, and as a single pre-mix formulation in 2006 and 2007.

[c]Analysis of variance indicated there was no significant treatment effect; therefore, no LSD was calculated.

[d]Treatment not included in this experiment.

Table 5. Effect of full-season application (seven sprays) of prothioconazole and tebuconazole alone and in combination with trifloxystrobin on final leaf spot intensity, Tifton, GA, 2002–2005.

		2002			2003			2004			2005		
		Rate of trifloxystrobin kg ai/ha			Rate of trifloxystrobin kg ai/ha			Rate of trifloxystrobin kg ai/ha			Rate of trifloxystrobin kg ai/ha		
Treatment	Rate	0	0.06	LSD	0	0.06	LSD	0	0.06	LSD	0	0.06	LSD
	kg ai/ha												
Nontreated	0	8.1	5.1	2.4	9.4	6.4	0.9	9.3	6.8	1.5	9.4	5.5	0.9
Tebuconazole	0.06	7.3	3.9	1.5	7.8	4.0	1.5	9.5	5.3	0.4	8.4	4.8	1.2
Prothioconazole	0.06	4.5	4.0	ns[b]	4.0	3.0	ns[b]	7.8	5.0	1.4	7.1	4.6	0.8
LSD (P = 0.05)		1.6	ns[b]		1.3	1.0		0.9	1.1		0.7	0.7	
Chlorothalonil	1.26	4.4			6.3			5.6			4.1		
Dunnett's MSD[c] (P = 0.05)		1.6			1.2			1.2			0.8		

[a]Leaf spot intensity was assessed shortly before plot inversion using the Florida 1–10 scale (Chiteka *et al.*,1988).
[b]Analysis of variance indicated there was no significant treatment effect; therefore, no LSD was calculated.
[c]Dunnett's minimum significant difference (MSD) was calculated for comparison of all other treatments to the chlorothalonil standard treatment.

Incidence of stem rot was 8.0% or lower in all treatments in 2002 and 9.5% or lower in 2004, with no differences ($P > 0.05$) among treatments (Data not shown). In 2003, stem rot incidence was similar ($P > 0.05$) for tebuconazole (9.8%) and prothioconazole (7.2%) treatments without trifloxystrobin. Plots treated with trifloxystrobin alone had higher incidence of stem rot (14.0%) than plots treated with prothioconazole + trifloxystrobin (4.8%), with tebuconazole + trifloxystrobin intermediate (9.8%) between the two (LSD = 5.4). In 2005, stem rot incidence was similar ($P > 0.05$) for tebuconazole (7.5%) and prothioconazole (9.0%) treatments without trifloxystrobin. Plots treated with trifloxystrobin alone had higher incidence of stem rot (16.5%) than plots treated with either tebuconazole + trifloxystrobin (7.5%) or prothioconazole + trifloxystrobin (6.0%) (LSD = 6.4).

Yields were low in all treatments in 2002. Neither main effects or interaction effects were significant ($P > 0.05$) for yield. Across SBI fungicide treatments, yields were 1564 kg/ha without and 1788 kg/ha with trifloxystrobin. Across trifloxystrobin treatments, yields ranged from 1488 kg/ha in the no SBI fungicide plots to 1813 kg/ha in plots treated with prothioconazole. Trifloxystrobin, SBI fungicide, and interaction effects on yield were significant in 2003 and 2005. In 2003 and 2005, among plots that received no trifloxystrobin, yields were greater for plots treated with prothioconazole than with tebuconazole (Table 6). In 2003, among treatments that included trifloxystrobin, plots treated with prothioconazole had yields greater than plots that received trifloxystrobin alone (Table 6). Yields of plots treated with tebuconazole + trifloxystrobin or prothioconazole + trifloxystrobin were similar to those of the chlorothalonil standard treatment in 2003 and 2005.

In 2004, main effects of trifloxystrobin and SBI fungicides were significant ($P \leq 0.05$) for yield, but there was no significant interaction ($P > 0.05$). Across all other treatments, yields were 3625 kg/ha and 2015 kg/ha (LSD = 778, $P = 0.05$) for trifloxystrobin vs. no trifloxystrobin, respectively. Yields from plots treated with prothioconazole were greater than those without an SBI fungicide (Table 6).

Discussion

Prothioconazole has shown great utility applied either alone (Dutzmann and Suty-Heinze, 2004; Jorgensen and Olsen, 2007) or in combination with strobilurin fungicides for control of cereal diseases in Europe (Dutzmann and Suty-Heinze, 2004) and control of pasmo (*Septoria linicola*) of flax (Halley *et al.*, 2004), and Sclerotinia stem rot (*Sclerotinia sclerotiorum*) of canola (Bradley *et al.*, 2006) in the U.S. Results of this study indicate that prothioconazole shows potential for enhanced leaf spot control in peanut compared with tebuconazole or chlorothalonil, and that it is effective in a variety of use patterns.

From these results, the level of control of leaf spot obtained with treatments that included four consecutive applications of 0.18 or 0.20 kg ai/ha of prothioconazole in a seven spray program with the other three applications being chlorothalonil is superior to that obtained with the 0.23 kg ai/ha tebuconazole block treatment and 1.26 kg ai/ha of chlorothalonil full season. Results corroborate findings by Damicone and Melouk (2006) that

Table 6. Effect of full-season application (seven sprays) of prothioconazole and tebuconazole alone and in combination with trifloxystrobin on peanut pod yield, Tifton, GA, 2002–2005.

		2002			2003			2004			2005		
		Rate of trifloxystrobin kg ai/ha			Rate of trifloxystrobin kg ai/ha			Rate of trifloxystrobin kg ai/ha			Rate of trifloxystrobin kg ai/ha		
Treatment	Rate	0	0.06	LSD	0	0.06	LSD	0	0.06	Avg[a]	0	0.06	LSD
	kg ai/ha	kg/ha			kg/ha			kg/ha			kg/ha		
Nontreated	0	1366	1609	ns[b]	2543	4527	1219	1219	2839	2030	3354	4228	ns[b]
Tebuconazole	0.06	1651	1805	ns[b]	4143	5301	2146	2126	4195	3161	3598	4642	ns[b]
Prothioconazole	0.06	1675	1951	ns[b]	5432	5679	ns[b]	2700	3840	3270	4810	4951	ns[b]
LSD (P = 0.05)		ns[b]	ns[b]		555	951				1207	1035	ns[b]	
Chlorothalonil	1.26		1609			4664			4333			4639	
Dunnett's MSD[c] (P = 0.05)			ns[b]			1106			1315			1207	

[a]There was no significant (P > 0.05) interaction effect according to analysis of variance. Therefore sterol biosynthesis inhibitor fungicides were compared across trifloxystrobin treatments, and trifloxystrobin treatments were compared across sterol biosynthesis inhibitor treatments.

[b]Analysis of variance indicated there was no significant treatment effect; therefore, no LSD or Dunnett's MSD was calculated.

[c]Dunnett's minimum significant difference (MSD) was calculated for comparison of all other treatments to the chlorothalonil standard treatment.

0.20 kg ai/ha of prothioconazole was superior to tebuconazole or chlorothalonil for preventing defoliation by early leaf spot. Our results also indicate that mixtures of 0.085 kg ai/ha of prothioconazole with 0.17 kg ai/ha of tebuconazole are superior to 0.23 kg ai/ha of tebuconazole for leaf spot control. In five of eight experiments, mixtures of prothioconazole + tebuconazole were also comparable to standard rates (1.26 kg ai/ha) of chlorothalonil for leaf spot control. However, in three of five experiments in Tifton in 2007, control achieved with use of prothioconazole + tebuconazole was not as good as that of the chlorothalonil standard. Our results also indicate that mixtures 0.063 kg ai/ha of prothioconazole and 0.063 kg ai/ha of trifloxystrobin are comparable to standard rates of chlorothalonil.

Although early leaf spot was the predominant foliar disease in peanut in test plots at Tifton and in Georgia production fields in 2001–2003, severe epidemics of late leaf spot occurred at Tifton in 2003–2007 Early leaf spot was prevalent in most of the experiments in which 0.20 kg ai/ha of prothioconazole alone was evaluated, but results from 2003 on Georgia Green and results from 2007 on the susceptible cultivar Carver indicate that this rate of prothioconazole can provide excellent control of late leaf spot as well. Our results suggest that prothioconazole at 0.20 kg ai/ha alone or at reduced rates in combination with an effective mixing partner can provide control of both leaf spot diseases.

The initial label for prothioconazole on peanut is for use in a premix combination with tebuconazole (Provost, Bayer CropScience, Research Triangle Park, NC) with standard application rates of 0.085 kg ai/ha prothioconazole + 0.17 kg ai/ha of tebuconazole. Combinations of prothioconazole and tebuconazole at those rates were examined in this study. For managing leaf spot, however, our results indicate that prothioconazole alone could also be of utility in block application regimes analogous to that currently used with tebuconazole. Tank-mix combinations of prothioconazole with the strobilurin fungicide trifloxystrobin also show potential for leaf spot control.

Integration of prothioconazole into peanut disease control systems will require consideration of several factors in addition to its efficacy for control of leaf spot. Development of resistance or increased tolerance to sterol inhibitors is a major concern. Tebuconazole and propiconazole have been widely used for disease control in peanut in the U.S. since 1994. Performance of tebuconazole compared to chlorothalonil has changed over the past ten years, with recent reports of tebuconazole being inferior to chlorothalonil in several experiments (Culbreath *et al.*, 2005; Culbreath *et al.*, 2006; Hagan *et al.*, 2004; Stevenson and Culbreath, 2006). Populations of both *C. arachidicola* and *C. personatum* have become less sensitive to tebuconazole since previous characterizations in the late 1990s (Stevenson and Culbreath, 2006; Stevenson *et al.*, 1999). That trend is evident in the relative performance of chlorothalonil and tebuconazole in this study as well. Although chlorothalonil full season and the tebuconazole block treatment provided similar levels of leaf spot control in all but one experiment between 2001 and 2003, the tebuconazole block treatment had higher leaf spot intensity ratings than the chlorothalonil full season in all experiments conducted in 2005–2007.

Efficacy of 0.063 kg ai/ha of prothioconazole was not consistent relative to the chlorothalonil standard across the four years in which they were compared. In 2002 and 2003, leaf spot control for prothioconazole at that rate was similar to or better than that of chlorothalonil, whereas in 2004 and 2005, the same rate of prothioconazole was inferior to the chlorothalonil standard. The reason for that change in relative efficacy has not been determined, but sensitivity of the pathogen populations to prothioconazole must be considered. Relative cross resistance to tebuconazole and prothioconazole have been reported in other pathogens, but the inherent activity of prothioconazole was still much greater (Kuck and Mehl, 2004).

Leaf spot control provided by the mixture of prothioconazole + tebuconazole was also inconsistent in 2007. Under severe epidemics in three experiments on the leaf spot susceptible cultivar Carver, the mixture of prothioconazole + tebuconazole was not as effective as chlorothalonil applied season-long for controlling leaf spot diseases. In two of the above experiments, the tebuconazole block treatment and nontreated control had similar leaf spot ratings. In contrast, in 2007, 0.20 kg ai/ha of prothioconazole applied full season gave control of late leaf spot that was superior to that for chlorothalonil season long, while late leaf spot intensity for tebuconazole was only slightly lower than in the nontreated control. Therefore, at a high enough rate, prothioconazole alone is still very effective. These results lead us to question how much leaf spot control is provided by the tebuconazole portion of the mixture, and whether the rate of prothioconazole in the mixture is sufficient to provide adequate control of leaf spot, especially if current trends toward reduced sensitivity to SBI fungicides continue.

Future studies should address determining how much of the leaf spot control achieved with mixtures of prothioconazole + tebuconazole is due to each fungicide, especially in fields where leaf spot pathogens have reduced sensitivity to tebuconazole. Since these two fungicides have similar general modes of action, sensitivity of populations of leaf spot pathogens to prothioconazole should also be monitored closely. Additional studies should evaluate the effects of mixing prothioconazole or prothioconazole + tebuconazole with the protectant fungicide chlorothalonil.

Other studies have indicated prothioconazole has good potential for control of soilborne diseases caused by *Sclerotium rolfsii* and *Rhizoctonia solani* (Musson *et al.*, 2006). Rates and application patterns used in the block application experiments of this study were intended to target both of these important diseases. Although neither disease occurred in any of these experiments at very high levels, results corroborate previous work in which prothioconazole was equal or better than tebuconazole for control of stem rot, and trifloxystrobin did not have good activity on *S. rolfsii* (Brenneman, unpublished). Other experiments have been conducted and are in progress in which these diseases are the primary focus. Although prothioconazole did not suppress Cylindrocladium black rot in the experiments of this study in which that disease occurred, it has provided suppression of this disease in other experiments (Brenneman and Young, 2007; Musson *et al.*, 2006). Determining the optimum use pattern of prothioconazole for suppression of this increasingly important disease is an objective of current research, and may be a major factor in determining how prothioconazole will be used on peanut in many areas.

Conclusions

Prothioconazole is a newly registered sterol inhibiting fungicide that shows potential for control of early and late leaf spot diseases of peanut. These results indicate the level of control of leaf spot obtained with treatments that included four consecutive applications of 0.18 or 0.20 kg ai/ha of prothioconazole in a seven spray program with the other three applications being chlorothalonil is superior to that obtained with industry standard treatments of 0.23 kg ai/ha of tebuconazole in a similar use pattern, and to that obtained with seven applications of 1.26 kg ai/ha of chlorothalonil. When applied on the same schedule, mixtures of 0.085 kg ai/ha of prothioconazole with 0.17 kg ai/ha of tebuconazole gave superior leaf spot control compared to 0.23 kg ai/ha of tebuconazole, but was not as consistent in controlling leaf spot as 1.26 kg ai/ha chlorothalonil. Leaf spot control with mixtures of a lower rate (0.06 kg ai/ha) of prothioconazole with trifloxystrobin were similar chlorothalonil full season. Recommendations for use of prothioconazole must take into consideration integrated management of foliar and soilborne diseases of peanut. Special consideration must also be given to resistance management, particularly in reduced rate mixes where reduced sensitivity to mixing partners is documented (i.e. tebuconazole) or is likely to occur (i.e. strobilurin fungicides). The variable control of leaf spot with low rates of prothioconazole illustrates how critical resistance management may be with this chemistry.

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