DISEASE INTENSITY, YIELD, AND LOAN VALUE AS INFLUENCED BY COTTON CULTIVAR SELECTION ALONG WITH PLANT GROWTH REGULATOR AND FUNGICIDE INPUTS

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Abstract

The impact of cotton cultivar, along with plant growth regulator (PGR) program and fungicide inputs on the foliar diseases target spot and areolate mildew along with yield and loan value was assessed in 2017, 2018, and 2019. While Deltapine 1646B2XF was used in all years, PhytoGen 499WRF, which was sown in 2017, was replaced with PhytoGen 490W3FE for 2018 and 2019. The standard PGR program consisted of 8 and 16 fl oz/A Pix applications at pin head square and 3rd week of bloom, while the excessive PGR program included 16 fl oz/A, 16 fl oz/A, and 24 fl oz/A Pix applications at pin head square, 3rd, and 6th week of bloom. Fungicide programs included 1) no-fungicide control, 2) single application of 4 fl oz/A Priaxor 4.17F at the 3rd week of bloom, and 3) application of 4 fl oz/A Priaxor 4.17F at the 3rd and 5th week of bloom. Target spot and areolate mildew intensity were rated separately using a 1 to 10 scoring system. Target spot-incited defoliation was greater in 2018 compared with the other study years with the two-application Priaxor program having the least defoliation. Also, significantly less target spot defoliation for the no-fungicide control and one- but not two application Priaxor program was recorded for Deltapine 1646B2XF than PhytoGen 499WRF/PhytoGen 490W3FE. Areolate mildew caused significant defoliation in 2019 and to a much lesser extent in 2017. Greater areolate mildew-incited defoliation was recorded above for the no-fungicide control on both cultivars than for either Priaxor program. Areolate mildew-incited defoliation declined for the excessive compared with standard PDR program in 2017 but not in 2019. PGR program had no impact on target spot or lint yield. Yield gains were noted for the two-application Priaxor program compared with the no-fungicide control on PhytoGen 490W3FE in 2018 and Deltapine 1646B2XF in 2019. Yield was greater for Deltapine 1646B2XF than for PhytoGen 499WRF or PhytoGen 490W3FE.

Introduction

Target spot, which is caused by the fungus *Corynespora cassiicola* (Berk. & M.A. Curtis) C.T. Wei, can cause significant yield losses in cotton (Bowen et al 2018; Hagan et al 2018). Mehl et al (2019) also reported a significant negative correlation between target spot-incited defoliation and yield. Disease distribution in the U.S. includes all cotton producing states except for Arizona and California (Butler et al. 2016; Conner et al 2013; Donahue 2012; Edmisten 2012; Fulmer et al 2012; Price et al 2015, Damicone, personal communication; Woodruff, personal communication). Galbieri et al (2014) and Wei et al (2014) reported target spot outbreaks in Brazil and China, respectively.

Strong-growing cotton with early canopy closure, dense canopy, and a high yield potential is most vulnerable to target spot, particularly when irrigated and/or near the Gulf Coast where frequent afternoon summer showers favor early disease onset and subsequent yield loss (Hagan 2014). Absence of a closed canopy at or after first bloom minimizes the risk of damaging target spot-incited defoliation, regardless of rainfall or irrigation patterns (Hagan, personal observation). The risk of damaging disease outbreaks declines sharply with increasing distance from the Gulf of Mexico.

Resistance is the most efficient and cost effective method of managing field crop diseases as compared with fungicides, which provide target spot control but inconsistent yield gains (Mehl et al 2019). Previously, significant differences in target spot-incited defoliation have been noted among cotton cultivars (Hagan et al 2018). More recently, Deltapine 1646 B2XF has often had significantly lower levels of defoliation compared with many other commercial cultivars in combination with excellent yield potential (Bowen et al 2019; Hagan et al 2020).

While cultivars with partial resistance to target spot dominate the Alabama cottonseed market (USDA-AMS 2021), fungicides are an effective tool for limiting premature defoliation and disease-incited yield loss in intensively managed susceptible cultivars (Hagan 2014). Yield protection obtained with registered fungicides in Alabama may range up to 250 lb. lint/A (Hagan et al 2014; Hagan et al 2018). In contrast, Mehl et al (2019) also reported inconsistent yield gains from the Headline, Quadris, and the more efficacious Priaxor Xemium Brand Fungicide on PhytoGen 499 WRF and Deltapine 1137B2RF despite significant reductions in premature defoliation. Subsequently, Mivavis TOP alone or in combination with Quadris along with Revyteck significantly reduced premature defoliation and gave superior yield protection on the target spot susceptible cultivar Stoneville 6182GLT (Hagan et al 2020).

Areolate mildew, which caused by the fungus *Ramulariopsis gossypii* (Speg.) U. Braun (synonym *Ramularia gosspii* (Speg.) Cif.) (Videira et al 2016), normally causes little or no yield loss in U.S. cotton but requires an aggressive fungicide program to avoid significant damage in Brazilian cotton (Da Silva et al 2019). While areolate mildew typically appears in mid- to late September in maturing cotton, mid-summer outbreaks can defoliate cotton and result in significant yield loss. Early June-planted cotton in Central and South Alabama and Georgia along with the Florida Panhandle is vulnerable to damaging disease outbreaks and protective fungicide applications help avoid significant yield loss (Hagan et al 2019). In addition, commercial cotton cultivars differ greatly in their susceptibility to areolate mildew with the current industry standard Deltapine 1646 B2XF being among the most susceptible (Hagan et al 2019).

Production Methods

Studies were conducted in 2017, 2018, and 2019 with cotton following one year of peanut or corn at the Brewton Agricultural Research Unit in Brewton, AL. The experimental design was a factorial arranged in a split split split-plot design with year as the main plot, cotton cultivar as the split, plant growth regulator (PGR) program as the split split-plot, and fungicide program as the split split split-plot treatment. Individual subplots consisted of four 25 ft rows spaced 3 ft apart arranged in four replications. While Deltapine 1646B2XF was used in all years, PhytoGen 499WRF, which was sown in 2017, was replaced with PhytoGen 490W3FE for 2018 and 2019. Cotton was hill dropped at a rate of 3 seed/row ft in a Benndale fine sandy loam on 10 May 2017, 7 May 2018, and 31 May 2019. Recommendations of the Alabama Cooperative Extension System for fertility along with insect and weed control, and harvest preparation were followed. Plots were irrigated as needed with a lateral irrigation system. Broadcast applications of fungicide and plant growth regulator (PGR) treatments were made with a high clearance sprayer on 2 with TX-12 nozzles on 18 in. spacing at 20 gal/A of spray volume at 60 psi. The standard PGR program consisted of an application of 8 and 16 fl oz/A Pix (mepiquat chloride) at pin head square and 3rd week of bloom on 5 July and 27 July 2017, 10 July and 19 July 2018, and 10 July and 30 July 2019, respectively, while the intensive PGR program included applications of 16 fl oz/A, 16 fl oz/A, and 24 fl oz/A Pix at pin head square, 3rd and 6th week of bloom, on 5 July, 27 July, and 15 August, 2017, 10 July, 19 July, and 7 August 2018, and 10 July, 30 July, and 19 August, 2019, respectively. Fungicide programs consisted of 1) a no fungicide control, 2) a single application of 4 fl oz/A Priaxor 4.17F at the 3rd week of bloom on 27 July 2017, and 3) an application of 4 fl oz/A Priaxor 4.17F at the 3rd and 5th week of bloom on 27 July and 15 August 2017, 20 July and 16 August 2018, and 13 August and 27 August, 2019, respectively.

Target spot and areolate mildew intensity was assessed at cut-out 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 (Chiteka et al 1988) on 18 September 2017, 17 September 2018, and 27 September 2019. An additional assessment of areolate mildew intensity was made on 4 October 2019. Defoliation values were calculated using the formula [% Defoliation = 100/(1+e(-(leaf spot scoring system -6.0672)/0.7975)] (Li et al 2012). Counts of open, locked (hardlock), and rotted bolls were made in 3 ft of a border row just prior to harvest. Cotton was mechanically harvested on 17 October 2017, 15 October 2018, and 24 October 2019 and samples collected for grading. Significance of treatment interactions were determined using PROC GLIMMIX in SAS 9.4. Statistical analyses were done on rank transformations for non-normal values. 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 and Discussion

A significant Year x Fungicide program and Cultivar x fungicide program illustrated that defoliation attributed to target spot as influenced by fungicide program differed by study year and cotton cultivar (Table 1).

Table 1. F values for general lineal model for defoliation attributed to target spot and areolate mildew along with gin out, lint yield, and loan value.

Source of Variation	% Defoliation		Gin Out	Lint Yield	Loan Value
	Target Spot	Areolate Mildew			
Year (YR)	8.24** [z]	264.71***	57.67***	25.65**	41.23***
Cultivar (CV)	29.55***	153.78***	218.39***	499.58***	49.77***
CV x Yr	2.23	96.16***	4.12*	1.30	70.88***
Growth Regulator (PGR)	0.02	12.70***	8.74**	0.55	0.55
Yr x PGR	0.26	3.30*	0.82	1.03	0.43
CV x PGR	0.03	4.73*	1.76	0.84	1.20
Yr x CV x PGR	0.46	2.17	0.82	0.41	0.94
Fungicide (Fung)	15.79***	425.88***	0.32	7.43***	0.55
Yr x Fung	3.26*	247.38***	1.02	0.90	0.27
CV x Fung	4.46*	144.87***	0.95	0.66	1.11
Yr x CV x Fung	1.55	90.35***	0.34	4.86**	0.57
PGR x Fung	0.11	13.20***	1.32	0.46	2.72^
Yr x PGR x Fung	0.37	3.34*	0.18	0.44	1.43
CV x PGR x Fung	0.51	6.03**	0.95	1.32	1.23
YR x CV x PGR x Fung	0.29	1.87	0.99	0.95	1.49

[z] Significance of *F*-values at the 0.10, 0.05, 0.01, and 0.001 levels are indicated by ^, *, **, or ***, respectively.

Defoliation levels for target spot were greater regardless of fungicide program in 2018 compared with the other study years with the two but not the one Priaxor application program reducing defoliation compared with the no fungicide control (Figure 1A). While target spot-incited defoliation was significantly lower in 2019, two applications of Priaxor were required to reduce disease-incited defoliation below levels recorded for the single application program and no fungicide control. For 2017, similarly low levels of target spot incited defoliation were recorded for both the one and two Priaxor application programs than for the no fungicide control.

Target spot-incited defoliation was not impacted by PGR program (data not shown).

Target spot-incited defoliation also differed significantly by cotton cultivar and fungicide program (Figure 1B). For the no fungicide control and one but not two Priaxor application programs, target spot-incited defoliation was lower for the Deltapine than the PhytoGen entries. On both entries, one Priaxor application failed to significantly reduce target spot defoliation compared with the no fungicide control. In addition, the two Priaxor application program for the PhytoGen entries along with the one and two Priaxor application programs for the Deltapine entry had similarly low target spot defoliation levels.

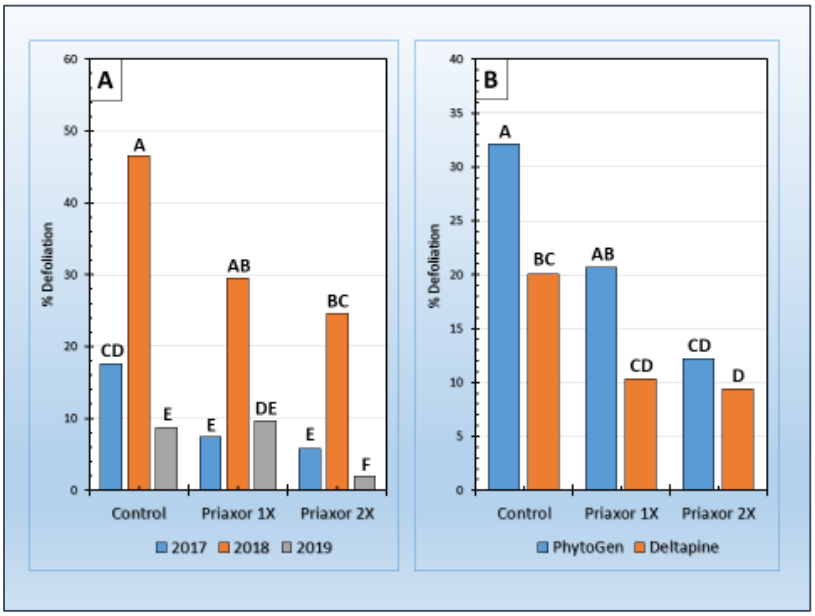

Figure 1. Year × Fungicide and Cultivar × Fungicide Interaction on target spot-incited defoliation.

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) unless otherwise indicated.

Defoliation attributed to areolate mildew was influenced by a Year x Cultivar x Fungicide Program and Cultivar x PGR x Fungicide Program interaction (Table 1). Areolate mildew-incited defoliation was noted in 2017 and 2019 with similar defoliation ratings reported for both the PhytoGen and Deltapine selections in each of those study years (Table 2). When compared with the no fungicide control, significant reductions in areolate mildew-incited defoliation were recorded in both of the above study years with the one and two application Priaxor programs. In addition, the one and two Priaxor application programs gave equally effective control of this disease except on Deltapine 1646 B2XF in 2019 when defoliation was lower for the two than the one Priaxor application program.

Table 2. Areolate mildew-incited defoliation as influenced by a year, cultivar, and fungicide interaction.

	Areolate Mildew (% defoliation [z])					
	PhytoGen [y]			Deltapine [y]		
Fungicide	2017	2018	2019	2017	2018	2019
No Fungicide Control	4.8 b[x]	0.0 e	18.9 ab	14.4 b	0.0 e	74.5 a
Priaxor single application	0.3 de	0.0 e	0.5 cd	0.8 de	0.0 e	1.8 c
Priaxor two applications	0.0 e	0.0 e	0.2 de	0.0 e	0.0 e	0.0 e

[z] Areolate mildew intensity was rated on a 1 to 10 leaf spot scoring system and converted to % defoliation values.
[y] PhytoGen 499WRF, which was grown in 2017, was replaced with PhytoGen 490W3FE in 2018 and 2019. Deltapine 1646B2XF was sown in all three-study years.
[x] Means followed by the same letter are not significantly different according to Fisher's protected least significant difference (LSD) test (P<0.05).
[w] Priaxor applications were scheduled at 3rd week of bloom for the single application program and 3rd and 5th week of bloom for the two-application program.

Across all study years, PGR status did not significantly affect areolate mildew-incited defoliation on the no fungicide control on PhytoGen and Deltapine entries (Table 2). Again, significant reductions in the level of areolate mildew-incited defoliation were obtained with one and two application Priaxor programs compared with the no fungicide controls regardless of cotton entry or PGR inputs. With the exception of the standard PGR program for Deltapine 1646B2XF, similar defoliation levels were recorded for the one and two application Priaxor programs.

Table 3. Areolate mildew-incited defoliation as influenced by a cultivar, PGR, and fungicide program interaction.

Fungicide	Areolate Mildew (% defoliation [z])			
	PhytoGen [y]		Deltapine [y]	
	Standard [x]	Aggressive	Standard	Aggressive
No Fungicide Control	9.1 a [w]	6.8 a	35.0 a	24.4 a
Priaxor single application [u]	0.5 c	0.2 c	0.6 b	1.0 c
Priaxor two applications	0.0 c	0.0 c	0.0 c	0.2 c

[z] Areolate mildew intensity was rated using a leaf spot scoring system (1 to 10 scale) and converted to % defoliation.
[y] PhytoGen 499WRF, which was grown in 2017, was replaced with PhytoGen 490W3FE in 2018 and 2019. Deltapine 1646B2XF was sown in all three-study years.
[x] The standard plant growth regulator (PGR) program consisted of applications of 8 and 16 fl oz/A Pix on at pin head square and 3rd week of bloom, respectively, while the aggressive PGR program included applications of 16 fl oz/A, 16 fl oz/A, and 24 fl oz/A Pix at pin head square, 3rd, and 5th week of bloom, respectively.
[w] Means followed by the same letter are not significantly different according to Fisher's protected least significant difference (LSD) test (P<0.05).
[u] Priaxor applications were scheduled at 3rd week of bloom for the single application program and 3rd and 5th week of bloom for the two-application program.

As indicated by a significant Year x Cultivar interaction, gin out differed by year and cotton cultivar (Table 1). In each year, gin out was greater for Deltapine 1646B2XF than either PhytoGen entry (Figure 2A). Gin out declined each succeeding study year for Deltapine 1646B2XF. While the PhytoGen entries had similar gin out in 2017 and 2018, values for PhytoGen 490W3FE sharply declined in 2019. Across all years, cultivars and PGR programs, similar gin out values were noted for all fungicide programs, including the no fungicide control (Figure 2B). For all cultivars, greater lint recovery was obtained with the standard than the aggressive PGR program (Figure 2C).

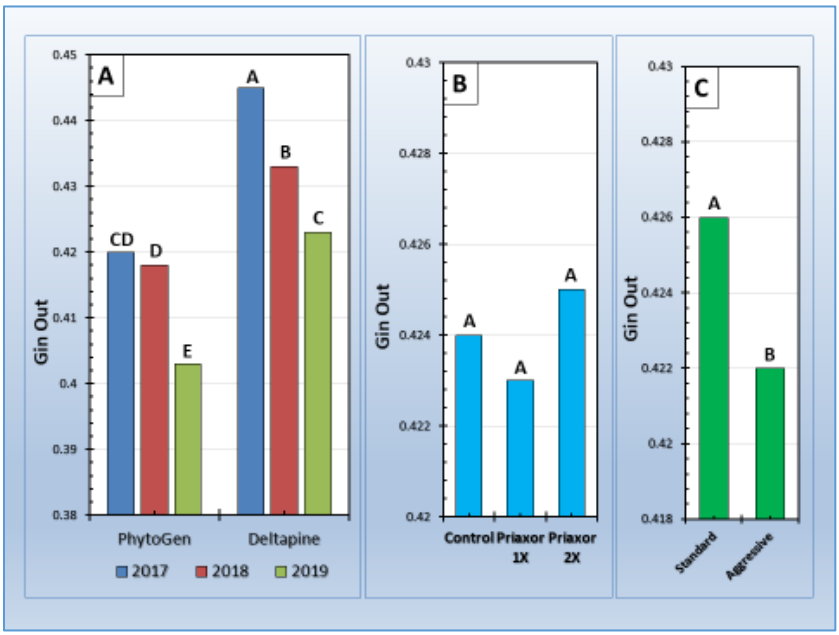

Figure 2. Interaction of year and cultivar, along with fungicide program and PDR program on gin out values.

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).

In each study year, greater lint yield was obtained for Deltapine 1646B2XF than either PhytoGen entries (Table 4). For all entries, greater lint yields were noted in 2019 than in previous years. When compared with the no fungicide

control, significant yield gains were recorded with two but not one Priaxor application for the PhytoGen 490W3FE in 2018 and for Deltapine 1646B2XF in 2019 following damaging outbreaks of target spot and areolate mildew, respectively. When low defoliation levels associated with either areolate mildew or target spot were observed, similar yields were recorded for the no fungicide control along with the one and two Priaxor application programs.

Table 4. Lint yield as influenced by year, cultivar, and fungicide program.

	Lint Yield (lb./A)					
	PhytoGen [z]			Deltapine [z]		
Fungicide	2017	2018	2019	2017	2018	2019
No Fungicide Control	1108 i [y]	859 j	1278 g	1477 de	1338 fg	1649 bc
Priaxor single application	1110 i	963 j	1298 g	1560 cd	1432 ef	1700 b
Priaxor two applications	1158 hi	1090 i	1264 gh	1533 de	1341 fg	1826 a

[z] PhytoGen 499WRF, which was grown in 2017, was replaced with PhytoGen 490W3FE in 2018 and 2019. Deltapine 1646B2XF was sown in all three-study years.
[y] Means followed by the same letter are not significantly different according to Fisher's protected least significant difference (LSD) test (P<0.05).

Loan value differed significantly by study year and cotton entry as well as PGR and fungicide program (Table 1).

Except for 2017 when greater valuation was obtained for the Deltapine than PhytoGen entry, loan values for in 2018 and 2019 were similar (Figure 3A). Loan value for the aggressive PGR program was not impacted by fungicide program but was greater for the standard PGR program with two Priaxor applications than the no fungicide control.

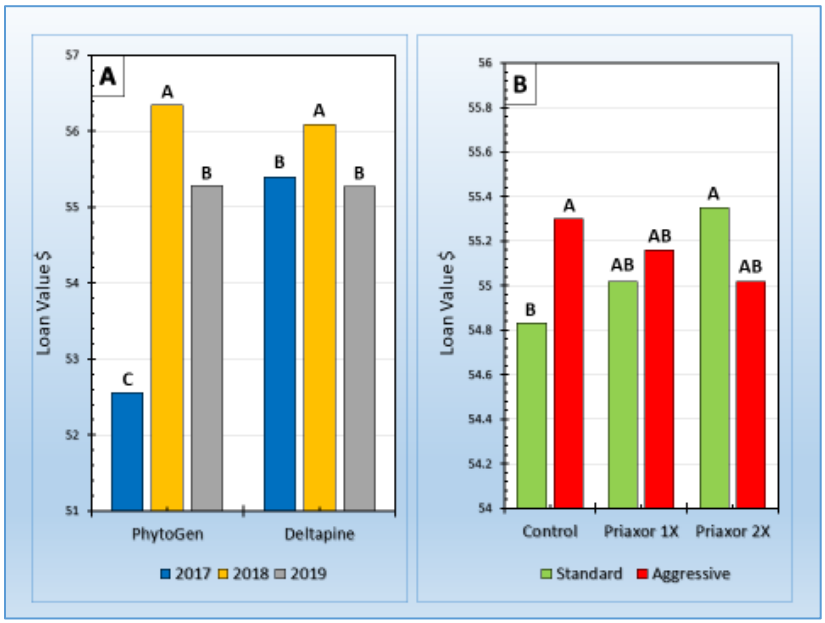

Figure 3. Loan value as influenced by a Year x Cultivar and PGR x Fungicide Program interaction.

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) or as otherwise indicated.

Summary

Cultivar selection is an effective tool for avoiding damaging outbreaks of target spot and areolate mildew in cotton (Hagan 2014, Hagan et al 2018). As has been previously reported (Bowen et al 2019), Deltapine 1646B2XF demonstrated superior resistance to target spot than either PhytoGen 499WRF or PhytoGen 490W3FE with the latter entry suffering a significant disease-related yield decline in 2018. While Deltapine 1646B2XF is highly susceptible to areolate mildew, defoliation ratings for the latter entry along with both PhytoGen entries did not significantly differ (Hagan et al 2019). Previously, PhytoGen 490W3FE showed superior resistance in Alabama to areolate mildew compared with other Deltapine, PhytoGen, and Stoneville entries (Hagan et al 2019). A significant yield decline associated with extensive areolate mildew-related defoliation (+75%) with Deltapine 1646B2XF occurred here in 2019 but not in 2017 when defoliation levels were numerically lower.

Employing an aggressive PGR program to sculpt the cotton canopy with the objective of suppressing target spot failed. Across all study years and cotton cultivars, target spot incited defoliation for the standard and aggressive fungicide programs was similar. In addition, PGR inputs also had limited affect areolate mildew-incited defoliation and none on lint yield. The aggressive PGR program also reduced gin out compared with the standard PGR program and did not affect lint loan value. So, no yield or quality advantage was obtained by increasing the rate of PGR inputs.

Previously, Mehl et al (2017) reported that fungicides delayed target spot development and reduced defoliation levels with yield preservation from fungicide inputs occurring with greater than 40% defoliation. In addition, application number had little impact on disease control or yield protection. In contrast, Bowen et al (2018) noted that two or three applications of the fungicide Priaxor increased the yield of target spot-damaged cotton compared with the no fungicide control. Here, two but no one application of Priaxor significantly reduced defoliation levels on both the target spot-susceptible and resistant cotton entries. Only when defoliation levels exceeded 40% on the susceptible PhytoGen entry in 2018 were there significant yield gains with two Priaxor applications.

With areolate mildew, the one and two application programs with Priaxor provided near equal disease control on both cotton entries in 2017 and 2019. Yield response to fungicide inputs differed with defoliation levels. In 2017 with light defoliation on both cotton entries, no yield gains were obtained with either the one or two Priaxor application programs compared with the no fungicide control. With approximately 19 and 75% defoliation on PhytoGen 490 W3FE and Deltapine 1646 B2XF no fungicide controls, respectively, in 2019, a significant yield gain was obtained on the latter but not the former cotton cultivar with the two but not the one Priaxor application program.

The onset and defoliation attributed to areolate mildew and target spot is highly variable with cultivar selection, canopy architecture and closure rate, along with weather patterns all influencing the development of both diseases (Bowen et al 2019). Hagan (2014) and Hagan et al (2018) have previously noted that disease resistant is an effective tool for greatly reducing the risk if damaging target spot and areolate mildew in cotton. Recent field trials illustrate that numerous commercial cotton cultivars are available with to resistance along with desirable yield and quality characteristics to one and in many cases both of the above diseases (Bowen et al 2019; Hagan et al 2019). Fungicides are a viable option for protecting cotton yields, particularly in locations where pressure from one or both diseases is sufficient to cause loss. In contrast to the one application recommendation by Mehl et al 2019, two applications of Priaxor gave significant yield protection under damaging areolate mildew and target spot pressure. As has been previously observed (Woodward et al 2016), no yield protection was noted where disease activity was low. To enhance fungicide use efficiency and avoid unnecessary expenses, accurate forecasting models for areolate mildew and target spot need to be developed.

Acknowledgements

Funding for this project was provided by the Alabama Agricultural Experiment Station and the Alabama Cotton Commission, and a cooperative research agreement with Cotton Incorporated.

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