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PLANT PATHOLOGY & NEMATOLOGY

Plant Growth Regulator and Fungicide Inputs Influence Diseases, along with Plant Growth and Yield Parameters for Selected Cotton Cultivars in Alabama

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ABSTRACT

The impact of cotton cultivar, plant growth regulator (PGR), and fungicide programs on the diseases target spot, areolate mildew, and hardlock, along with plant growth and yield variables, were assessed in 2017, 2018, and 2019. Deltapine 1646 B2XF [DP1646] was planted in all years; PhytoGen 490 W3FE replaced PhytoGen 499 WRF in 2018. Standard and aggressive PGR programs included two and three mepiquat chloride applications, respectively. Fungicide programs included a no-fungicide control, along with one or two applications of 147 g ai ha^{-1} fluxapyroxad + pyraclostrobin. Compared with the PhytoGen cultivars, DP1646 suffered less target spot-incited defoliation for the no-fungicide control and one- but not two-fungicide-application programs. Target spot defoliation was greatest in 2018 with no-fungicide control and the two-fungicide-application program having the greatest and lowest defoliation, respectively. In 2019, areolate mildew defoliation was greater for no-fungicide control than one- or two-fungicide-application programs. Hardlock incidence differed by year and cultivar but not PGR or fungicide program. PGR program impacted areolate mildew-incited defoliation, plant height, and lint content but not target spot-incited defoliation, hardlock incidence, open boll counts, yield, and loan value. Fungicide-related yield gains were noted for target spot-damaged PHY490 in 2018 and areolate mildew-damaged DP1646 in 2019. DP1646 had greater yield than either PhytoGen cultivar. Loan values, which differed only in 2017, were not impacted by PGR or fungicide program. Overall, cultivar and fungicide, but not PGR program significantly influenced disease-incited defoliation, growth parameters, yield, and loan value.

Target spot, which is caused by the fungus *Corynespora cassiicola* (Berk. & M.A. Curtis) C.T. Wei, can cause significant yield loss on selected cotton (*Gossypium hirsutum* L.) cultivars (Bowen et al., 2018; Hagan et al., 2018). Mehl et al. (2020) noted a significant negative correlation between target spot-incited defoliation and yield. Target spot is characterized by the appearance of circular brown lesions with a concentric ring pattern that begins on the leaves in the lower and mid-canopy around at the third week of bloom and is followed quickly by chlorosis of symptomatic leaves and premature defoliation extending from the lower canopy towards the shoot terminals at cut-out (Conner et al., 2013; Fulmer et al., 2012). This disease has been reported in nearly all U.S. cotton-producing states east of the Rocky Mountains (Butler et al., 2016; Conner et al., 2013; Donahue, 2012; Edmisten, 2012; Fulmer et al., 2012; Price et al., 2015). Excessive defoliation and associated yield losses of up to 70% occur primarily in the southern half of Alabama and Georgia, as well as in the Florida Panhandle with the risk of damaging disease outbreaks declining with increasing distance from the Gulf of Mexico (Fulmer et al., 2012; Hagan, 2014). Galbieri et al. (2014), Wei et al. (2014), and Salunkhe et al. (2019) subsequently reported target spot outbreaks in cotton in Brazil, China, and India, respectively. Factors contributing to target spot development in cotton include rapid early and mid-season growth coupled with early canopy closure, a dense leaf canopy, and frequent showers (Hagan, 2014). Regardless of cultivar, rainfall, or irrigation patterns, the absence of a closed canopy at or shortly after first bloom minimizes disease (Hagan, personal observation).

Due to declining profit margins attributed to increasing production costs and stagnant prices, resistance is the most efficient and cost-effective method of managing diseases of field crops as compared to

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fungicides (Stevenson et al., 2007). Previously, significant differences in target spot-incited defoliation were noted among cotton cultivars (Hagan et al., 2018), indicating susceptibility differences among cultivars. The past commercial standard, Deltapine 1646 B2XF (USDA-AMB 2022), often had significantly less target spot-incited defoliation along with superior yield potential compared with many other commercial cultivars in the Coastal and mid-South (Bowen et al., 2018; Hagan et al., 2020).

Whereas less susceptible cultivars, such as Deltapine 1646 B2XF, dominate the Alabama cottonseed market (USDA-AMS, 2022), fungicides are a useful tool for limiting premature defoliation and disease-incited yield loss in intensively managed target spot-susceptible cultivars (Hagan, 2014). Yield protection provided by registered fungicides in Alabama ranged up to 280 kg ha^{-1} (Hagan et al., 2014, 2018). Despite significant reductions in premature defoliation in multiple locations across the South, Mehl et al. (2020) reported inconsistent yield gains from pyraclostrobin, azoxystrobin, and fluxapyroxad + pyraclostrobin on PhytoGen 499 WRF and Deltapine 1137 B2RF. Subsequently, pydiflumetofen + difenoconazole alone or in combination with azoxystrobin as well as mefentrifluconazole + fluxapyroxad + pyraclostrobin significantly reduced premature defoliation and gave superior yield protection on the target spot-susceptible cultivar Stoneville 6182GLT (Hagan et al., 2020). As noted above, location with respect to the Gulf of Mexico along with rainfall distribution, cultivar selection, and production practices greatly influence disease development and subsequent fungicide performance.

Areolate mildew (syn. gray mold; Ramularia leaf spot), caused by the fungal pathogens *Ramulariopsis gossypii* (Speg.) U. Braun (syn. *Ramularia gossypii* [Speg.] Cif.; *Mycospharella areola* Ehlrich & F.A. Wolf) and *Ramulariopsis pseudoglycines* U. Braun (syn. *Ramularia areola* Atk.) (Videira et al., 2016), was first described on cotton in Alabama in the late 19th century (Atkinson, 1890) and occurs sporadically in U.S. cotton with outbreaks largely confined to the southern half of Alabama and Georgia and the Florida Panhandle. Recently, *R. pseudoglycines* was recognized as the causal fungus of this disease in Mississippi (Conner et al., 2023) and Georgia (Hill et al., 2025), and *R. gossypii* was identified as the causal fungus at multiple locations in Alabama (Baryah et al., 2025). Diagnostic symptoms of areolate mildew include small, angular, light-green-to-yellow lesions with white powdery conidial masses on upper surfaces of leaves in the lower and mid-canopy, followed by leaf chlorosis, necrosis, and defoliation (Silva et al., 2019). Areolate mildew typically appears in maturing cotton causing little damage; however, August outbreaks in early to mid-May plantings cause substantial premature defoliation and sizable yield loss (Hagan, personal observation). Given favorable weather patterns, late-planted cotton is particularly vulnerable to damaging disease outbreaks. Protective fungicides, all of which are also registered for target spot control (Smith et al. 2025), might be needed to avoid significant yield loss (Hagan et al., 2019b).

Damaging areolate mildew outbreaks routinely occur in the Cerrado region of Brazil (Silva et al., 2019) as well as in southern India (Chattannavar et al., 2006) with elevated disease recorded in humid compared with arid areas (Ramanagouda and Ashtaputre, 2019). Estimated areolate mildew-incited yield losses in Brazil were reported at 19 and 38% for partially resistant and susceptible cultivars, respectively, along with reductions in lint quality (Gilio et al., 2017; Tormen and Blum, 2019). In addition, a combination of multiple fungicide applications along with partially resistant cultivars when available are required to minimize the risk of substantial yield loss (Lamas and Chitarra, 2014; Silva et al., 2019). Superior areolate mildew control is provided by triazoles compared with strobilurins when applied alone, and the combination of pyraclostrobin + fluxapyroxad proved particularly efficacious (Tormen and Blum, 2019). Depending on cultivar and weather patterns, six to eight fungicide applications could be needed to protect Brazilian cotton from areolate mildew (Silva et al., 2019). Chattannaar et al. (2006) noted significantly reduced disease indices and yield protection with the fungicides ziram, carbendazim, and tridemorph compared with no-fungicide control, with none of the former fungicides currently marketed in the U.S.

Fungicide resistance in the causal fungi of areolate mildew is a serious issue in Brazilian, but not in U.S. cotton due to limited disease distribution and severity resulting from minimal foliar fungicide inputs (Silva et al., 2019). Commercial cultivars dominating in the southeastern U.S. differ greatly in their susceptibility to areolate mildew with Deltapine 1646 B2XF being among the most susceptible, whereas many others display partial disease resistance (Hagan et al., 2019a; Strayer-Scherer et al., 2023). In Brazil, the differential response of cotton genotypes to areolate mildew has been attributed in part to the genetic variability in *R. pseudoglycines* (Cia et al., 2013).

Boll rot and hardlock are often widespread but overlooked yield-limiting diseases in cotton, particularly across the coastal South and Florida Panhandle (Mailhot et al., 2008; Marois et al., 2007). Possible losses to both these enigmatic but destructive diseases (referred to as hardlock for the remainder of the paper) approached 70% of anticipated yield (Srivastava et al., 2010; Wright et al., 2004). A number of fungi (Batson, 2001; Palmateer et al., 2004) along with the bacterium *Xanthomonas malvacearum* (E. F. Sm.) Dows. (Thaxton and El-Zik, 2001) are frequently isolated from symptomatic bolls. *Fusarium verticillioidies* (Saccardo) Nirenberg (syn. *Fusarium moniliforme*) is associated with hardlock in Florida (Mailhot et al., 2007; Srivastava et al., 2010), with multiple *Fusarium* spp., including *F. verticillioides*, also being isolated from decayed bolls in Georgia (Sparnicht and Roncadori, 1972). On symptomatic bolls, lint fibers in damaged locules remain compacted at maturity rather than fluffing sufficiently for mechanical harvesting; affected lint also can display an orange-pink discoloration (Srivastava et al., 2010; Wright et al., 2004). Often, diseased bolls, which shrivel, turn black, and sometimes covered with the pink-to-orange conidial masses of the causal fungi, are found in the lower and mid-canopy (Batson, 2001). Wounding of the flowers by flower thrips (*Frankliniella* spp.) (Mailhot et al., 2007) and the boll exocarp by the brown stink bug (*Euschistus servus* Say) (Willrich et al., 2004) and tarnished plant bug (*Lygus lineolaris* [Palisot de Beauvois]) (Dorman et al., 2021) in conjunction with high rainfall or extended periods of free moisture in the leaf canopy increased the occurrence of hardlock and associated yield loss (Batson, 2001; Ranney et al., 1971). In Florida, disease outbreaks are associated with rain events at boll cracking, coupled with a dense leaf canopy over-lapping the row middles and intensive management practices such as high plant populations and excess nitrogen fertility (Marois et al., 2007; Wright et al., 2004). In contrast, minimal hardlock develops under drier weather patterns or in arid climates, even in irrigated cotton (Snow et al., 1981; Wright et al., 2004). Sizable reductions in hardlock indices, reported for early June- compared to mid-April- to early May-planted cotton, are linked with drier late-summer weather patterns, which would likely suppress disease but could also reduce yield in rainfed cotton (Lawrence, 2007). Impact of fungicide inputs on hardlock development and subsequent yield protection are mixed. Marois and Wright (2004), but not Croft et al. (2006), obtained significant reductions in hardlock incidence and yield gains with multiple mid-summer applications of thiophanate methyl. In addition, reduced hardlock incidence was obtained with selected ergosterol biosynthesis inhibitor and carboxamide fungicides in 2020 (Hagan et al., 2020) but not in 2019 (Hagan et al., 2019b). Variations in hardlock incidence between cultivars such as those described by Strayer-Scherer et al. (2023) are attributed by Padgett et al. (2003) to differences in maturity group and canopy architecture.

Plant growth regulators (PGRs), primarily mepiquat chloride, are universally applied to cotton in the southeastern U.S. to manage canopy architecture by suppressing stem elongation, reducing node numbers, increasing fruit retention, accelerating maturity, and improving harvest efficiency, which then can enhance lint yield and fiber quality (Hand et al., 2023; Reddy et al., 1996; Zhao and Oosterhuis, 2000). Application rates and numbers for optimum mepiquat chloride efficacy vary by year, location, weather, moisture status, nitrogen fertility, and cultivar and are particularly useful for slowing aggressive vegetative growth (Chalise et al., 2022; Hand et al., 2023; Iqbal et al., 2004). Hand et al. (2023) noted that excessive irrigation-induced growth could be managed with an aggressive PGR program employing three- rather than the typical two-application program. Snow et al. (1981) reported a numerical reduction of hardlock along with significant yield gains with a single application of mepiquat chloride. Prior to this study, the impact of mepiquat chloride application rate and timing on the development of foliar diseases in cotton by manipulating plant growth and rate of canopy closure, which can influence the development of areolate mildew and target spot, has not been investigated. Here, the influence of typical and aggressive PGR programs along with fungicide inputs on the severity of target spot, areolate mildew and hardlock, along with plant height, boll set, mainstem node counts, gin out, lint yield, and loan value were assessed over a three-year period on intensively managed cotton cultivars with supplemental irrigation.

MATERIALS AND METHODS

Studies were conducted in 2017, 2018, and 2019 with cotton cropped the following year after cotton, corn, and peanut, respectively, at the Brewton Agricultural Research Unit in Brewton, AL (31.142, -87.050). The experimental design consisted of a factorial set of treatments arranged in a split-split-split plot with year as the main plot, cotton cultivar as the split, PGR program as the split-split plot, and fungicide program as the split-split-split plot treatment. Individual subplots consisted of four 7.6-m rows spaced 0.9 m apart arranged in four replications. 'Deltapine 1646 B2XF' [DP1646] (Bayer CropScience, St. Louis, MO) was produced in all years; however, 'PhytoGen 499 WRF' [PHY499] (Corteva Agriscience, Indianapolis, IN), sown in 2017, was replaced with 'PhytoGen 490 W3FE' [PHY490] (Corteva Agriscience, Indianapolis, IN) in 2018 and 2019. All cultivars have similar days to maturity but are no longer distributed in the U.S.

Cotton was hill dropped at a rate of 9.8 seed m^{-1} 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 for cotton were followed (Smith et al., 2025). Plots were irrigated as needed with a lateral irrigation system. Broadcast applications of fungicide and PGR treatments were made with a high-clearance sprayer with TX-12 nozzles on 0.48-m spacing at 187 l ha^{-1} of spray volume at 69 pKa. The standard PGR program consisted of an application of 24.5 g ai ha^{-1} and 49.0 g ai ha^{-1} mepiquat chloride (MepStar®, Albaugh, LLC, Ankeny, IA) at pinhead square and the third week of bloom on 5 and 27 July 2017, 10 and 19 July 2018, and 10 and 30 July 2019, respectively. The intensive PGR program included applications of 49.0, 49.0, and 73.6 g ai ha^{-1} mepiquat chloride at pinhead square and the third and sixth week of bloom, on 5 July, 27 July, and 15 Aug. 2017; 10 July, 19 July, and 7 Aug. 2018; and 10 July, 30 July, and 19 Aug. 2019, respectively. Fungicide programs consisted of 1) a no-fungicide control, 2) one application of 147 g ai ha^{-1} fluxapyroxad + pyraclostrobin (Priaxor® Xemium® brand fungicide 4.17F, BASF Corporation, Research Triangle, NC) at the third week of bloom on 27 July 2017 and 2018, and 13 Aug. 2019, and 3) an application of 147 g ai ha^{-1} fluxapyroxad + pyraclostrobin at the third and fifth week of bloom on 27 July and 15 August 2017, 27 July and 16 Aug. 2018, and 13 and 27 Aug. 2019, respectively.

Target spot and areolate mildew intensity were separately 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 Sept. 2017, 17 Sept. 2018, and 27 Sept. 2019 with an additional assessment on 4 Oct 2019. Defoliation values were calculated using the formula from Li et al. (2012):

$$\%\, Defoliation = \frac{100}{1 + e^{-\frac{Leaf\ Spot\ Scoring\ System - 6.0672}{0.7975}}}$$

Prior to harvest, counts of open, rotted, and hardlock bolls were made in 0.9 m of a border row. Data for the rotted and hardlocked bolls were pooled and reported as counts of hardlocked bolls. Concurrently, final plant heights were recorded on five plants per plot in 2018 and 2019. Cotton was mechanically harvested on 17 Oct. 2017, 15 Oct. 2018, and 24 Oct. 2019, and 0.5-kg ginned fiber samples from each plot in all years were submitted to the USDA classing office in Memphis, TN for High Volume Instrument testing to determine micronaire, length, fiber length uniformity, strength, b+, trash content, color, and leaf grades. Loan values were calculated using the Cotton Incorporated Loan Value Calculator (https://www.cottoninc.com/cotton-production/ag-resources/cotton-farming-decision-aids/2023-upland-loan-calculator/ [verified 28 Feb. 2026]). Significance of treatment interactions were determined using PROC GLIMMIX in SAS 9.4. Statistical analyses were done on rank transformations for non-normal data for target spot- and areolate mildew-incited defoliation along with open and hardlocked bolls. Means were separated using Fisher's protected least significant difference test ($p < 0.05$). Actual variable means are presented.

In 2017, 2018, and 2019, total production season rainfall was 1647, 1036, and 649 mm. The study area was not irrigated due to abundant season-long rainfall in 2017. One and five irrigation events in 2018 and 2019 totaled 15 mm and 60 mm, respectively. Also, an extended period without rainfall or supplemental irrigation occurred in 2018 between cut-out and harvest.

RESULTS

A significant year × fungicide program ($p = 0.0151$) and cultivar × fungicide program ($p = 0.0120$) demonstrated that defoliation attributed to target spot as influenced by fungicide program differed significantly by year and cultivar (Table 1). Target spot-incited defoliation was not impacted by PGR program ($p = 0.8798$) (data not shown). Averaged over cultivars and PGR treatments, defoliation levels due to target spot were greater in 2018 compared with the other years, regardless of fungicide program; and the lowest defoliation was recorded for two of three fungicide programs in 2019 (Figs. 1A, 2A), which had substantially lower rainfall totals than in the previous two years. In 2017, similarly low target spot-incited defoliation was recorded for both fungicide programs compared to the no-fungicide control. The two-application program reduced target spot-incited defoliation in each year compared with the no-fungicide control, whereas the one-application program reduced defoliation only in 2017 (Fig. 1A). Although target spot-incited defoliation was significantly lower in 2019, two fungicide applications were required to reduce disease-incited defoliation below similarly greater levels recorded for the one-application program and the no-fungicide control.

Averaged over years and PGR treatments, target spot-incited defoliation also differed significantly by cultivar and fungicide program (Fig. 1B). For the no-fungicide control and one- but not the two-fungicide-application programs, target spot-incited defoliation was lower for DP1646 than the PhytoGen cultivars, and with the latter cultivars, the one-application program failed to significantly reduce target spot defoliation when compared with the no-fungicide control. In addition, the two-application program on the PhytoGen cultivars along with both programs for DP1646 had similarly low target spot defoliation levels.

Defoliation attributed to areolate mildew was influenced by a year × cultivar × fungicide program ($p < 0.0001$) and cultivar × PGR × fungicide program ($p = 0.0033$) interaction (Table 1). Areolate mildew-incited defoliation was noted in 2017 and 2019 with similar defoliation ratings reported for both PhytoGen cultivars and DP1646 in no-fungicide controls in each of those study years (Table 2). When compared with the no-fungicide control, significant reductions in areolate mildew-incited defoliation

Table 1. *F* values for general linear model for target spot, areolate mildew, and hardlock along with total open bolls, plant height, gin turnout, lint yield, and loan value

Source of Variation	Target Spot	Areolate Mildew	Hardlock Bolls	Open Bolls	Plant Height	Gin Turnout	Lint Yield	Loan Value
Year (Y)	**8.24** [z]**	**264.71*** **	**85.95*** **	**19.07*** **	**81.33*** **	**57.67*** **	**25.65** **	**41.23*** **
Cultivar (C)	**29.55*** **	**153.78*** **	**40.47*** **	**26.88*** **	**21.04*** **	**218.39*** **	**499.58*** **	**49.77*** **
Y x C	**2.23**	**96.16*** **	**0.55**	**2.70**	**0.05**	**4.12* **	**1.30**	**70.88*** **
Growth Regulator (PGR)	**0.02**	**12.70*** **	**0.28**	**1.56**	**21.04*** **	**8.74** **	**0.55**	**0.55**
Y x PGR	**0.26**	**3.30* **	**0.21**	**2.60**	**0.95**	**0.82**	**1.03**	**0.43**
C x PGR	**0.03**	**4.73* **	**0.09**	**0.01**	**0.16**	**1.76**	**0.84**	**1.20**
Y x C x PGR	**0.46**	**2.17**	**0.47**	**0.58**	**1.29**	**0.82**	**0.41**	**0.94**
Fungicide (F)	**15.79*** **	**425.88*** **	**1.12**	**0.14**	**0.24**	**0.32**	**7.43*** **	**0.55**
Y x F	**3.26* **	**247.38*** **	**0.33**	**0.14**	**0.50**	**1.02**	**0.90**	**0.27**
C x F	**4.46* **	**144.87*** **	**0.33**	**1.39**	**3.38**	**0.95**	**0.66**	**1.11**
Y x C x F	**1.55**	**90.35*** **	**0.36**	**3.58** **	**1.86**	**0.34**	**4.86** **	**0.57**
PGR x F	**0.11**	**13.20*** **	**0.69**	**0.52**	**2.04**	**1.32**	**0.46**	**2.72**
Y x PGR x F	**0.37**	**3.34* **	**1.18**	**0.12**	**1.17**	**0.18**	**0.44**	**1.43**
C x PGR x F	**0.51**	**6.03** **	**0.40**	**2.24**	**0.08**	**0.95**	**1.32**	**1.23**
Y x C x PGR x F	**0.29**	**1.87**	**0.52**	**1.07**	**0.33**	**0.99**	**0.95**	**1.49**

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

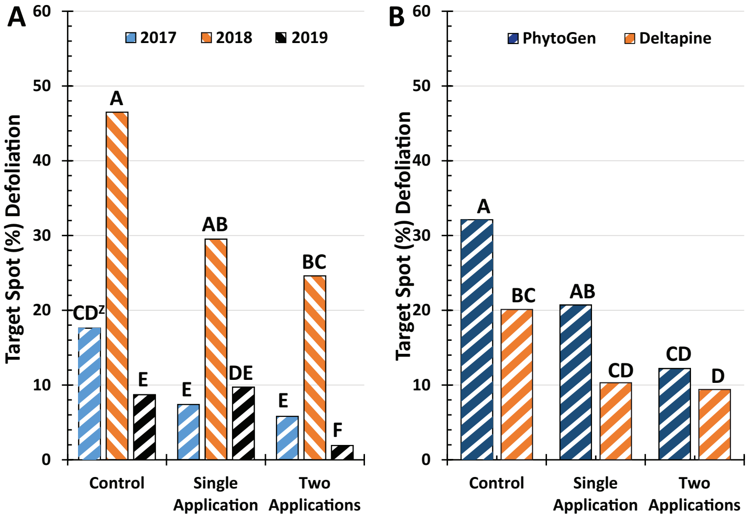

Fig. 1. Target spot-incited defoliation as influenced by an interaction of A) year × fungicide and B) cultivar × fungicide. In each figure, bars labeled with the same letter are not significantly different according to Fisher's protected least significant difference test ($p < 0.05$).

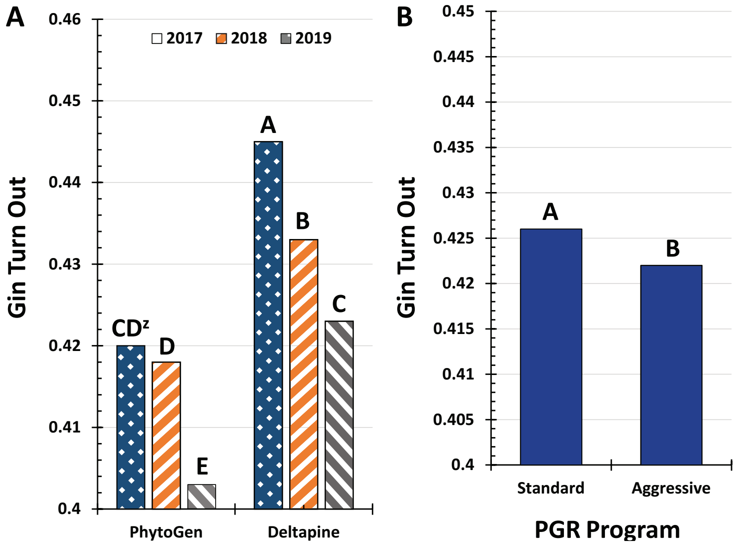

Figure 2. Gin turnout (% lint content) as influenced by an interaction of A) year × cultivar and B) PGR program. In each figure, bars labeled with the same letter are not significantly different according to Fisher's protected least significant difference test ($p < 0.05$). The standard PGR program consisted of applications of 24.5 g ai ha^{-1} and 49.0 g ai ha^{-1} mepiquat chloride at pin head square and 3rd week of bloom, respectively; the aggressive PGR program included applications of 49.0, 49.0, and 73.6 g ai ha^{-1} mepiquat chloride at pin head square, 3rd, and 5th week of bloom, respectively.

were obtained in the above years with the one- and two-application programs. In addition, both above fungicide programs gave equally effective disease control except on DP1646 in 2019 when defoliation levels were lower for the two- than the one-application program.

Throughout all study years, PGR inputs did not significantly affect areolate mildew-incited defoliation for the no-fungicide control (Table 3). Significant reductions in the level of areolate mildew-incited defoliation occurred with one- and two-application fungicide programs compared with the no-fungicide control regardless of cultivar or PGR program. On DP1646, greater areolate mildew-incited defoliation was noted with the standard than the aggressive PGR treatment, whereas similar defoliation levels were recorded for the one- and two-fungicide-application programs for both PGR programs on the PhytoGen cultivars.

Table 2. Areolate mildew-incited defoliation (%), counts of open bolls, and lint yield as influenced an interaction of year, cultivar, and fungicide program

			Cotton Cultivars			
		PhytoGen[z]			Deltapine[z]	
Fungicide program	**2017**	**2018**	**2019**	**2017**	**2018**	**2019**
			Areolate Mildew Defoliation[y]			
			(%)			
No-fungicide control	4.8 b[x]	0.0 e	18.9 ab	14.4 b	0.0 e	74.5 a
Single application[w]	0.3 de	0.0 e	0.5 cd	0.8 de	0.0 e	1.8 c
Two applications	0.0 e	0.0 e	0.2 de	0.0 e	0.0 e	0.0 e
			Open Boll Counts			
			(No. bolls m^{-1})			
No-fungicide control	43.5 ef	25.8 h	64.0 ab	65.9 a	37.1 fg	54.4 abcd
Single applicationw	49.5 cde	27.8 h	56.2 abc	57.6 abc	31.1 gh	65.8 a
Two applications	44.8 def	26.5 h	49.3 b-e	61.9 abc	33.5 gh	67.5 a
			Lint Yield			
			(kg ha^{-1})			
No-fungicide control	1242 h	963 j	1432 g	1656 de	1681 g	1848 bc
Single application[w]	1244 h	1079 i	1455 g	1749 cd	1799 ef	1905 b
Two applications	1298 h	1222 h	1417 g	1718 d	1685 fg	2047 a

[z] PhytoGen 499 WRF, which was grown in 2017, was replaced with PhytoGen 490 W3FE in 2018 and 2019 with Deltapine 1646 B2XF sown in all years.

[y] Areolate mildew intensity was rated on a 1 to 10 leaf spot scoring system and converted to % defoliation values.

[x] Means for each variable followed by the same letter are not significantly different according to Fisher's protected least significant difference test ($p < 0.05$).

[w] Applications of 147 g ai ha-1 fluxapyroxad + pyraclostrobin were scheduled at 3rd week of bloom for the single application program and at the 3rd and 5thweek of bloom for the two-application program.

Table 3. Areolate mildew-incited defoliation (%) as influenced by a significant cultivar × PGR × fungicide programs interaction

		Areolate Mildew		
	PhytoGen[z]		Deltapine[z]	
Fungicide program	**Standard**	**Aggressive**	**Standard**	**Aggressive**
		% defoliation[y]		
No-fungicide control	9.1 a[x]	6.8 a	35.0 a	24.4 a
Single application[w]	0.5 c	0.2 c	0.6 b	1.0 c
Two applications	0.0 c	0.0 c	0.0 c	0.2 c

[z] PhytoGen 499 WRF, which was grown in 2017, was replaced with PhytoGen 490 W3FE in 2018 and 2019 with Deltapine 1646 B2XF sown in all study years.

[y] Areolate mildew intensity was rated using a leaf spot scoring system (1 to 10 scale) and converted to % defoliation values.

x Means followed by the same letter are not significantly different according to Fisher's protected least significant difference test ($p < 0.05$).

[w] The standard PGR program consisted of applications of 24.5 g a.i. ha-1 and 49.0 g a.i. ha-1 mepiquat chloride at pin head square and 3rd week of bloom, respectively; the aggressive PGR program included applications of 49.0, 49.0, and 73.6 g a.i. ha-1 mepiquat chloride at pin head square, 3rd, and 5th week of bloom, respectively.

Hardlock incidence was significantly impacted by year ($p < 0.0001$) and cultivar ($p < 0.0001$) but not PGR ($p = 0.5989$) or fungicide program ($p = 0.3296$), or any interactions (Table 1). Across cultivars, PGR, and fungicide programs, greater numbers of hardlocked bolls were recorded in 2018 than in other study years where hardlock counts were similarly low (Table 4). When averaged over study years, DP1646 had significantly lower hardlock counts than the PhytoGen cultivars. Over the study period, symptoms of bacterial blight were not observed on the foliage or bolls.

Open harvestable boll counts, as indicated by a significant year × cultivar × fungicide program interaction ($p < 0.0090$), differed across study years, cultivars, and fungicide program (Table 1) but not PGR program ($p = 0.2143$). For both PhytoGen cultivars and DP1646, the fewest open bolls across all fungicide programs were recorded in 2018 with the latter cultivar having greater boll counts in 2017 (Table 2). In addition, DP1646 had greater open boll counts for the no-fungicide control and two-application program than these same programs on PHY499 in 2017 along with the two-application program in 2019 for PHY490. In addition, greater numbers of open bolls were noted for the no-fungicide control in 2019 for PHY490 compared with PHY499 in 2017 but not for the one- and two-application programs.

Final plant height significantly differed by year ($p < 0.0001$), cultivar ($p < 0.0001$), and PGR ($p < 0.0001$) but not fungicide program ($p = 0.7856$) or any interaction (Table 1). Greater final plant height was noted in 2018 than 2019 with DP1646 being significantly taller than PHY490 (Table 4). In addition, cotton was taller when maintained with the standard compared with aggressive PGR program. Fungicide program had no impact on plant height (Table 4).

As indicated by a significant year × cultivar interaction ($p = 0.0190$), gin turnout (% lint content) differed by year and cultivar (Table 1); PGR

Table 4. Hardlock boll counts, total fruiting node counts, plant height, and loan value as influenced by year, cotton cultivar, PGR and fungicide program. Data for significant interactions are not included

Variable	Hardlock	Plant height[z]	Loan value
	No. bolls m^{-1}	cm	¢
Year			
2017	8.5 b[y]	---[x]	---
2018	25.9 a	53.9 a	---
2019	6.7 b	39.8 b	---
Cultivar			
PhytoGen 499 WFX/490 W3FE	16.7 a	43.5 b	---
Deltapine 1646 B2FX	10.7 b	48.4 a	---
PGR program[w]			
Standard	14.0 a	48.3 a	55.1 a
Aggressive	13.5 a	45.3 b	55.2 a
Fungicide program[v]			
No-fungicide control	13.0 a	47.0 a	55.1 a
Single application	14.6 a	47.0 a	55.2 a
Two applications	13.6 a	46.5 a	55.3 a

[z] Counts of node of first harvestable boll, mainstem nodes per plant and average height for 5 randomly selected plants in each plot were recorded in 2018 and 2019.

[y] Means for each variable followed by the same letter are not significantly different according to Fisher's protected least significant difference test ($p < 0.05$).

[x] --- = significant interaction between two or more variables with data presented in a table or figure.

[w] The standard PGR program consisted of applications of 24.5 g a.i. ha^{-1} and 49.0 g a.i. ha^{-1} mepiquat chloride at pin head square and 3rd week of bloom, respectively; the aggressive PGR program included applications of 49.0, 49.0, and 73.6 g a.i. ha^{-1} mepiquat chloride at pin head square, 3rd, and 5th week of bloom, respectively.

[v] Applications of 147 g a.i. ha^{-1} fluxapyroxad + pyraclostrobin were scheduled at 3rd week of bloom for the single application program and at the 3rd and 5th week of bloom for the two-application program.

program also significantly ($p = 0.0039$) affected gin turnout. In each year, gin turnout, which was greater for DP1646 than either PhytoGen cultivar (Fig. 2A), declined each succeeding study year for the former cultivar. PhytoGen entries had similar gin turnout in 2017 and 2018; however, values for PHY490 sharply declined in 2019. Across all years, cultivars, and PGR programs, similar gin turnout ($p = 0.7255$) was noted for all fungicide programs, including the no-fungicide control (data not shown). For all cultivars, gin content was greater for the standard than the aggressive PGR program (Fig. 2B).

A significant year × cultivar × fungicide interaction ($p = 0.0028$) showed that lint yield differed by year, cultivar, and fungicide program (Table 1). For all cultivars, greater lint yields were noted in 2019 than in the previous years with 2018 having the lowest and 2017 intermediate values. When compared with the no-fungicide control, significant yield protection was recorded for target spot-damaged DP1646 in 2019 with the two- but not the one-application program (Table 2). In contrast, both fungicide programs increased yield on PHY490 in 2018 with the two-application program having greater yield. When lower target spot defoliation levels were observed in 2017 compared with 2018 for both cultivars, similar yields were recorded for all fungicide programs, including the no-fungicide control. Similar yield ($p = 0.3991$) of 1588 and 1571 kg ha^{-1} was recorded for the standard and aggressive PGR programs, respectively.

Loan value differed significantly($p < 0.0001$) by year and cultivar according to a year × cotton interaction but not PGR ($p = 0.4609$) or fungicide program ($p = 0.5779$) (Table 1). Except for 2017 when greater valuation was noted for DP1646 than PHY499, loan values in 2018 and 2019 were similar for PHY490 and DP1646 (Fig. 3). Also, loan values for both cultivars were similarly greater in 2018 than 2019.

DISCUSSION

Target Spot and Areolate Mildew. Until recently, foliar diseases incited by fungi did not influence the yield or quality of U.S. cotton (Baird, 2011). Within the past two decades, areolate mildew and target spot have emerged as serious threats to cotton profitability primarily in Alabama, Florida, and Georgia. As a result, the development of cost-effective programs incorporating cultivar selection and management practices are needed to meet the challenge of minimizing the risk of significant yield and quality losses to these and other damaging diseases. This study shows the influence of cultivar, fungicide inputs, along with plant growth regulators on shaping the leaf canopy to improve air circulation thereby suppressing areolate mildew, target spot, and hardlock.

As has been observed in previous Alabama studies (Bowen et al., 2019; Hagan, 2014; Hagan et al. 2018), the level of defoliation attributed to target spot differs greatly by cultivar, location, and year. In

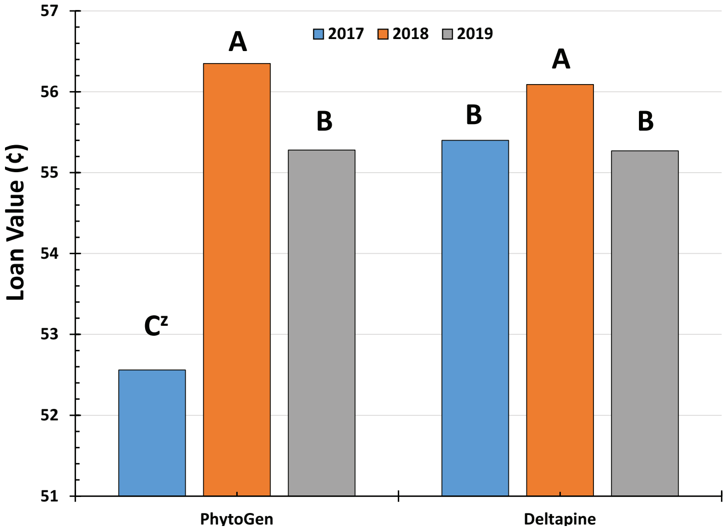

Figure 3. Loan value (¢) as influenced by a year × cultivar interaction. Bars headed by the same letter are not significantly different according to Fisher's protected least significant difference test ($p < 0.05$).

this study, disease-incited defoliation was greater in 2018 compared with 2017 and 2019. The impact of adequate to excessive seasonal rainfall on target spot development was inconsistent. Defoliation levels were greater in 2018 than 2017 despite higher rainfall totals in the earlier study year. Not surprisingly, the least target spot development was recorded, despite supplemental irrigation, in the dry summer of 2019. Areolate mildew was originally described on cotton in Central Alabama (Atkinson, 1890) but was either absent or unobtrusive in Alabama cotton over the succeeding 120 years. In 2017, areolate mildew was confirmed in cotton with extensive disease-related defoliation observed at multiple locations across South and Central Alabama in 2018 (Hagan et al., 2019a, b). In this study, the greatest areolate mildew development was observed during the dry summer of 2019 compared with the much wetter summers of 2017 and 2018.

For this study, selection of cultivars with tolerance or resistance is the preferred and least costly method for managing outbreaks of target spot or areolate mildew in cotton (Hagan, 2014; Hagan et al., 2018). Previously, DP1646 suffered significantly less target spot-incited defoliation compared with PHY490 and PHY499 (Bowen et al. 2019). Bowen et al. (2019) noted that the latter compared with former cultivar had significantly lower disease-incited yield loss. In addition, PHY499, regardless of fungicide program, previously suffered greater target spot-incited defoliation when compared with selected Deltapine, Fibermax, PhytoGen, and Stoneville cultivars (Hagan et al., 2018). Although DP1646 proved highly susceptible to areolate mildew at multiple Alabama sites in 2018 (Hagan et al., 2019a), defoliation ratings for this cultivar and the PhytoGen cultivars here did not significantly differ. Concurrently, PHY490 showed reduced areolate mildew-incited defoliation at one of two Alabama locations compared with all but one of eight Deltapine, PhytoGen, and Stoneville cultivars (Hagan et al., 2019a). Recently, Strayer-Scherer et al. (2023) noted greater areolate mildew-incited defoliation on DP1646 than on three of eight other commercial cultivars with Stoneville 5091 B3XF, PhytoGen 332 W3FE, and PhytoGen 400 W3FE having similarly lower defoliation ratings. In contrast to the U.S., breeding areolate mildew-resistant germplasm is a priority in Brazil with several resistant breeding lines and commercial cultivars having been released in the past decade (Cia et al., 2009; Silva et al., 2017, 2019). However, adoption of areolate mildew-resistant cultivars has been limited there due to superior resistance to other damaging diseases such as cotton blue disease along with greater yield and lint quality in susceptible cultivars (Silva et al., 2019).

Suppressed target spot development and reduced defoliation levels with yield preservation occurring at greater than 40% defoliation was reported with application number having little impact on disease control or yield (Mehl et al., 2020). In contrast, Bowen et al. (2019) noted that two or three applications of fluxapyroxad + pyraclostrobin increased the yield of target spot-damaged cotton compared with the no-fungicide control. Here, two but not one fungicide application significantly reduced defoliation levels on both the target spot-susceptible and resistant cotton entries. Only when defoliation levels exceeded 40% on PHY490 in 2018 were there significant yield gains with two applications of fluxapyroxad + pyraclostrobin compared with the no-fungicide control. Strayer-Scherer et al. (2023) also reported a significant reduction in areolate mildew- and target spot-incited defoliation along with yield protection across nine cultivars, including DP1646, with an intensive fungicide program.

With areolate mildew, the one- and two-application programs with fluxapyroxad + pyraclostrobin provided near equal disease control in 2017 and in 2019 on PHY490 but not DP1646 when disease pressure was high. Yield response to fungicide inputs differed with defoliation levels. In 2017, with light defoliation on both cultivars, no yield gains were obtained with either one- or two-fungicide-application programs despite significant reductions in areolate mildew compared with the no-fungicide control. With approximately 19 and 75% defoliation on PHY490 and DP1646 no-fungicide controls, respectively, in 2019, a significant yield gain was obtained on the latter but not former cultivar with the two- but not one-fungicide-application program. In Brazil, greater lint quality obtained with multiple fungicide applications (Tormen and Blum, 2019), which would be reflected here as a gain in loan value, was not observed.

Employing an aggressive compared with a standard PGR program to manipulate plant growth to suppress target spot failed. Across years and cultivars, target spot-incited defoliation for the standard and aggressive PGR programs was similar. In addition, the PGR program had limited effect on areolate mildew-incited defoliation with minor but significant differences noted between the standard and aggressive program with the single fungicide program on DP1646. Although application rates for mepiquat chloride were generally lower compared with this study, Snow et al. (1981) also reported similar hardlock levels regardless of application number and rate. Also, a denser leaf canopy resulting from shorter internodes (Reddy et al., 1996) with an aggressive PGR program can interfere with fungicide deposition on the bolls and leaves, thereby possibly compromising fungicide efficacy. Overall, PGR program had a limited impact on areolate mildew, target spot, and hardlock.

Although a significant reduction of plant height and lint content was observed with the aggressive compared with standard PGR program, loan value, which includes lint quality values when calculated, and lint yield was not impacted. Reductions in plant height but not yield gains were also reported by Chalise et al. (2022) and Hand et al. (2023) with an aggressive compared with a standard PGR program. Gwathmey and Craig (2003) also saw shorter plants with multiple reduced-rate applications, compared with a single mepiquat chloride application. As was seen here, York (1983) also did not record PGR × cultivar interactions for lint content, harvestable boll counts, and plant height. In contrast, Snow et al. (1981) reported reduced hardlock indices and higher lint yields with a single application of mepiquat chloride compared with a non-treated control, but increasing application rates or number did not result in further reductions in disease or yield gains.

In summary, cultivar selection, canopy architecture, and closure rate, along with weather patterns influence the onset and level of defoliation attributed to areolate mildew and target spot (Bowen et al., 2018; Silva et al., 2019). Hagan (2014) and Hagan et al. (2018) previously noted that disease-resistant cultivars are an effective tool for reducing the risk of damaging target spot outbreaks in cotton. Results confirm the value of resistant cultivars for managing areolate mildew as described by Cia et al. (2013) and Silva et al. (2019) in Brazil. Although recent field trials illustrate that numerous commercial cotton cultivars are available with sufficient resistance along with desirable yield and quality characteristics to one, and in many cases, to both diseases, this information is not compiled for distribution to stakeholders (Bowen et al., 2018; Hagan et al., 2019a). Fungicides are a viable option for protecting yields, particularly an intensively managed cotton at locations where elevated pressure from areolate mildew and/or target spot potentially cause economic loss. In contrast to the single fungicide application recommendation by Mehl et al. (2020), two fungicide applications consistently gave significant yield protection when compared with the no-fungicide control from areolate mildew and target spot. As has been observed (Woodward et al., 2016), no yield gains with fungicides were noted where disease activity was low. To enhance fungicide efficiency and avoid unnecessary expenses, accurate forecasting models for areolate mildew and target spot are needed as does a database detailing cultivar reaction to these diseases.

Hardlock. As reported in an Alabama study at the same location (Hagan et al., 2017a), as well as by Snow et al. (1981) in Louisiana, sizable differences in hardlock are observed between cultivars. Typically, damaging hardlock outbreaks occur every three to five years (Hagan et al., 2017a; Snow et al., 1981) with year-to-year variations in disease likely linked to the timing of rain events from flowering through boll maturation along with intensive management practices such as elevated nitrogen fertility and plant populations, which favor rapid canopy closure and dense leaf canopy, thereby creating a favorable microenvironment for rapid disease onset and development (Padgett et al., 2003; Snow et al., 1981; Wright et al., 2004). Subsequently, cooler night temperatures during flowering along with greater temperature variability but not elevated humidity were associated with increased *F. verticillioides*-incited hardlock in Florida cotton (Mailhot et al., 2008). Here, however, significant differences in hardlock incidence occurred in 2018 and 2019 despite nearly identical night temperatures (Bowen, personal communication), suggesting that other factors likely influence disease development. Western flower thrips (Mailhot et al., 2007), lygus bugs (Dorman et al., 2021), and southern green stink bugs (Willrich et al., 2004) also have been linked with increased hardlock incidence; these insect pests were controlled by employing weekly scouting reports coupled with timely insecticide applications (Smith et al., 2025).

Previously, Mailhot et al. (2008) and Hagan et al. (2017a) linked greater hardlock incidence with reduced yield. Like Padgett et al. (2003) and Marois et al. (2007), increasing hardlock incidence here was negatively correlated (R = -0.59, $p < 0.0001$) with lint yield (Bowen, personal communication). In a previous Alabama study, increasing hardlock/

boll rot indices were not correlated with the yield of selected commercial cultivars (Lawrence, 2007). Not surprisingly, a positive correlation between increasing counts of open bolls and yield was noted (R = 0.53, $p < 0.002$) (Bowen, personal communication).

Depending on canopy density and weather conditions, cotton cultivars differ in their response to hardlock. Whereas no differences in hardlock incidence were reported in Florida cultivar screening studies (Marois et al., 2007), Padgett et al. (2003) in Louisiana reported less hardlock in mid- than early maturing cultivars, with rainfall coinciding with boll cracking for the former than latter maturity group. In Alabama, cultivar response to hardlock varied significantly with greater disease indices noted in 2016 (Hagan et al., 2017b), 2018 (Hagan, personal observation), and 2022 (Strayer-Scherer et al., 2023) when a lush canopy likely coincided with favorable weather. Although all cultivars herein have similar maturity, lower hardlock was recorded here for DP1646 than for the PhytoGen cultivars. In a separate 2018 study at the same location, hardlock indices were greater for PHY490 than DP1646 with the mid-maturing cultivars Deltapine 1538 B2XF, Deltapine 1553 B2XF, Stoneville 4946 GLB2, Stoneville 5115 GLT, and late maturing Stoneville 6182 GLT, also having similarly lower disease ratings (Hagan, personal communication). Subsequently, Strayer-Scherer et al. (2023) reported that PhytoGen 480 W3FE suffered greater hardlock incidence, but not lower yield compared with DP1646 with an additional seven early and mid-maturity cultivars having similar disease indices to both former cultivars. Variations in plant architecture between cultivars can impact the microclimate within the canopy, thereby resulting in differences in hardlock incidence (Padgett et al., 2003). Also, leaf shape influences hardlock with early maturing cultivars with the okra leaf trait having lower disease indices than those with normal leaves (Soomro et al., 2000). However, similar disease ratings for commercial cultivars across maturity groups in previous Alabama trials suggest that another defense mechanism might account for differential cultivar response to hardlock. Marois et al. (2007) indicated that disease occurrence might be reduced with cultivars having a brief, heavy flowering period, which would minimize the time the blooms are vulnerable to *F. verticillioidies* infection. Clearly, additional studies are needed to identify mechanisms that account for differential cultivar response to hardlock observed in field trials and might prove useful in managing this disease in the future.

Mixed results have been obtained with fungicide inputs for hardlock control and protecting cotton yield. Here, one and two applications of fluxapyroxad + pyraclostrobin, which were scheduled at first bloom along with the third and fifth week of bloom, respectively, failed to reduce hardlock compared with the no-fungicide control. Fungicide associated yield gains on PHY490 in 2018 and DP1646 in 2019 were linked with the control of target spot and areolate mildew, respectively, and not hardlock. Similarly, Strayer-Scherer et al. (2023) saw greater yields associated with significant reductions in defoliation associated with target spot and areolate mildew but not hardlock across nine cultivars. However, Marois and Wright (2004) obtained a significant reduction in hardlock incidence and increased yield with weekly applications of thiophanate-methyl during flowering and boll opening. Mailhot et al. (2008) observed that weekly applications of thiophanate-methyl during bloom were effective under moderate-to-heavy but not low disease pressure. The failure of thiophanate-methyl and azoxystrobin to reduce hardlock or increase yield under low disease pressure was echoed by Padgett et al. (2003). Concurrently, Seebold et al. (2004) reported that two, three, or four applications of 0.22 or 0.45 kg ai ha^{-1} thiophanate-methyl made on 7 or 14 d schedules beginning at first bloom at multiple locations across the Southern region failed to reduce hardlock when compared with the no-fungicide control; however, significant yield gains were obtained with multiple applications of this fungicide. Subsequently, Croft et al. (2006) and Bonnette et al. (2006) in South Carolina along with Lawrence (2007) in Alabama confirmed the failure of thiophanate methyl, regardless of application number, to reduce hardlock incidence and in contrast to the above studies, increase yield. While applications were scheduled during flowering and early boll set here and in other field trials (Croft et al., 2006; Hagan et al., 2020; Marois and Wright, 2004; Seebold et al., 2004), erratic fungicide efficacy is not surprising given the likely poor coverage of the blooms and developing bolls in the lower to mid-canopy with over-the-top broadcast fungicide applications (Hillocks, 1992). Previously, Hagan et al. (2018) reported superior target spot control with drop compared with standard broadcast nozzles, which was likely due to enhanced coverage of the leaves in lower to mid-canopy; here, the use of drop nozzles could have enhanced fungicide coverage of the flowers and developing bolls, thereby elevating target coverage and enhancing product efficacy and reducing hardlock incidence. Regardless, no fungicides are currently registered in the U.S. for the control of hardlock in cotton, though some applications of strobilurin and carboxamide fungicides targeting areolate mildew or target spot could provide some protection.

Overall, areolate mildew, target spot, and hardlock significantly differed by year with mid- and late-summer weather patterns likely influencing the incidence of each disease. With significant disease pressure, the two-application-fungicide program consistently proved effective in reducing the defoliation attributed to areolate mildew or target spot along with protecting lint yield but had no influence on hardlock development. PGR program impacted plant height, lint content, and to a lesser extent areolate mildew but had no effect on target spot and hardlock along with boll set, lint yield, and loan value. As previously noted, additional studies are needed to identify breeding lines and ultimately facilitate the release of adapted commercial cultivars displaying resistance to areolate mildew, target spot, and possibly hardlock as this is the most cost-efficient method of managing diseases in cotton. In addition, development of predictive models using weather inputs for all the above diseases would also be useful in enhancing fungicide use efficiency on cotton.

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REFERENCES

Atkinson, G.F. 1890. A new *Ramularia* on cotton. Bot. Gaz. 15:166–168.

Baird, R.E. 2011. Other foliar diseases. pp. 23–24 In T.L. Kirkpatrick and C.S. Rothrock (eds.), Compendium of Cotton Diseases, 2nd Ed. Am. Phytopath. Soc., St. Paul, MN.

Baryah, K.K., Z. Noel, and A. Strayer-Scherer. 2025. Isolation and characterization of *Ramularia* species population in Alabama cotton. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 14-16 Jan. 2025. Natl. Cotton Counc. Am., Memphis, TN.

Batson, W.E. 2001. Boll rots. pp. 36–38 In T.L. Kirkpatrick and C.S. Rothrock (eds.), Compendium of Cotton Diseases. Am. Phytopath. Soc., St. Paul, MN.

Bonnette, W.W., J.K. Croft, and J.D. Mueller. 2006. Efficacy of nine fungicides for control of hardlock. pp. 21–22 *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 3-6 Jan. 2006. Natl. Cotton Counc. Am., Memphis, TN.

Bowen, K.L., A.K. Hagan, M. Pegues, J. Jones, and H.B. Miller. 2018. Epidemics and yield losses due to *Corynespora cassiicola* on cotton. Plant Dis. 102(12):2494–2499. https://doi.org/10.1094/PDIS-03-18-0382-RE

Bowen, K.L., A.K. Hagan, K. Burch, H.B. Miller, D. Moore, and L. Wells. 2019. Reaction of cotton cultivars and breeding lines to target spot. pp. 744–746 *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 8-10 Jan. 2019. Natl. Cotton Counc. Am., Memphis, TN.

Butler, S., H. Young-Kelly, T. Raper, A. Cochran, J. Jordan, S. Shrestha, K. Lamour, A. Mengistu, A. Castro, and P. Shelby. 2016. First report of target spot caused by *Corynespora cassiicola* on cotton in Tennessee. Plant Dis. 100(2):535. https://doi.org/10.1094/PDIS-07-15-0785-PDN

Chalise, D.P., J.L. Snider, L.C. Hand, P. Roberts, G. Vellidis, A. Ermanis, G.D. Collins, L.N. Lacerda, Y. Cohen, A. Pokhrel, V. Parkash, and J.M. Lee. 2022. Cultivar, irrigation management, and mepiquat chloride strategy: Effects on cotton growth, maturity, yield, and fiber quality. Field Crops Res. 286:108633. https://doi.org/10.1016/j.fcr.2022.108633

Chattannavar, S.N., A.S. Sharmila, and B.M. Khadi. 2006. Field evaluation of fungicides against *Ramularia areola* Atk. of cotton. J. Cotton Res. Dev. 20(1):145–146.

Chiteka, Z.A., D.W. Gorbet, F.M. Shokes, T.A. Kucharek, and D.A. Knauft. 1988. Components of resistance to late leaf spot in peanut. II. Levels of variability-implications for selection. Peanut Sci. 15(2):76–81. https://doi.org/10.3146/i0095-3679-15-1-8

Cia, E., M.G. Fuzatto, J.H. Kondo, G.A. Ohl, and R. Galbieri. 2013. Recão de genótipos de algodoeiro à mancha de *Ramularia* em diferentes é ambientes. Summa Phytopath. 39(3):193–197. https://doi.org/10.1590/S0100-54052013000300008.

Cia, E., M.G. Fuzatto, A.L. Martins, M.D. Michelotto, W.P. Almeida, and A.P. Oliveira. 2009. Reação de genótipos de algodoeiro ã incidência da mancha de *Ramularia* em condições naturais de infestação. pp. 1452–1455 In Congresso Brasileiro do Algodão, 7.2009, Foz do Iguaçu. Anais. EMBRAPA/Algodão, Campina Grande.

Conner, A., A.M. Jimenez Madrid, T. Wilkerson, S. Tripathi, and T. Allen. 2023. First report of areolate mildew of cotton caused by *Ramulariopsis pseudoglycines* in Mississippi. Plant Dis. 107(10):3290. https://doi.org/10.1094/PDIS-03-23-0566-PDN

Conner, K., A.K. Hagan, and L. Zhang. 2013. First report of *Corynespora cassiicola*-incited target spot on cotton in Alabama. Plant Dis. 97(10):1379. https://doi.org/10.1094/PDIS-02-13-0133-PDN

Croft, J.K., M.A. Jones, and J.D. Mueller. 2006. Effects of foliar fungicide on Deltapine 555 BR and Paymaster 1218 BR. pp. 107–119 *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 3-6 Jan. 2006. Natl. Cotton Counc. Am., Memphis, TN.

Donahue, M. 2012. Cotton leaf spot severe in Santa Rosa County. Univ. of Florida, IFAS. Available online at: http://blogs.ifas.ufl.edu/santarosaco/2012/08/24/cotton-leaf-spot-severe-in-santa-rosa-county/ (verified 27 Feb. 2026).

Dorman, S.J., J. Opoku, H.L. Mehl, and S.V. Taylor. 2021. Fusarium hardlock associated with *Lygus lineolaris* (Hemiptera: Miridae) injury in southeastern cotton. Plant Dis. 105(1):53–59. https://doi.org/10.1094/PDIS-03-20-0569-RE

Edmisten, K. 2012. Target leaf spot found in North Carolina cotton. Southeast Farm Press August 23, 2012. [Online]. Available at https://www.farmprogress.com/cotton/target-leaf-spot-found-in-north-carolina-cotton (verified 27 Feb. 2026).

Fulmer, A.M., J.T. Walls, B. Dutta, V. Parkunan, J. Brock, and R.C. Kemerait Jr. 2012. First report of target spot caused by *Corynespora cassiicola* on cotton in Georgia. Plant Dis. 96(7):1066. https://doi.org/10.1094/PDIS-01-12-0035-PDN

Galbieri, R.D., C.E.B. Araújo, L. Kobayasti, L. Girotto, J.N. Matos, M.S. Marangoni, W.P. Almeida, and Y.R. Mehta. 2014. Corynespora leaf blight of cotton in Brazil and its management. Amer. J. Plant Sci. 5:3805–3811. https://dx.doi.org/10.4236/ajps.2014.526398

Gilio, T.A.S., D.V. de Araújo, K.A. Araújo, T.E. Fregonese, R.C. Franzon, and J.A. Pizzato. 2017. Estimated damage caused by Ramularia leaf spots on cotton. African J. Ag. Res. 12(1):12–19. https://doi.org/10.5897/AJAR2016.11727

Gwathmey, C., and C. Craig. 2003. Managing earliness in cotton with mepiquat-type growth regulation. Crop Manag. 2(1):1–8. https://doi:10.1094/CM-2003-1222-01-RS

Hagan, A.K. 2014. Target spot management options in Alabama. pp. 45–48 *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 6-8 Jan. 2014. Natl. Cotton Counc. Am., Memphis, TN.

Hagan, A.K., K.L. Bowen, K. Burch, and H.D. Miller. 2017a. Target spot-incited defoliation and yields of selected cotton varieties over a three-year period in Southwest Alabama. pp. 233–241 *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 4-6 Jan. 2017. Natl. Cotton Counc. Am., Memphis, TN.

Hagan, A.K., K.L. Bowen, K. Burch, and H.D. Miller. 2017b. Variation in target spot severity and yield among cotton cultivars and fungicide program, 2016. Plant Dis. Manage. Rep. 11:FC055.

Hagan, A.K., K.L. Bowen, K. Burch, H.D. Miller, D. Moore, and L. Wells. 2019a. Reaction of cotton cultivars and breeding lines to areolate mildew in Alabama. pp. 746–751 *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 8-10 Jan. 2019. Natl. Cotton Counc. Am., Memphis, TN.

Hagan, A.K., K.L. Bowen, K. Burch, M. Pegues, J. Jones, and H.B. Miller. 2019b. Efficacy and yield protection from fungicide inputs for the control of foliar diseases in cotton. pp. 240–245 *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 8-10 Jan. 2019. Natl. Cotton Counc. Am., Memphis, TN.

Hagan, A.K., K.L. Bowen, H.B. Miller, and R.L. Nichols. 2018. Target spot-incited defoliation and yields of selected cotton cultivars. Plant Health Prog. 19(2):156–162. https://doi.org/10.1094/PHP-12-17-0082-RS

Hagan, A.K., K. Burch, and H.B. Miller. 2020. Efficacy and yield protection from developmental fungicides compared for the control of target spot in cotton. pp. 302–307 *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 8-10 Jan. 2020. Natl. Cotton Counc. Am., Memphis, TN.

Hagan, A.K., H.L. Campbell, K.L. Bowen, M. Pegues, and J. Jones. 2014. Target spot control with registered fungicides on two cotton varieties, 2013. Plant Dis. Manage. Rep. 8:FC162.

Hand, C., S. Culpepper, J. Vance, G. Harris, B. Kemerait, Y. Liu, C. Perry, D. Hall, J. Mallard, W. Porter, P. Roberts, A. Smith, S. Virk, S. Bag, and H. Sintim. 2023. 2023 Georgia Cotton Production Guide. Univ. of Georgia Extension. Available online http://www.ugacotton.com/production-guide/ (verified 27 Feb. 2026).

Hill, R., B. Culver, I.B. Schardong, E.D. Beasley, A.J. Madrid, I. Small, R.C. Kemerait, K. Bissonnette, D.C. Jones, N. Suassuna, D. Pinho, and P.W. Chee. 2025. Identification and distribution of *Ramulariopsis* species in Georgia. In Proc. Beltwide Cotton Conf., New Orleans, LA. 14-16 Jan. 2025. Natl. Cotton Counc. Am., Memphis, TN.

Hillocks, R.J. 1992. Fungal diseases of the boll. pp. 239–261. *In* R.J. Hillocks (ed.), Cotton Diseases. C.A.B. International, Wallingford, UK.

Iqbal, M., M.Z. Iqbal, R.S.A. Khan, K. Hayyat, and M.A. Chang. 2004. Response of new cotton variety MNH-700 to mepiquat chloride under varying plant population. Pak. J. Biol. Sci. 7(11):1898–1902. https://doi:10.3923/pjbs.2004.1898.1902

Lamas, F.M., and L.G. Chitarra. 2014. Diagnóstico dos sistemas de produção de algodão em Mato Grosso. Dourados, MS: Embrapa Agropecuária Oeste; Embrapa Agropecuária Oeste. Documentos, 123.

Lawrence, K.S. 2007. Diagnosing boll rot problems. pp. 13–14 *In* Proc. Beltwide Cotton Conf., New Orleans, LA., 9-12 Jan. 2007. Natl. Cotton Counc. Am., Memphis, TN.

Li, Y., A. Culbreath, C.Y. Chen, S.J. Knapp, C.C. Holbrook, and B. Guo. 2012. Variability in field response of peanut genotypes from the U.S. and China to tomato spotted wilt virus and leaf spots. Peanut Sci. 39(1):30–37. https://doi.org/10.3146/PS11-6.1

Mailhot, D.J., J.J. Marois, and D.L. Wright. 2007. Influence of flower thrips on Fusarium hardlock severity. Plant Dis. 91(11):1423–1429. https://doi:org/10.1094/PDIS-91-11-1423

Mailhot, D.J., J.J. Marois, and D.L. Wright. 2008. Influence of weather conditions on hardlock severity. pp. 265–269 *In* Proc. Beltwide Cotton Conf., Nashville, TN. 8-11 Jan. 2008. Natl. Cotton Counc. Am., Memphis, TN.

Marois, J.J., and D.L. Wright. 2004. Etiology, epidemiology, and control of Fusarium hardlock of cotton in the southeast: the possibilities. pp. 331–336 *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 5-9 Jan. 2004. Natl. Cotton Counc. Am., Memphis, TN.

Marois, J.J., D.L. Wright, B. Leite, D.L. Mailhot, and E. Osekre. 2007. Hardlock of cotton: Historical review and perspectives. Proc. World Cotton Research Conf.-4, Lubbock TX. 10-14 Sept. 2007. Lubbock, TX. https://wcrc.confex.com/wcrc/2007/techprogram/P1837.HTM

Mehl, H.L., N.S. Dufault, T.W. Allen, A.K. Hagan, P. Price, R.C. Kemerait, H. Kelly, M.J. Mulvaney, and R.L. Nichols. 2020. Multi-year regional evaluation of foliar fungicide applications for cotton target spot management in the southeastern U.S. Plant Dis. 104(2):438–447. https://apsjournals.apsnet.org/doi/10.1094/PDIS-06-19-1150-RE

Padgett, G.B., D.J. Boquet, W. Rea, J.P. Caylor, and C. Shrivers. 2003. Boll rot epidemics in Louisiana cotton. pp. 211 *In* Proc. Beltwide Cotton Conf., Nashville, TN. 6-10 Jan. 2003. Natl. Cotton Counc. Am., Memphis, TN.

Palmateer, A.J., K.S. McLean, G. Morgan-Jones, and E. van Santen. 2004. Frequency and diversity of fungi colonizing tissues of upland cotton. Mycopathologia 157(3):303–316. https://doi.org/10.1023/B:MYCO.0000024184.56337.f5

Price, P., R. Singh, and D. Fromme. 2015. First report of target spot caused by Corynespora cassiicola in Louisiana cotton. Plant Health Prog. 16(2):223–224. https://doi.org/10.1094/PHP-BR-15-0036

Ramanagouda, G., and S.A. Ashtaputre. 2019. Collection and characterization of grey mildew (Ramularia areola Atk.) pathogen of cotton. Ind. Phytopathology 72(2):301–307. https://doi.org/10.1007/s42360-019-00123-y

Ranny, C.D., J.S. Hursh, and O.H. Newton. 1971. Effects of bottom defoliation on microclimate and the reduction of boll rot of cotton. Agron. J. 83(3):259–263. https://doi.org/10.2134/agronj1971.00021962006300020019x

Reddy, A.R., K.R. Reddy, and H. Hodges. 1996. Mepiquat chloride (PIX)-induced changes in photosynthesis and growth of cotton. J. Plant Growth Regul. 20(3):179–183. https://doi.org/10.1007/BF00043305

Salunkhe, V.N., S.P. Gawande, D.T. Nagrale, N.S. Hiremani, N. Gokte-Narkhedkar, and V.N. Waghmare. 2019. First report of Corynespora leaf spot of cotton caused by *Corynespora cassiicola* in Central India. Plant Dis. 103(7):1785. https://doi.org/10.1094/PDIS-05-18-0823-PDN

Seebold, K., R. Kemerait, J.J. Marois, D.L. Wright, B. Padgett, J. Mueller, K. McLean, and T. Estes. 2004. Results of the regional hardlock project. pp. 337–340 *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 5-9 Jan. 2004. Natl. Cotton Counc. Am., Memphis, TN.

Silva, J.C., W. Bettiol, and N.D. Suassuna. 2019. Ramularia leaf spot: an emergent disease of cotton in Brazil. Tropic. Plant Pathol. 44(6):473–482. https://doi.org/10.1007/s40858-019-00308-w

Silva, J.C., N.D. Suassuna, and W. Bettiol. 2017. Management of Ramularia leaf spot on cotton using integrated control with genotypes, a fungicide and *Trichoderma asperellum*. Crop Prot. 94:28–32. https://dx.doi.org/10.1016/j.cropro.2016.12.006

Smith, R.H., S.H. Graham, A. Jacobson, A. Strayer-Scherer, E.J. Sikora, K.S. Lawrence, S. Brown, S. Lee, C. Burmester, D. Monks, and J.W. Everest. 2025. Cotton Insect, Disease, Nematode, and Weed Recommendations for 2025. AL Coop. Ext. Sys. 2025 IPM-0415. Available online at https://www.aces.edu/wp-content/uploads/2023/02/IPM-0415_Cotton2025_121624L-G.pdf (verified 27 Feb. 2026).

Snow, J.P., S.H. Crawford, G.T. Berggren, and J.G. Marshall. 1981. Growth regulator tested for cotton boll rot control. Louisiana Ag. 24(3):3–4.

Soomro, A.R., A.W. Soomro, G.H. Mallah, A.M. Memon, A.H. Soomro, and A.D. Kalhoro. 2000. Okra leaf cotton, its commercial utilization in Sindh. Pak. J. Bio. Sci. 3(1):188–190.

Sparnicht, R.H., and R.W. Roncadori. 1972. Fusarium boll rot of cotton: pathogenicity and histopathology. Phytopath. 62(12):1381–1386.

Srivastava, P., D.J. Mailhot, B. Leite, J.J. Marois, D.L. Wright, and R.L. Nichols. 2010. *Fusarium verticillioides* (Saccardo) Nirenberg associated with hardlock of cotton. Curr. Microbiol. 61(1):79–84. https://doi.org/10.1007/s00284-009-9578-5

Stevenson, W.R., R.V. James, D.A. Inglis, D.A. Johnson, R.T. Schotzoko, and R.E. Thornton. 2007. Fungicide spray programs for Defender, a new potato cultivar with resistance to late and early blight. Plant Dis. 91(10):1327–1336. https://doi.org/10.1094/PDIS-91-10-1327

Strayer-Scherer, A., K. Burch, and H. Mote. 2023. Evaluating the impact of fungicide application timings and cultivar selection on areolate mildew and target spot in Alabama cotton. pp. 260–266 *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 10-12 Jan. 2023. Nat. Cotton Counc. Am., Memphis, TN.

Thaxton, P.M., and K.M. El-Zik. 2001. Bacterial blight. pp. 35 In T.L. Kirkpatrick and C.S. Rothrock (eds.), Compendium of Cotton Diseases. Am. Phytopath. Soc., St. Paul, MN.

Tormen, N.R., and L.E.B. Blum. 2019. Ramularia leaf spot effect on yield and fiber quality of cotton submitted to fungicide application. Rev. Caatinga, Mossoró 32(3):634–646. https://doi.org/10.1590/1983-21252019v32n308rc

United States Department of Agriculture, Agriculture Marketing Service [USDA-AMS]. 2022. Cotton Varieties Planted, 2022 Crop. Agricultural Marketing Service – Cotton and Tobacco Program. Available online https://www.ams.usda.gov/mnreports/cnavar.pdf (verified 27 Feb. 2026).

Videira, S.I.R., J.Z. Groenewald, U. Braun, H.D. Shin, and P.W. Crous. 2016. All that glitters is not *Ramularia*. Stud. Mycol. 83:49–163. https://doi.org/10.1016/j.simyco.2016.06.001

Wei, Y.-X., H. Zhang, J.-J. Pu, and X.-M. Liu. 2014. First report of target spot of cotton caused by *Corynespora cassiicola* in China. Plant Dis. 98(7):1006. https://doi.org/10.1094/PDIS-12-13-1243-PDN

Willrich, M.M., B.R. Leonard, and G.B. Padgett. 2004. Influence of southern green stink bug, *Nezara virdula* L. on late season yield losses in cotton, *Gossypium hirsutum* L. Environ. Entomol. 33(4):1095–1101. https://doi.org/10.1603/0046-225X-33.4.1095

Woodward, J.E., D.M. Dodds, C.L. Main, L.T. Barber, R.K. Boman, J.R. Whitaker, K.L. Edmisten, J.C. Banks, N.W. Buehring, and T.W. Allen. 2016. Evaluation of foliar applications of strobilurin fungicides in cotton across the Southern United States. J. Cotton Sci. 20(2):116–124. https://doi.org/10.56454/KNUG2785

Wright, D.L., J.J. Marois, and P. Wiatrak. 2004. History and overview of the hardlock problem in humid areas of the Deep South. pp. 328–330 *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 5-9 Jan. 2004. Natl. Cotton Counc. Am., Memphis, TN.

York, A. 1983. Cotton cultivar response to mepiquat chloride. Agron. J. 75(4):663–667. https://doi.org/10.2134/agronj1983.00021962007500040020x

Zhao, D., and D.M. Oosterhuis. 2000. Pix Plus and mepiquat chloride effects on physiology, growth, and yield of field-grown cotton. J. Plant Growth Regul. 19(4):415–422. https://link.springer.com/article/10.1007/s003440000018