Effect of In-Furrow and Early-Season Banded Applications of Fungicides on Incidence of Early Leaf Spot of Peanut

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ABSTRACT

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Field experiments were conducted in Tifton, GA, in 2012-2014 to determine the effect of in-furrow applications of prothioconazole and early-season banded applications of prothioconazole or pyraclostrobin on incidence of early leaf spot (*Cercospora arachidicola*) of peanut (*Arachis hypogaea*). In each year, border rows were planted in May as a source of inoculum for plants in the treatment plots. Plots were planted in August or September after epidemics of early leaf spot were severe in the border plots. Fungicide application regimes included two rates (100 and 200 g a.i./ha) of prothioconazole applied in-furrow at planting, and 200 g a.i./ha of prothioconazole or 164 g a.i./ha of pyraclostrobin applied concentrated in a 30-cm band 21 days after planting (DAP). Incidence (percent of leaflets with one or more leaf spot) of early leaf spot was monitored until 54 to 57 days after planting in each year. In all years, disease incidence was below 10% at 28 DAP in plots treated with 200 g a.i./ha of prothioconazole in-furrow compared to over 40% in nontreated plots at the same time. In-furrow applications of 100 g a.i./ha of prothioconazole were less effective, but suppressed leaf spot incidence compared to the control. Banded applications of either fungicide at 21 DAP resulted in a decrease in leaf spot incidence, and prevented increase in leaf spot incidence for 19 days or longer.

INTRODUCTION

In the southeastern United States, management of early leaf spot, caused by *Cercospora arachidicola* S. Hori; late leaf spot, caused by *Cercosporidium personatum* (Berk. & M. A. Curtis) Deighton; and stem rot, caused by *Sclerotium rolfsii* (Sacc.), diseases of peanut (*Arachis hypogaea* L.) is heavily reliant upon multiple applications of fungicides. Fungicides targeted primarily for leaf spot control typically are initiated 30 to 35 days after planting (DAP) with subsequent applications made at 14-day intervals, and fungicides applied for management of stem rot typically are applied between 60 and 90 DAP (Kemerait et al. 2013). Recent studies have shown a benefit to soilborne disease suppression with early applications of the sterol biosynthesis-inhibiting fungicide prothioconazole. Application of prothioconazole banded over the peanut row at 20 to 30 DAP provided suppression of stem rot that complemented the standard applications made mid-season (Brenneman et al. 2011; Tsai et al. 2013) and in-furrow application of prothioconazole at planting suppressed Cylindrocladium black rot (CBR), caused by *Cylindrocladium parasiticum* Crous, M.J. Wingfield, & Alfenas (Brenneman and Augusto 2010; Brenneman et al. 2011; Phipps et al. 2010). Prothioconazole also has excellent activity against early and late leaf spot (Culbreath et al. 2008). The effect of in-furrow application or early-season banded applications to young plants on leaf spot has not been thoroughly characterized.

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Objectives of this study included determining the effect of in-furrow and early-season applications of prothioconazole on early-season incidence of leaf spot, with implications for whether either in-furrow or early-season applications of prothioconazole have potential to substitute for one or more early-season fungicide applications typically made for leaf spot control. In-furrow or early-season banded applications of prothioconazole are relatively expensive fungicide treatments, with current costs of fungicide and application estimated at $57.75/ha for in-furrow and $65.00/ha or more for banded applications. However, if either of those treatments can eliminate the need for one or more applications of the fungicides typically applied for leaf spot control, the net additional cost of applying such a treatment will help make in-furrow or early-season sprays for soilborne disease control more affordable.

EFFECT OF IN-FURROW OR BANDED APPLICATIONS OF FUNGICIDES ON INCIDENCE OF LEAF SPOT

Border rows of peanut were planted in a field of Tifton sandy loam at the University of Georgia Coastal Plain Experiment Station, Lang Farm, Tifton, GA, on 21 May 2012 and 27 May 2013, and at the Coastal Plain Experiment Station, Black Shank Farm on 27 May 2014. The leaf spot-susceptible cultivar Georgia-09B (Branch 2010) was used in all three years. All fields had been planted to cotton (*Gossypium hirsutum* L.) the previous year and planted to peanut two years prior.

Test plots were planted after epidemics in the nontreated border rows were severe, with over 75% of the leaflets with lesions and noticeable defoliation by leaf spot (Fig. 1). In all three years, early leaf spot was the predominant foliar disease both in the border rows and the experimental plots. Plots were planted on 15 August 2012, 10 September 2013, and 17 August 2014.

In all years, treatments included: (i) nontreated control; (ii) a 0.5× rate in-furrow application of prothioconazole (Proline 480, Bayer CropScience, Research Triangle Park, NC) (100 g a.i./ha); (iii) a full-rate in-furrow application of prothioconazole (200 g a.i./ha); (iv) early-emergence (21 DAP) 30-cm banded application of prothioconazole (200 g a.i./ha); and (v) a full-rate early-emergence 30-cm banded application of pyraclostrobin (Headline, BASF, Research Triangle Park, NC) (164 g a.i./ha). Pyraclostrobin was applied with a non-ionic surfactant (0.25% v:v of the spray solution) (Induce, Helena Chemical Co., Collierville, TN). Experimental design was a randomized complete block design with five replications in 2012 and 2014, and 4 replications in 2013. Plots were 7.6 m long and 1.8 m wide and bordered on both sides by the earlier border row planting (Fig. 1). Row spacing was a uniform 0.91 m (1.83-m bed).

In-furrow treatments were made using a CO_2-propellant sprayer mounted on the planter. One ConeJet TX-6 hollow-cone nozzle (TeeJet Technologies, Springfield, IL) was used in each row for fungicide application (Rideout et al. 2002). Nozzles were placed in the furrow opener of the planter to allow fungicide application directly onto the seed itself, as well as the width of the open seed furrow. In-furrow applications were made using 47 liter/ha of water. Postemergence applications were made using a multiple-boom, tractor-mounted, CO_2-propellant sprayer. Fungicide applications were made using one Hypro TR80 flat-fan spray nozzle (Hypro, New Brighton, MN) centered directly over the row. The boom was positioned approximately 25 cm above the ground to provide an approximately 30-cm-wide band at the soil surface. Banded applications were made using 60.3 liters of water/ha at a pressure of 345 kPa.

Disease assessment. Early leaf spot incidence was assessed visually as the percentage of leaflets with one or more leaf spot lesions for each plot 27, 29, 33, 43, and 56 DAP in 2012; 17, 20, 24, 28, 35, 37, 41, 48, 53, and 57 DAP in 2013; and 19, 28, 33, 36, 40, 43, 47, and 54 DAP in 2014. The entire plot was examined for each evaluation. Area under the disease progress curve (AUDPC) was calculated for each plot using incidence of leaf spot from the multiple evaluations (Shaner and Finney 1977). Since evaluation number and time during which incidence was monitored varied among the 3 years, standardized AUDPC (SAUDPC) was calculated by dividing AUDPC for each plot by the duration (in days) for which leaf spot incidence was monitored (Madden et al. 2007).

Statistical analysis. SAUDPC was analyzed across years using SAS Proc GLIMMIX, where treatment was considered a fixed effect, and year, replication, and year*treatment were considered random effects. Leaf spot incidence was compared within each year and by evaluation date, due to a significant treatment* evaluation date interaction using SAS Proc Mixed for Repeated Measures ($P \leq 0.05$). Analysis within each evaluation date was done using SAS Proc GLIMMIX, where treatment was a fixed effect, and replication was a random effect. The pdiff lines option of Proc GLIMMIX was used for separation of the least square means. All subsequent reference to significant effects of differences among means indicates significance at $P \leq 0.05$ unless otherwise stated.

EFFECT OF FUNGICIDE APPLICATIONS ON INCIDENCE OF LEAF SPOT

Within all years, SAUDPC for incidence of early leaf spot was lower for all treatments than for the nontreated control, and was lower for the 200 g a.i./ha in-furrow prothioconazole treatment than the 100 g a.i./ha treatment (Table 1). SAUDPC was lower for the banded pyraclostrobin treatment than the banded prothioconazole treatment in 2012 and 2014, but was similar for those two treatments in 2013 (Table 1).

FIGURE 1

Plot configuration for leaf spot experiments. Border rows were planted early in the season. Plots (shown by smaller plants between rows of larger plants) were planted after epidemics of early leaf spot (*Cercospora arachidicola*) were severe (greater than 75% of the leaflets had lesions) in the border rows.

TABLE 1
Effect of in-furrow and early-season banded applications of fungicides on standardized area under the disease progress curve for early leaf spot, Tifton, GA 2012-2014.

Treatment	Rate (g a.i./ha)	Application method	SAUDPC[w] 2012	2013	2014
Nontreated	—	—	73.5 a[z]	58.4 a[z]	54.2 a[z]
Prothioconazole	100	In-furrow[x]	67.1 b	35.9 b	46.7 b
Prothioconazole	200	In-furrow[x]	57.9 c	27.1 c	42.0 c
Prothioconazole	200	Banded[y]	35.0 d	27.2 c	31.7 d
Pyraclostrobin	164	Banded[y]	30.8 e	27.0 c	20.7 e

[w] Area under the disease progress curve (AUDPC) was calculated from multiple evaluations of incidence (percent of leaflets with one or more lesion) and standardized by dividing by total duration (days) that disease incidence was monitored in each year.

[x] Fungicide was applied in-furrow at time of planting.

[y] Fungicide was applied in a 30-cm band directly over row 21 days after planting. Total broadcast rate was concentrated in the 30-cm band.

[z] Numbers within the same column followed by the same letter do not differ significantly ($P > 0.05$) SAS Proc GLIMMIX, pdiff lines Option.

In 2012, disease incidence in the nontreated control was 27% at the time of the first evaluation 26 DAP, and increased to 77% by 42 DAP (Fig. 2). Significant treatment effects ($P < 0.01$) on early leaf spot incidence were observed by the time of the first rating 26 DAP. The full-rate in-furrow treatment with prothioconazole resulted in lower incidence of early leaf spot compared to the nontreated plots for evaluations at 26, 28, and 33 DAP (Figs. 2 and 3) ($P < 0.01$). Incidence of leaf spot in plots treated with the lower rate of prothioconazole in-furrow, and early-emergence banded application of prothioconazole or pyraclostrobin were intermediate at the 26 DAP evaluation date (Fig. 2). Disease incidence increased rapidly from 9.4% to 73.6% between 28 and 42 DAP in plots that received in-furrow prothioconazole treatments. By 42 DAP, incidence in those plots was similar ($P \geq 0.22$) to that in the control plots, ranging from 73.6% in the full-rate prothioconazole treatment to 77% in the control (Fig. 2). At 42 DAP, treatments of banded applications of prothioconazole or pyraclostrobin had incidences similar to each other ($P = 0.09$) and lower than that in any other treatment ($P < 0.01$) (Fig. 2). By 54 DAP, incidence in both early postemergence banded treatments had increased greatly to 77%, but was still lower than in any other treatment (88% to 91%) ($P < 0.01$) (Fig. 2). Final incidence was similar in the pyraclostrobin and prothioconazole postemergence treatments ($P = 0.86$) (Fig. 2).

There was a similar, although more dramatic temporal pattern of the treatment effects in 2013 compared to 2012. Incidence of early leaf spot in nontreated plots increased rapidly between 17 and 28 DAP, but more gradually after that time than in other years (Fig. 2). Leaf spot incidence for the full-rate in-furrow prothioconazole was lower than that of the nontreated control at all rating times ($P < 0.01$) (Fig. 2). Incidence in the plots treated with banded prothioconazole or pyraclostrobin were similar to each other for all evaluations ($P \geq 0.13$) (Fig. 2). Incidence in both of the banded application treatments was higher than that in plots treated with full-rate in-furrow treatment of prothioconazole at 24 ($P < 0.01$) and 28 DAP ($P < 0.01$), but was similar to that treatment at 35 DAP ($P > 0.50$) (Fig. 2). For all ratings after 35 DAP, incidence in plots that received either of the banded application treatments was lower than for plots that received any other treatment ($P < 0.01$) except the full rate of prothioconazole in-furrow (Fig. 2). Final incidence was similar ($P > 0.06$) for the full rate of prothioconazole in-furrow treatment and the banded prothioconazole treatment (Fig. 2).

In 2014, incidence of early leaf spot increased rapidly in nontreated plots from 19 to 36 DAP (Fig. 2). In-furrow application of the full rate of prothioconazole resulted in very low incidence of leaf spot at 28 DAP, but incidence increased rapidly after that time. By 40 DAP, both in-furrow prothioconazole treatments resulted in incidences similar to that of the nontreated control ($P \geq 0.18$). Banded application of prothioconazole or pyraclostrobin resulted in similarly low incidences of leaf spot through 40 DAP ($P \geq 0.18$) (Fig. 2). After 40 DAP, incidence of leaf spot increased rapidly in the banded prothioconazole treatment (Fig. 2). The pyraclostrobin treatment resulted in lower incidence of leaf spot than the prothioconazole treatment at both 43 ($P < 0.01$) and 47 DAP ($P < 0.01$) (Fig. 2). By 55 DAP, incidence in all fungicide-treated plots was similar to that in the nontreated plots ($P \geq 0.14$).

IMPLICATIONS FOR RESEARCH ON PEANUT FOLIAR DISEASES

Onset of epidemics of early leaf spot in peanut varies greatly and can be affected by the amount of inoculum present, planting date, and environmental conditions. Subsequently, those factors contribute to variation in the ideal timing for initiation of fungicide applications for leaf spot management (Shokes et al. 1982) and the ability to evaluate the effects of early-season fungicides on those epidemics. The use of differential planting dates for border rows and treatment plots helped provide more consistent potential for disease development for evaluation of effects on foliar diseases of peanut of fungicides primarily targeted at soilborne diseases through in-furrow or early-season applications.

IMPLICATIONS FOR MANAGEMENT OF LEAF SPOT IN PEANUT

In-furrow applications of prothioconazole at 200 g a.i./ha and banded early-season applications of prothioconazole or pyraclo-

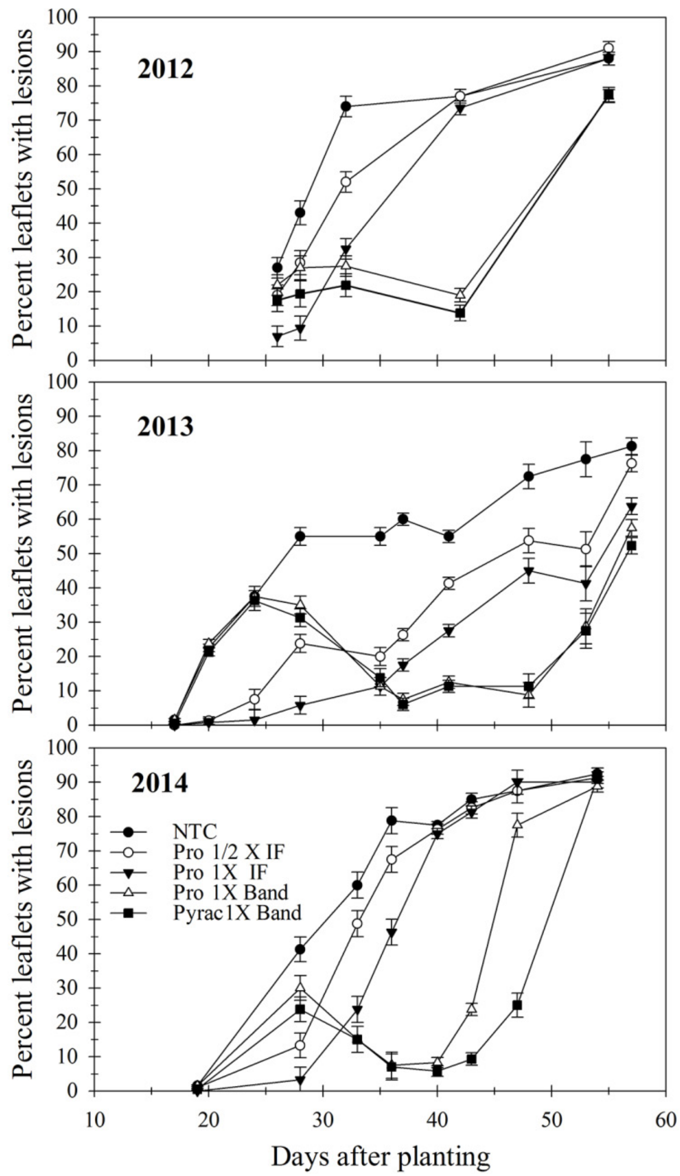

FIGURE 2

Effect of in-furrow (IF) applications of 100 (0.5×) and 200 (1×) g a.i./ha of prothioconazole (Pro) and banded (Band) applications of 200 g a.i./ha of prothioconazole or 164 (1×) g a.i./ha of pyraclostrobin (Pyrac) on incidence of early leaf spot of peanut, Tifton, GA, 2012-2014. NTC = nontreated control. Error bars represent standard errors of treatment least square means within a sample date based on analysis with SAS Proc GLIMMIX.

strobin provided excellent control of early leaf spot under high disease pressure, with inoculum from adjacent border rows much greater than would be typically expected in commercial production. Although systemic uptake and movement of the fungicides were not addressed directly, effects on leaf spot incidence by in-furrow application of prothioconazole and banded early-season applications of prothioconazole or pyraclostrobin indicate that both fungicides provided control on leaves that were not present at the time of application. Systemic movement is a possible explanation for that effect.

Results from 2012 and 2014 indicated that in-furrow application of prothioconazole provided little control of leaf spot after 28 DAP. Standard fungicide regimes for leaf spot control in Georgia typically are initiated 30 to 40 DAP. Although in-furrow application of prothioconazole prevented leaf spot development soon after plant emergence, there was little indication from these results that such early applications could substitute for initial fungicide applications of a standard leaf spot management program. With normal planting dates, leaf spot epidemics typically become apparent after 30 DAP. However, these results indicate that in-furrow applications of prothioconazole would improve leaf spot control in situations where epidemics begin earlier.

Banded applications of either prothioconazole or pyraclostrobin at 21 DAP stopped rapid increases in leaf spot incidence in all three years (for middle assessment dates) and resulted in reductions in incidence of leaf spot after 32, 24, and 28 DAP in 2012, 2013, and 2014, respectively. Lower incidence was likely due to some combination of (i) loss of symptomatic leaves or leaflets, (ii) development of new leaves, and (iii) curative activity of the fungicides applied. In a recent laboratory study, applications of prothioconazole or pyraclostrobin reduced the numbers of early leaf spot lesions when applied to peanut leaves as late as 7 days after inoculation and restricted the size of lesions by over 60% when applied as late as 13 days after inoculation (Cantonwine et al. 2008; Johnson and Cantonwine 2014). In the field, similar leaf spot control was achieved with delayed applications of these systemic fungicides compared to the protectant chlorothalonil (Culbreath et al. 2006; Culbreath et al. 2010). These results suggest that a banded application of either of these fungicides at 21 DAP would be more effective for managing an early-season outbreak of leaf spot than the in-furrow treatment of prothioconazole, even if infections had occurred before the initial application. Increases in leaf spot incidence after an initial decline following application of those fungicides were not observed in either banded treatment until after 42 DAP in 2012 or 48 DAP in 2013. In 2014, incidence increased noticeably after the 40 DAP evaluation for prothioconazole but not until after the 43 DAP evaluation for pyraclostrobin. It was not determined whether the initial increases in incidence of leaf spot after the banded application were due to the endpoint of duration of efficacy of the fungicides in or on the leaf tissue or emergence of leaves that had less than effective concentrations. Regardless of factors affecting the duration of control, banded applications of prothioconazole prevented noticeable increase in incidence of leaf spot for 19 days or longer after application in each year, and that similar applications of pyraclostrobin prevented increase in incidence for at least 21 days after application.

The incubation period for *C. arachidicola* varies. It is reported to be as little as 6 to 8 days during optimal conditions (Shokes and Culbreath 1997), but 10 to 11 days on susceptible genotypes has been more commonly observed in controlled studies (Cantonwine et al. 2008; Johnson and Cantonwine 2014). The incubation period can vary greatly among cultivars. Incubation period for Georgia-09B has been reported to be 7.5 days (Gong et al. 2015). Based on an approximately 7-day incubation period previously reported (Gong et al. 2015; Shokes and Culbreath 1997), and delays in increases in leaf spot incidence 20 to 28 days after the in-furrow or banded applications, these results suggest approximately a 14-day period of protection from high levels of inoculum from nontreated borders, if the delays were due solely to duration of efficacy of the fungicide in previously protected leaves. However, if the observed increase in incidence was

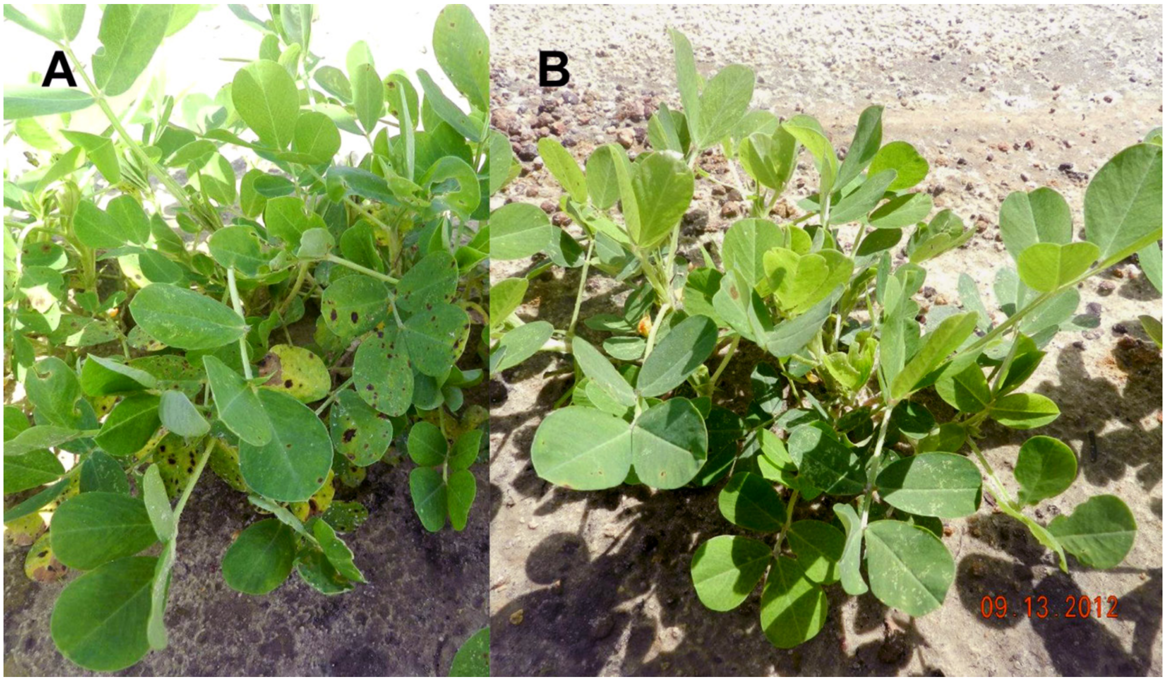

FIGURE 3

Severe early leaf spot (*Cercospora arachidicola*) on nontreated peanut plants (**A**) 28 days after planting compared to a few small lesions evident on plants in plots that received in-furrow application of 200 g a.i./ha of prothioconazole (**B**) at planting.

dependent on disease development in new unprotected leaves, the duration of utility for leaf spot control of either application method may be considerably greater than indicated here. That was not addressed in this study, but consideration of the methods used for these evaluations and the results obtained under circumstances of great potential for disease development prompts the hypothesis that these treatments may have longer duration of efficacy if epidemic development is dependent upon secondary inoculum from treated plants. Studies are in progress to determine whether that is the case.

Results from this study indicate that in-furrow application of prothioconazole or banded application of prothioconazole or pyraclostrobin 21 DAP have substantial effects on leaf spot development. Although both in-furrow and early postemergence banded applications of prothioconazole provided control of early leaf spot, the period of control provided with the banded post emergence sprays would likely be of greater utility for leaf spot management. The time between postemergence applications of prothioconazole and observation of net increases in leaf spot incidence indicates that such an application at 21 DAP could potentially replace the initial application in a typical fungicide program. Experiments are in progress that address that substitution more directly, and to determine whether an application at 21 DAP or later might suffice for leaf spot control until the next fungicide application is needed for stem rot control. Experiments are also in progress comparing broadcast versus banded applications for those early applications. Considering the cost of either an in-furrow or early-season banded application of the fungicides evaluated, such applications would not be indicated solely for management of leaf spot. However, if such applications are warranted for management of stem rot, the efficacy for leaf spot control may help mitigate the cost of such a treatment as well as improve early-season management of both diseases.

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