TARGET SPOT-INCITED DEFOLIATION AND YIELDS OF SELECTED COTTON VARIETIES OVER A THREE-YEAR PERIOD IN SOUTHWEST ALABAMA

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Abstract

A study was conducted at the Brewton Agriculture Research Unit (BARU) in 2014, 2015, and 2016 to assess the reaction of selected mid- and full-season commercial cotton varieties to target spot, incited by *Corynespora cassiicola*, as well as disease impact on yield. The experimental design was a factorial set of treatments arranged in a split plot, with the cotton varieties Phytogen 499 WRF, Phytogen 575 WRF, Deltapine 1137 B2RF, Deltapine 1252 B2RF, Fibermax 1944 GLB2, and Stoneville 6448 GLB2 as whole plots and a fungicide program consisting of four or five applications of Headline SC at 9 fl oz/A + Bravo Ultrex at 1.5 pt/A as the split plot treatment. Fungicide treatments were designed to minimize target spot incited defoliation and subsequent yield loss. The site was irrigated as needed in all study years and managed for maximum yield. Final % defoliation and rAUC defoliation values differed by cotton variety and fungicide program. While final % defoliation and rAUC for all the above varieties were lower for the fungicide- than non-fungicide treated controls, lower values for each of these variables were obtained for the fungicide-treated Phytogen 575 WRF, Deltapine 1252 B2RF, Stoneville 6448 GLB2, and Fibermax 1944 GLB2 compared with Phytogen 499 WRF. For the non-fungicide treated controls, higher defoliation and rAUC values were obtained for the latter than for the other five remaining varieties, which had similarly lower values for both disease severity variables. Over the study period, equally higher yields were noted in 2014 and 2015 than 2016, when elevated hard lock counts were recorded. In addition, Fibermax 1944 GLB2 had higher yields than Phytogen 499 WRF, Phytogen 575 WRF, Deltapine 1137 B2RF, Deltapine 1252 B2RF, and Stoneville 6448 GLB2 with all of the latter varieties having similar yields. Finally, seed yields were higher for the fungicide- than non-fungicide treated controls. While higher open boll counts were recorded in 2014 than either of the following two study years, hardlock boll counts progressively increased each study year from a low of 2.4 in 2014 to 11.7 in 2016. Rotted boll counts were higher in 2015 and 2016 than in 2014. For 2015, counts of rotted bolls were higher for the fungicide-treated than non-fungicide treated control with the latter treatment having similar rotted boll counts as the fungicide-treated and non-fungicide treated control in 2016.

Introduction

Target spot, which is caused by the fungus *Corynespora cassiicola*, occurs in all Southern cotton producing states (Butler et al. 2016; Conner et al. 2013; Donahue 2012; Edmisten, 2012; Fulmer et al. 2012; Price et al. 2016), as well as Brazil (Galbieri et al, 2014) and China (Wei et al, 2014). In 2016, damaging target spot outbreaks highlighted by immature boll shed were observed in the Mid-South states of Arkansas, Louisiana, Mississippi, and Tennessee (Kelly and Raper, 2017; Shultz, 2017). As was observed in 2016 in Southwest Alabama along with Mid-South states, target spot outbreaks are associated with frequent showers in July and August.

Disease resistant or tolerant varieties remain the most cost effective tool for minimizing losses to plant diseases. Previously, sizable differences in the level of target spot-incited defoliation have been observed among mid-late and late maturing flex cotton varieties at multiple Alabama sites (Hagan et al, 2015b; Hagan et al, 2015c; Hagan et al, 2016a). For the susceptible variety Phytogen 499 WRF, lint yield losses up to 400 lb lint/A, which translates into a \$280/A income loss at the current world market price, have been observed in Southwest Alabama (Hagan, 2015b). In contrast, significantly less defoliation along with lower target spot-incited yield losses and minimal yield gains from fungicide inputs have been recorded for the target spot 'tolerant' varieties Deltapine 1050 B2RF, Deltapine 1137 B2RF, and Deltapine 1252 B2RF (Hagan et al, 2013; Hagan et al, 2015a). Currently, target spot-tolerant varieties dominate the cotton seed market in south Alabama (USDA, 2016; Hagan, personal observation). A preliminary report has been published (Hagan et al, 2016b).

The objective of this multi-year study was to assess the reaction of commercial mid-late and late maturing cotton varieties to target spot in an irrigated production system under high disease pressure as well as quantify target spot related yield losses or each of the varieties over time.

Methods

The study site at BARU in Brewton AL, which was previously cropped to peanut or corn, was prepared for planting in 2014, 2015, and 2016 with a KMC ripper bedder. Soil fertility and pH were adjusted according to the results of a soil assay done by the Auburn University Soil Testing Laboratory. Cotton varieties were sown at rate of 3 seed/ft on 23 May 2014, 13 May 2015, and 5 May 2016. Weed and insect control recommendations of the Alabama Cooperative Extension System were followed. Cotton growth was managed with multiple applications of recommended rates of Pix (mepiquat). This study received a total of 3.4, 2.8, and 2.5 inches of water in 2014, 2015, and 2016, respectively via a lateral irrigation system. The experimental design was a factorial set of treatments arranged as a split-plot with cotton variety as the whole plot and fungicide treatment as the split-plot treatment. Individual split-plots consisted of four 25 ft rows spaced 3 ft apart. Depending on the study year, four or five replications of treatments were included. Alleys between replications were cut with a bushhog several weeks prior to harvest. Three to five broadcast applications of 9 fl oz/A Headline 2.09SC + 1.0 pt/A Bravo Ultrex were made in each study year at two week intervals beginning at either pinhead square or 1st week of bloom through the 5th or 7th week of bloom with a ‘high-boy’ sprayer with TX-12 nozzles on a 20 inch spacing at spray volume of 20 gal/A at 60 psi. A non-fungicide treated control was included.

Target spot intensity was assessed at 2-week intervals beginning at the 3rd and ending at the 9th of bloom using a 1 to 10 leaf spot scoring system where 1 = no disease, 2 = very few lesions in canopy, 3 = few lesions noticed in lower and upper canopy, 4 = some lesions seen and < 10% defoliation, 5 = lesions noticeable and < 25% defoliation, 6 = lesions numerous and < 50% defoliation, 7 = lesions very numerous and < 75% defoliation, 8 = numerous lesions on few remaining leaves and < 90% defoliation, 9 = very few remaining leaves covered with lesions and < 95% defoliation, and 10 = plants defoliated. Defoliation values were calculated from intensity data using the formula [% Defoliation = 100/(1+e(-(leaf spot scoring system -6.0672)/0.7975)] (Li et al, 2012). Area under disease progress curve (AUDPC) values for defoliation, which were calculated from defoliation data recorded over time, were converted to rAUC values by dividing by the number of days over which observations were made in each study year. Cotton was mechanically harvested on 4 November 2014, 14 October 2015, and 5 October 2016. Counts of open bolls were made in 3 ft of a border row just prior to harvest. Final defoliation ratings are displayed. Significance of interactions was determined using PROC GLIMMIX procedure in SAS. Statistical analyses were done on rank transformations for non-normal defoliation along with open, unopen, locked, and rotted boll data. Non-transformed data are reported. Means were separated using Fisher’s protected least significant difference (LSD) test ($P \leq 0.05$) unless otherwise indicated.

Results

While monthly rainfall totals and temperatures were at or above the 30 year average during the study period in 2014, mean monthly temperatures from May to mid-October 2015 were above the 30 year average, and rainfall totals were below average in June but at or above average for the remainder of the study period. For 2016, mean monthly temperatures from May to early September were average, while rainfall totals, which were well below average in June, were above the 30 year average for July, August, and September. Overall, rainfall and temperature patterns from July through September were conductive to the development of target spot in cotton.

Final target spot (%) defoliation, the season-long rAUC defoliation value, and yield differed by study year (Table 1). While similarly higher final target spot defoliation levels were noted for 2015 and 2016 compared to 2014, the rAUC season-long defoliation value was higher in 2015 than 2014 or 2016 with the least defoliation being noted in the former study year (Table 2). Despite significantly lower final target spot % defoliation and rAUC season-long defoliation values in 2014 compared with 2015, similarly higher seed cotton yields were noted for those two study years than in 2016.

Table 1. *F* values for generalized linear models for effects of year, variety, and fungicide program on target spot defoliation, rAUC, and yield.

	Target spot		
Source of variance	Final % defoliation	rAUC defoliation	Seed yield
Year	7.83* [Z]	25.28***	119.84***
Cotton Variety	29.63***	30.86***	6.01***
Year × variety	1.38	0.63	1.60
Fungicide program	162.22***	192.01***	6.69*
Year × fungicide program	0.34	2.41	0.38
Variety × fungicide program	5.14***	7.61***	1.66
Year x variety × fungicide program	0.54	1.12	0.58

[Z] Significance at 0.05, 0.01, and 0.001 levels is indicated by *, **, and ***, respectively.

Table 2. Target spot final % defoliation, rAUC defoliation values, and seed yield as influenced by study year.

	Target spot defoliation		Seed yield
Year	Final % [Z]	Season-long rAUC [Y]	lb/A [X]
2014	19.2 b [W]	7.0 c	4167 a
2015	29.3 a	15.8 a	4054 a
2016	27.7 a	10.2 b	2557 b

[Z] Target spot intensity was rated using a leaf spot scoring system (1 to 10 scale) and converted to % defoliation values.
[Y] rAUC defoliation values were calculated by dividing AUDPC values dividing by the number of days over which observations were made in each study year.
[X] Seed cotton yield = total weight of seed + lint.
[W] Means in each column followed by the same letter are not significantly different according to Fisher's protected least significant difference (LSD) test ($P \leq 0.05$).

Final target spot (%) defoliation and rAUC season-long defoliation values differed by cotton variety and fungicide program (Table 1). The non-fungicide treated Phytogen 499 WRF (PHY499) suffered higher final % defoliation than any other variety except for Fibermax 1944 GLB2 (FM1944), which also had defoliation levels that matched those of Phytogen 575 WRF (PHY575), Deltapine 1137 B2RF (DP1137), Deltapine 1252 B2RF (DP1252), and Stoneville 6448 GLB2 (ST6448) (Fig. 1A). With the exception of Deltapine 1137 B2RF, higher target spot-incited defoliation levels were recorded for the non-fungicide treated control compared with the Headline + Bravo Utrex fungicide program on the remaining five varieties. The Headline + Bravo Ultrex treated Phytogen 499 WRF had higher final defoliation levels than the remaining varieties with Deltapine 1137 B2RF having the highest final % defoliation ratings and Deltapine 1252 B2RF had lower ratings than the former variety and Fibermax 1944 GLB2. In addition, the fungicide-treated Phytogen 499 WRF along with the non-fungicide treated Phytogen 575 WRF, Deltapine 1137 B2RF, Deltapine 1252 B2RF, Fibermax 1944 GLB2, and Stoneville 6448 GLB2 had similar final % defoliation values.

Overall, rAUC season-long defoliation rankings mirrored those for final target spot % defoliation. Similarly lower rAUC defoliation values were noted for the non-fungicide treated Phytogen 575 WRF, Deltapine 1137 B2RF, Deltapine 1252 B2RF, Fibermax 1944 GLB2, and Stoneville 6448 GLB2 as compared with the higher values for Phytogen 499 WRF (Fig 1B). Significant reductions in rAUC defoliation for all cotton varieties were obtained with the Headline + Bravo Ultrex fungicide program. The fungicide-treated Phytogen 499 WRF had a higher rAUC defoliation value than all other varieties except for Deltapine 1137 B2RF. The rAUC defoliation values for the fungicide-treated Phytogen 575 WRF, Deltapine 1252 B2RF, Fibermax 1944 GLB2, and Stoneville 6448 GLB2 were similarly low. As was noted above for final defoliation, similar rAUC defoliation values were noted for the fungicide-treated Phytogen 499 WRF and non-fungicide treated Phytogen 575 WRF, Deltapine 1137 B2RF, Deltapine 1252 B2RF, Fibermax 1944 GLB2, and Stoneville 6448 GLB2.

Since interactions for year, cotton variety, and fungicide program for seed yield were not significant, data presented for these variables are pooled by variety and fungicide program (Table 1). Over the three-year study period, higher seed yields were recorded for Fibermax 1944 GLB2 compared with Phytogen 499 WRF, Phytogen 575 WRF, Deltapine 1137 B2RF, Deltapine 1252 B2RF, and Stoneville 6448 GLB2 with the latter five varieties having similarly lower yields (Fig. 2A). Higher yields were noted across all cotton varieties for the Headline + Bravo Ultrex-treated compared with non-fungicide treated cotton (Fig. 2B).

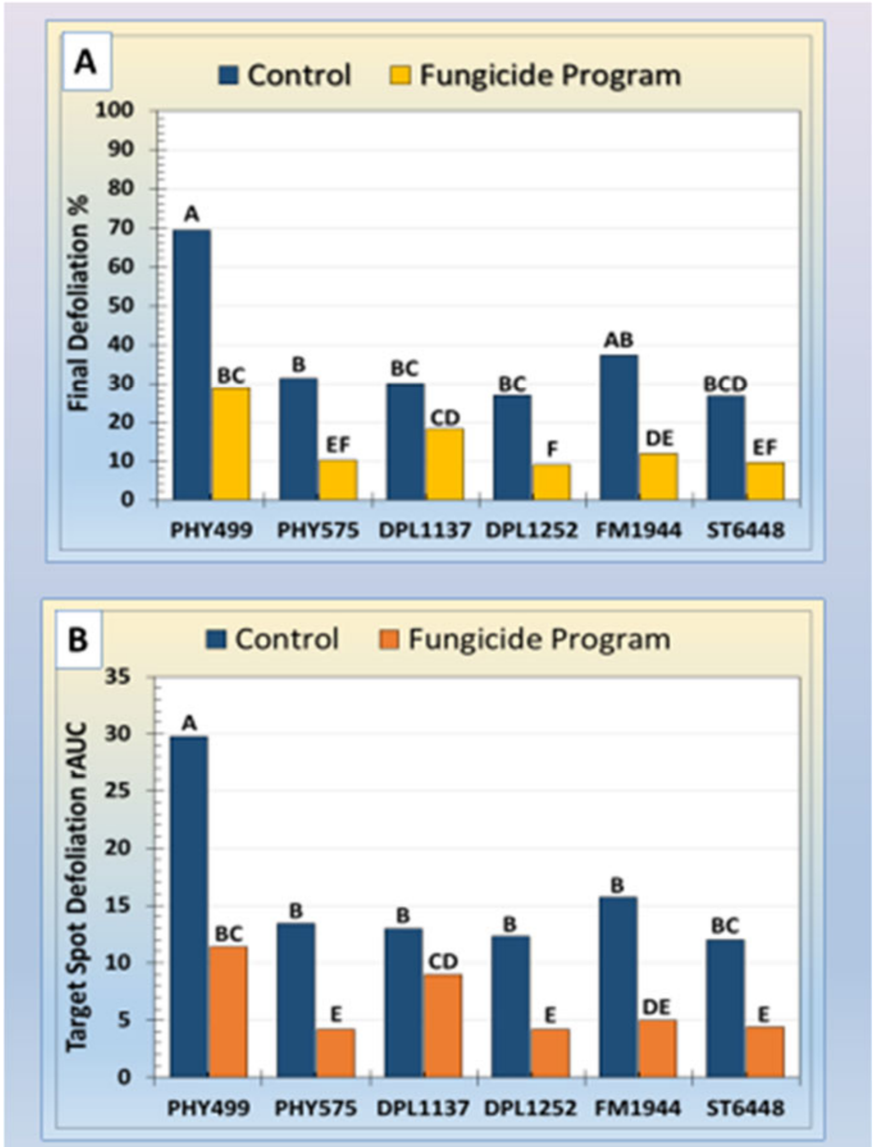

Figure 1. Target spot A) (%) defoliation and B) rAUC season-long defoliation values as impacted by cotton variety and fungicide program. Means in each figure followed by the same letter are not significantly different according to Fisher's protected least significant difference (LSD) test (P<0.05).

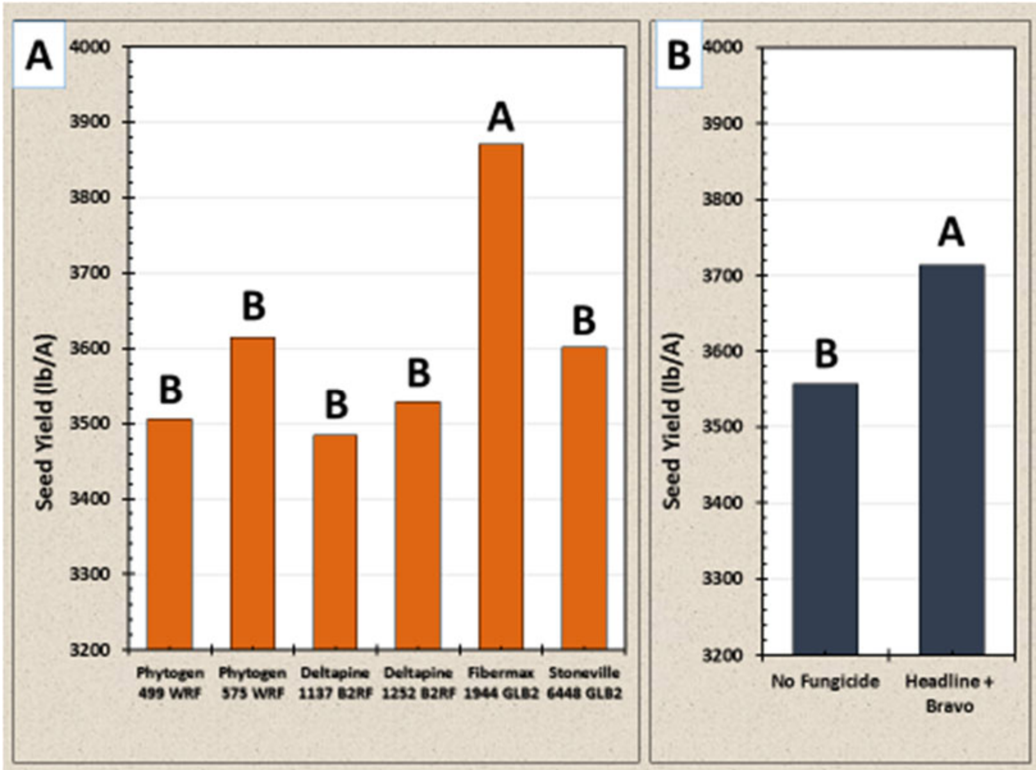

Figure 2. Seed yield as impacted by A) cotton variety and B) fungicide program. Means followed by the same letter in each figure are not significantly different according to Fisher's protected least significant difference (LSD) test (P<0.05).

With the exception of a year × fungicide program interaction for rotted bolls, interactions between year, cotton variety and fungicide program for open, unopened, locked, and rotted bolls were not significant (Table 3), and data presented for these variables are pooled by year, variety, and fungicide program (Table 4, 5).

Study year had a significant impact on counts of open and hardlock but not unopened bolls (Table 3). While open boll counts were significantly higher in 2014 compared with the two following years, similar unopen boll counts were recorded in all study years (Table 4). A significant stepwise increase in hardlock boll counts, which peaked in 2016 at 11.7 locked bolls per 3 foot of row, occurred over the three year study period.

Open and unopen boll counts were similar across all six cotton varieties and both fungicide programs over the three-year study period (Table 4). Locked boll counts were lower for Phytogen 575 WRF than for the other five cotton varieties. The Headline + Bravo fungicide program and non-fungicide treated control, however, had similar locked boll counts. Finally, similarly low rotted boll counts were recorded for all six cotton varieties.

With a significant year × fungicide program interaction, rotted boll counts differed by year and fungicide program (Table 3). Rotted boll counts were higher in 2015 but not 2014 and 2016 for the fungicide treated- than non-fungicide treated cotton (Fig. 3). For the non-fungicide treated controls, rotted boll counts were lower in 2014 than the similarly higher counts recorded in the following two years. In contrast, rotted boll counts were higher in 2015 compared with 2014 and 2016, which had similarly lower counts.

Table 3. F values for generalized linear models for effects of year, variety, and fungicide program on boll count variables.

	Boll counts			
Source of variance	Open	Unopen	Locked	Rotted
Year	69.54*** [Z]	0.54	54.39***	6.29*
Cotton variety	0.49	1.41	2.91*	1.47
Year × variety	1.03	1.52	1.10	1.13
Fungicide program	0.11	0.03	0.29	1.66
Year × fungicide program	0.53	0.71	0.64	3.23*
Variety × fungicide program	0.70	0.55	1.28	1.05
Year × variety × fungicide program	1.39	0.78	0.55	1.06

[Z] Significance at 0.05, 0.01, and 0.001 levels is indicated by *, **, and ***, respectively.

Table 4. Open, unopen, and hardlock (locked) boll counts by study year.

	Boll Counts		
Year	Open	Unopen	Locked
2014	74 a	2.6 a	2.4 c
2015	47 b	3.9 a	4.7 b
2016	48 b	3.4 a	11.7 a

[Z] Boll counts were made on 3.2 ft of row just prior to harvest.

[Y] Means in each column followed by the same letter are not significantly different according to Fisher's protected least significant difference (LSD) test ($P \leq 0.05$).

Table 5. Boll counts as influenced by cotton variety and fungicide program.

	Boll counts [Z]			
Cotton variety	Open	Unopen	Locked	Rotted
Phytogen 499 WRF	59 a [Y]	3.3 a	6.8 a	1.0 a
Phytogen 575 WRF	54 a	3.7 a	4.2 b	0.5 a
Deltapine 1137 B2RF	57 a	3.0 a	6.0 a	0.6 a
Deltapine 1252 B2RF	56 a	4.4 a	6.0 a	0.9 a
Fibermax 1944 GLB2	58 a	1.8 a	7.1 a	0.7 a
Stoneville 6448 GLB2	54 a	3.4 a	6.4 a	0.4 a
Fungicide Program				
Headline + Bravo Ultrex	57 a	3.2 a	6.1 a	---
Non-fungicide treated control	56 a	3.3 a	6.4 a	---

[Z] Boll counts were made on 3 ft of row just prior to harvest.

[Y] Means in each column followed by the same letter are not significantly different according to Fisher's protected least significant difference (LSD) test ($P \leq 0.05$).

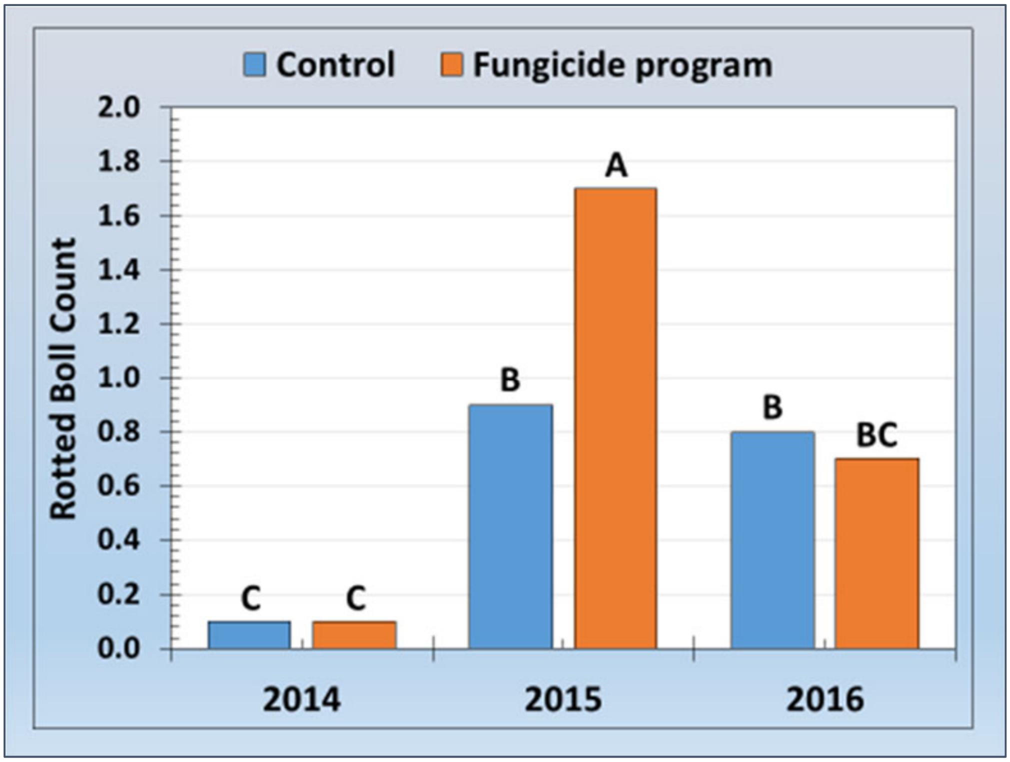

Figure 3. Counts of rotted bolls as influenced by an interaction between year and fungicide program. Means followed by the same letter are not significantly different according to Fisher's protected least significant difference (LSD) test ($P \leq 0.05$).

Summary

Tolerant varieties are an effective tool for managing target spot in cotton. As previously reported (Hagan et al, 2015c; Hagan et al, 2016a; Hagan et al, 2016b), Phytogen 499 WRF is among the most susceptible commercial cotton varieties to target spot. Over the three year study period, final % defoliation values were noticeably higher for non-fungicide treated Phytogen 499 WRF than Phytogen 575 WRF, Deltapine 1137 B2RF, Deltapine 1252 B2RF, and Stoneville 6448 GLB2, all of which suffered less target spot-incited defoliation. Season-long defoliation, as indicated by rAUC values, was also similarly lower for the latter four varieties along with Fibermax 1944 GLB2 compared with Phytogen 499 WRF. The absence of a year × variety interaction illustrates that ranking of cotton varieties with respect to target spot final % defoliation and season-long rAUC defoliation values was consistent over the study period.

When compared with the non-fungicide treated control, the Headline + Bravo Ultrex fungicide program reduced final % and season-long rAUC defoliation across all varieties except for the former but not latter disease rating on Deltapine 1137 B2RF. The lack of a significant interaction between year and fungicide program showed that the fungicide program gave similar target spot control in each study year on all varieties. Previous Alabama studies (Hagan et al, 2015a) have shown that two properly timed fungicide applications give the same level of disease control as the multiple application Headline + Bravo Ultrex program employed here.

The mean yield gain obtained with the 'chemical umbrella' multi-application Headline + Bravo Ultrex fungicide program over the three year study period was a modest 157 lb seed cotton/A. When converted to a lint cotton yield of approximately 65 lb/A, this yield gain was valued at the current world market price ($0.70 per pound) at approximately $45 per acre, which would barely cover product and application costs for a two application program. While the non-significant variety × fungicide program interactions suggests that fungicide inputs generally increased yield across all varieties, five of six varieties suffered relatively minor disease-related premature defoliation, so resulting yield gains would likely be relatively small when compared with Phytogen 499 WRF. Results of this same study from 2015 (Hagan et al, 2016b) showed significant lint yield gains from fungicide inputs in excess of 200 lb lint/A for Phytogen 499 WRF and Fibermax 1944 GLB2, with minimal fungicide-linked yield gains on the remaining four varieties. Multiple Alabama studies have shown little if any yield benefit from the multi-application 'chemical umbrella' as compared with the recommended and less costly two application programs on Phytogen 499 WRF (Hagan et al, 2015a).

Hardlock, which is caused by the fungus *Fusarium verticillioides* (Marois et al, 2007), has emerged as a damaging disease at this study site. Over the last three years, hardlock boll counts have quadrupled from 2.4 to 11.7 locked bolls per 3 ft of row and is associated with the 1500 lb/A seed yield decline observed between 2015 and 2016. The lower hardlock boll counts reported for Phytogen 575 WRF, compared with the similarly higher counts noted for the other varieties screened, did not translate into higher yields. In addition, no reduction in hardlock boll counts was obtained here with the 'chemical umbrella' Headline + Bravo Ultrex fungicide program. Similarly elevated hardlock boll counts were also recorded in 2016 in multiple cotton trials at this study location and the Gulf Coast Research and Extension Center (Hagan, personal observation). As noted above, no reductions in hardlock incidence were obtained with fungicides in field studies at either of the above sites in 2016, while the differences in hardlock boll counts noted between selected cotton varieties did not result in significant yield gains. Most likely, the increased incidence of hardlock can be attributed to frequent showers observed at both locations beginning at flowering in July through boll cracking in mid-August (Marois et al, 2007). Additional studies need to be conducted to assess the efficacy of several newly released fungicides for the management of hardlock as well as target spot in cotton.

All of the cotton varieties screened herein will shortly be replaced with varieties possessing Enlist and Extend technology. While the reaction to target spot of the varieties screened here and in other Alabama studies is well documented (Hagan et al, 2015b; Hagan et al, 2015c, Hagan et al, 2016a; Hagan et al, 2016b), the reaction of upcoming variety releases to target spot as well as their response to fungicide inputs, particularly under high disease pressure, has not been established. The focus of future studies will need to establish the susceptibility of newly released varieties to target spot, determine the magnitude of potential disease-incited yield losses and the efficacy of registered and experimental fungicides to provide effective yield protection under a high *Corynespora cassiicola* inoculum pressure.

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