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PLANT PATHOLOGY AND NEMATOLOGY

Effect of Seeding Rate on Verticillium Wilt Incidence, Yield, and Value For Three Cotton Cultivars

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ABSTRACT

Recommendations for managing Verticillium wilt in cotton include planting a partially resistant cultivar at a high seeding rate. Previous work on seeding rates was done with non-transgenic cotton cultivars and did not include seed and technology cost or lint value. The objective of this study was to compare the profitability of different seeding rates within traditional row spacing in fields infested with *Verticillium dahliae*. Three seeding rates (6.5, 13.0, and 22.7 seed m^{-2}) and three cultivars ('AFD 5065B2F', 'Americot (AM) 1532B2RF', and 'Fibermax (FM) 9063B2F') were planted in small plots arranged in a randomized complete block design. The test was conducted at one location in 2008 and three locations in 2009. Plant stands averaged 4.6, 8.4, and 14.3 plants m^{-2} for the low, intermediate and high seeding rates, respectively. Verticillium wilt incidence was negatively related to seeding rate. At the lowest seeding rate, Verticillium wilt incidence was lower for AFD 5065B2F than AM 1532B2RF or FM 9063B2F; whereas, disease incidence was similar for all three cultivars at the highest seeding rate. At the intermediate seeding rate, AFD 5065B2F had a lower incidence of wilt than FM 9063B2F. Lint yield was positively affected by seeding rate with yields averaging 1248, 1399, and 1490 kg lint ha^{-1} for the low, intermediate and high seeding rates, respectively. Crop value was reduced for the low seeding rate ($1260 ha^{-1}) when compared to the intermediate ($1381 ha^{-1}) and high seeding rate ($1360 ha^{-1}). Producers with Verticillium wilt would benefit economically by planting at least 13 seed m^{-2}.

Verticillium wilt has long been recognized as an economically important disease in cotton (Ezekiel and Dunlap, 1940; Miles, 1934; Miles and Persons, 1932; Presley, 1950; Shapovalov and Rudolph, 1930; and Sherbakoff, 1929). The fungus, *Verticillium dahliae* Kleb., overwinters in soil as microsclerotia, which are formed in decaying plant tissue (Huisman and Ashworth, 1974). Microsclerotia germinate and infect nearby roots (Isaac, 1953). Hyphae penetrate the xylem and the fungus then spreads rapidly by conidia up the vascular system to branches and leaves (Presley, et al., 1966). Verticillium wilt symptoms include chlorosis and necrosis on leaves, vascular discoloration, and in some cases severe defoliation (Leyendecker, 1950).

Lint yield of cotton plants infected with *V. dahliae* is related to the growth period that occurred before symptoms are observed (Pullman and DeVay, 1982). Earlier symptom expression results in severe stunting, poor square retention, and fewer bolls at the end of the season (Pullman and DeVay, 1982). Tzeng et al. (1985) found that many of these changes occurred several weeks before foliar symptoms were observed. Marani and Yaacobi (1976) found that the best predictor of Verticillium wilt tolerance in cotton cultivars was by wilt symptoms displayed in the latter part of flowering, after most of the bolls had been set. There was a stronger correlation between wilt severity and yield when wilt was measured near the end of flowering than in the middle of flowering. Wilt severity was also a better predictor of yield than was vascular discoloration in the stem.

Factors that lead to an increase in Verticillium wilt severity in plants include highly susceptible cultivars (Bell, 1992), presence of defoliating *V. dahliae* pathotypes (Bejarano-Alcazar et al., 1995), high population densities of microsclerotia in the soil (Paplomatas et al., 1992), low air temperature (Garber and Presley, 1971), excessive irrigation (Cappaert et al., 1992) and low seeding rate (Minton et al., 1972). The main strategies for managing Verticillium wilt in cotton are wilt-tolerant cultivars and crop rotations to slow the increase of inoculum, as well as high plant densities and water management, (DeVay et al., 1989). Unfortunately,

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Verticillium wilt tolerance has long been associated with strong vegetative growth, late maturity, and a small fruit load; all of these agronomic traits have negative effects on lint yield (Marani and Yaacobi, 1976).

Of these factors, cultivar selection and seeding rate are the easiest for producers to incorporate into a disease management system. Seeding rate has repeatedly been shown to affect the incidence of Verticillium wilt (Blank et al., 1953; Brody et al. 1990; Leyendecker, 1950; Minton et al., 1972). Minton et al. (1972) indicated seeding rates that resulted in 300,000 to 400,000 plants ha^{-1} were recommended in cotton. These rates could not be obtained in normal row spacing (79 to 101 cm), so a combination of narrow row spacing and high seeding rates were necessary. A typical seeding rate in non-wilt cotton fields may range from 81,000 to 129,300 seed ha^{-1} and with a 75% germination rate, would result in 60,750 to 96,975 plants ha^{-1}.

Production practices and economics of cotton farming have changed significantly in recent years with the rapid adoption of transgenic technology in cotton in the U.S. In 2009, 98% of the upland cotton produced in the U.S. contained one or more transgenic traits (USDA Agricultural Marketing Service, 2009). Because of this technology, the price of cotton seed has increased greatly thereby making seed the primary input cost. A seeding rate recommended by Minton et al. (1972) would require 73 kg of seed ha^{-1}, equating to approximately \$836 ha^{-1}. In the Southern High Plains of Texas in 2009, a seeding rate of 129,300 ha^{-1} (13 seed m^{-2}) would cost approximately \$171 ha^{-1}, based on typical seed costs for 2008 in this region (www.plainscotton.org/Seed/PCGseed09.xls verified on 23 March, 2010) for a cultivar with the BollGuard II and Roundup Ready Flex traits. A high seeding rate may cause a reduction in the incidence of wilt and subsequent increase in yield, but the cost of a high seeding rate with current transgenic technology may be higher than the benefits in Verticillium wilt fields. The objective of this study was to compare the profitability of different seeding rates within traditional row spacing in fields infested with *V. dahliae*.

MATERIALS AND METHODS

Field trials were conducted in three irrigated test sites located on the Southern High Plains of Texas (Table 1). Cotton had been grown repeatedly at these sites and each field had a history of Verticillium wilt. At each site, two composite soil samples (20 cores taken at a depth of 8 to15 cm with a narrow bladed shovel) were taken from an area of approximately 0.4 ha at the time of planting and assayed for microsclerotia of *V. dahliae* as previously described (Wheeler and Rowe, 1995). Three seeding rates (6.5, 13.0, and 22.7 seed m^{-2}) and three cultivars (‘AFD 5065B2F’, ‘Americot (AM) 1532B2RF’, and ‘Fibermax (FM) 9063B2F’) were planted in small plots (1-m wide [= two-rows] and 10.8 m long) with the nine treatments arranged in a randomized complete block design with four replications of each seeding rate and cultivar combination. Therefore, each of the four sites had a total of 36 plots. The plots were planted with a four-row planter, modified with retrofited Kincaid seed cones (Kincaid Equipment and Manufacturing, Haven, KS).

Table 1. Characteristics of fields infested with *Verticillium dahliae* used in seeding rate studies during 2008 and 2009.

Field Name	Year	Soil type[z]	Irrig[y]	Planting date	Harvest date	Plants m^{-2} at three seeding rates			*V. dahliae*[w] cm^{-3} soil
						6.5	13.0	22.7	
Floyd08	2008	Pu	cp	30 Apr	28 Oct	5.3 c[x]	10.2 b	17.1 a	6.8
Floyd09	2009	Pu	cp	14 May	16 Oct	3.9 c	7.2 b	11.5 a	17.3
Lock09	2009	Pu	fur	12 May	6 Nov	3.8 c	7.3 b	12.8 a	18.8
Slat09	2009	Ac	drip	19 May	27 Oct	5.3 c	9.9 b	15.8 a	15.8

[z] Pu = Pullman clay loam (0-1% slope), Ac = Acuff loam (0-1% slope).

[y] Irrigation type, cp=center pivot (every other furrow), fur = furrow (every other furrow), drip (subsurface drip with tape every other furrow).

[x] Means with different letters were significantly different at $P < 0.001$, based on the Pdiff t-test in PROC MIXED, SAS, SAS Institute, version 9.1, Cary, NC.

[w] *Verticillium dahliae* microsclerotia density at planting, averaged across two composite soil samples.

An assumption was made that not all cultivars would perform the same in Verticillium wilt fields, so an effort was made to select cultivars that might respond differently in this study (Table 2). Three cultivars were chosen which differ in crop maturity, plant type (picker harvest versus stripper harvest), ability to yield well in Verticillium wilt fields and different intensity of symptom development of wilt. Selecting cultivars with different growth and disease related parameters was done to provide for a more robust study of the effect of seeding rate.

Table 2. Characteristics of cotton cultivars used in trials conducted in *Verticillium dahliae* infested fields during 2008 and 2009.

Cultivar	Maturity	Type[x]	Yield[w] rank	Disease[w] incidence rank
AFD 5065B2F[z]	Early	Stripper	24	5
Americot 1532B2RF[y]	Medium	Picker	48	43
Fibermax 9063B2F[z]	Early/ Medium	Picker	11	20

[z] www.bayercropscienceus.com/export/sites/bcsus/bcsus_resources/crops/download_gallery/2008_FiberMax_Southwest_Variety_Guide.pdf

[y] www.americot.com/images/AM_1532_B2RF.pdf

[x] Stripper cotton cultivars were developed in the west Texas area and usually have a tighter boll type that is better for harvest with a cotton stripper. Picker type cotton usually has looser lint that is easier to pull from the bolls, and was developed to be harvested with cotton pickers.

[w] The results from variety testing in Verticillium wilt fields done in 2008 (Wheeler and Woodward, 2008). The lower the number for the rank, the better the performance of the cultivar. There were 59 cultivars ranked in the publication.

All plants in each plot were counted 35 to 45 days after planting. In early and late August, the number of plants in each plot with symptoms of Verticillium wilt were counted, and divided by the total number of plants, to obtain an incidence of Verticillium wilt. Early August refers to the first 10 days of the month and represented the middle of the flowering period, and late August was the last week of the month and represented the time of late flowering when most bolls had been set. Symptom expression typical of Verticillium wilt included chlorosis and necrosis of leaves (Fig. 1) or defoliation in extreme cases. Plots were harvested with a cotton stripper (John Deere 484, model is no longer manufactured), modified with a small cage and load cells. For two of the four replications, a 1000 g sample of harvested cotton (lint, seed, burrs, trash, etc.) was collected and ginned to obtain lint and seed percentages for the harvested cotton. An average of the turn-out for the two replicates was used to calculate lint for all four plots. A 50 g sample of lint was saved after ginning and subjected to HVI™ testing, and loan values were calculated based on the appropriate (2008 or 2009) loan charts (Anonymous, 2008 and 2009). The base price of cotton was set at \$1.145 kg^{-1} lint in the 2008 Farm Bill which requires the lint to meet certain quality criteria with respect to micronaire, length, strength, uniformity, etc. Deductions or premiums are assessed for lint that is worse or better than the baseline quality factors.

Figure 1. Symptoms of leaf necrosis due to *Verticillium dahliae* in cotton.

Loan values from each site were analyzed using mixed models analysis of variance (PROC MIXED, SAS version 9.1, SAS Institute, Cary, NC) with seeding rate, cultivar, and their interaction in the model statement, using the Satterthwaithe option. Replication was considered a random factor. If both cultivar and seeding rate, or their interaction term (cultivar x seeding rate), were significant ($P \leq 0.10$), then the average loan value for each cultivar/seeding rate combination was used in calculating the value of the lint per hectare. If the interaction term was not significant, and either cultivar or seeding rate was significant ($P \leq 0.10$), then the average loan value for that significant factor was used to calculate the value of the lint per hectare. The cost of seed and technology fees for each seeding rate were obtained using the Plains Cotton Growers Seed Cost Calculator (www.plainscotton.org/Seed/PCGseed09.xls verified on 23 March, 2010) and ranged from a low of \$70 ha^{-1} to a high of \$301 ha^{-1} (Table 3). Lint yield (kg ha^{-1}) was determined by multiplying the weight of the stripper harvested cotton ha^{-1} by the lint percentage. Value (\$ ha^{-1}) was calculated for each seeding rate and cultivar by multiplying lint yield by the loan value and subtracting the seed and technology cost (Table 3).

Analysis of dependent factors was conducted across the combined four sites. Plant stand, incidence of wilt in early and late August, lint yield, and value ha^{-1} were analyzed by mixed models analysis of variance (PROC MIXED, SAS Institute, version 9.1, Cary, NC), with the model statement that the dependent factor = cultivar (C), seeding rate (S) and C x S, using the Satterthwaithe option. Site, replication(site), site x C, site x S, site x C x S were defined as random factors. The least squares means statement was used to estimate means, and the PDIFF option was used to make appropriate individual comparisons. Cultivar and/or seeding rate with a $P \leq 0.05$ were considered significant, and an interaction term with a $P \leq 0.10$ was considered significant. For lint yield, an additional factor was incorporated into the model: plant stand m^{-2} as both a linear and quadratic factor. The solution (value of the slopes) was requested if plant stand was significant at $P \leq 0.05$. Sites were analyzed together if all the random factors with interactions between site and one or more independent variables were not significant at $P \leq 0.10$. If there were significant interactions between sites, then individual site analyses were also conducted. There was no combined analysis conducted on loan value.

RESULTS AND DISCUSSION

Verticillium dahliae populations in the four fields at the time of planting averaged 6.8, 17.3, 18.8, and 15.8 microsclerotia cm^{-3} soil (Table 1). Disease intensity for susceptible cotton cultivars has been found to increase progressively with increasing density of microsclerotia and all susceptible cultivars can be infected by a density of 10 microsclerotia g^{-1} soil (Ashworth, 1983). The average density of microsclerotia in all four test sites was above 10 microsclerotia g^{-1} soil, except for Floydada in 2008 (Table 1). While average microsclerotia density differed at the four field sites used in the tests, densities were all sufficient to cause significant levels of wilt and subsequent yield losses. Microsclerotia density is not the only factor that affects the severity of wilt. Irrigation amounts (Cappaert et al., 1992) and frequencies (Leyendecker, 1950), soil (Leyendecker, 1950) and air temperature (Garber and Presley, 1971), and isolate aggressiveness (Bejarano-Alcazar et al., 1995) may all impact the level of disease. The four test sites were selected to encompass a wide variety of conditions, so results that were significant across all sites would be considered robust.

Plant stands were significantly different ($P < 0.001$) among seeding rates at all sites (Table 1), but plant stands did not differ by cultivar ($P >$

Table 3. Cost of seed and technology fees and loan values for three seeding rates and cultivars in 2008 and 2009.

Cultivar[z]	Seed ha^{-1}	Seed and technology cost (\$ Ha^{-1})[y]		Loan values (\$ kg^{-1} of lint)			
		2008	2009	Floyd08	Floyd09	Lock09	Slat09
AFD 5065B2F	56,101	70.37	74.13	1.148	1.118	0.999	1.040
AM 1532B2RF	56,101	74.50	84.21	1.047	1.102	0.999	1.014
FM 9063B2F	56,101	78.43	85.87	1.124	1.169	0.999	1.054
AFD 5065B2F	126,751	140.73	148.24	1.186	1.118	1.021	1.078
AM 1532B2RF	126,751	148.98	168.43	1.139	1.102	1.021	1.018
FM 9063B2F	126,751	156.86	171.74	1.186	1.169	1.021	0.971
AFD 5065B2F	221,814	246.26	259.43	1.126	1.118	1.076	1.050
AM 1532B2RF	221,814	260.74	294.74	1.062	1.102	1.076	1.034
FM 9063B2F	221,814	274.53	300.53	1.197	1.169	1.076	1.070

[z] AFD = Associated Farmers Delinting, AM = Americot, FM = Fibermax.

[y] Adapted from EXCEL file obtained from www.plainscotton.org/Seed/PCGseed09.xls.

0.10) (Table 4). Average plant stands for the low, intermediate and high seeding rates were 4.6, 8.6, and 14.3 plants m^{-2}. This is an average of 71, 65, and 63% emergence for the low, intermediate, and high seed rate planted.

Verticillium wilt incidence in early August was affected by cultivar (P = 0.003) and seeding rate (P = 0.0013) in the combined analysis (Table 4). Wilt incidence in early August was greater for AM 1532B2RF (6.5%) and FM 9063B2F (6.9%) than for AFD 5065B2F (4.7%). Wilt incidence in early August was greater for the low seeding rate (8.7%) than for the intermediate (5.5%) or high (3.9%) seeding rate.

Wilt incidence in late August differed among cultivars (P = 0.031) and seeding rates (P < 0.001), and their interaction was significant (P = 0.015) for the combined analysis. For all three cultivars, wilt incidence in late August was less for the intermediate seeding rate than the low seeding rate (Fig. 2). At the lowest seeding rate, AFD 5065B2F had less wilt than AM 1532B2RF and FM 9063B2F (Fig. 2). At

Table 4. The F-value[z], denominator degrees of freedom (DF), and probability (Pr) of a independent variable being significant for Verticillium wilt trials conducted at four locations, and the combined analysis across all four locations.

Dependent Variable	Site	Cultivar (C)			Seeding rate (S)			C X S		
		DF	F	Pr>F	DF	F	Pr>F	DF	F	Pr>F
Stand	comb[y]	6	0.4	0.689	6	111.8	<0.001	12	0.4	0.807
Stand	Floyd08	27	20.4	<0.001	27	895.4	<0.001	27	5.2	0.003
Stand	Floyd09	27	6.9	0.004	27	209.8	<0.001	27	0.9	0.462
Stand	Lock09	24	5.4	0.012	24	181.7	<0.001	24	2.6	0.063
Stand	Slat09	24	0.5	0.620	24	60.7	<0.001	24	0.3	0.905
Early wilt	comb	18	8.2	0.003	6	24.7	0.001	18	1.7	0.186
Late wilt	comb	6	6.6	0.031	6	27.3	0.001	108	3.3	0.015
Late wilt	Floyd08	24	2.1	0.148	24	42.6	<0.001	24	1.5	0.228
Late wilt	Floyd09	24	10.9	<0.001	24	38.1	<0.001	24	0.6	0.643
Late wilt	Lock09	24	1.7	0.200	24	26.2	<0.001	24	1.5	0.249
Late wilt	Slat09	27	15.6	<0.001	27	50.0	<0.001	24	1.3	0.280
Kg Lint ha^{-1}	comb	6	1.8	0.247	18	36.8	<0.001	18	0.6	0.697
Kg Lint ha^{-1}	Floyd08	24	11.5	<0.001	24	6.0	0.008	24	1.2	0.336
Kg Lint ha^{-1}	Floyd09	27	3.4	0.048	27	33.8	<0.001	27	2.7	0.054
Kg Lint ha^{-1}	Lock09	24	14.2	<0.001	24	13.1	<0.001	24	1.9	0.150
Kg Lint ha^{-1}	Slat09	24	5.4	0.012	24	7.6	0.003	24	0.4	0.78
Value ($) ha^{-1}	comb	6	2.6	0.158	18	3.8	0.042	18	0.5	0.755
Value ($) ha^{-1}	Floyd08	24	20.5	<0.001	24	3.5	0.048	24	2.0	0.148
Value ($) ha^{-1}	Floyd09	27	12.4	<0.001	27	10.9	<0.001	27	7.8	<0.001
Value ($) ha^{-1}	Lock09	24	28.1	<0.001	24	3.1	0.066	24	2.7	0.055
Value ($) ha^{-1}	Slat09	24	8.6	0.002	24	0.1	0.875	24	1.5	0.242
Loan value	Floyd08	8	12.4	0.004	8	6.2	0.024	8	1.7	0.245
Loan value	Floyd09	9	3.0	0.100	9	0.7	0.544	9	1.3	0.333
Loan value	Lock09	9	2.8	0.117	9	3.3	0.086	9	1.3	0.326
Loan value	Slat09	9	3.3	0.087	9	2.3	0.155	9	4.8	0.024

[z]Analysis conducted was with PROC MIXED in SAS version 9.1, SAS Institute, Cary, NC. The random term in the individual locations was replication. In the combined analysis across all sites, the random terms were site, replication(site), site x C, site x S, site x C x S.

[y]comb is the combined analysis of all four sites.

the intermediate seeding rate, AFD 5065B2F had less wilt than FM 9063B2F; and at the high seeding rate, all three cultivars had similar levels of wilt (Fig. 2). AFD 5065B2F has exhibited reduced incidence of Verticillium wilt in previous field trials using intermediate seeding rates (Wheeler and Woodward, 2008); and this cultivar exhibited reduced incidence of wilt symptoms at both the low and intermediate seeding rates in these trials. The effects of cultivar on wilt for individual trials was inconsistent, but seeding rate affected wilt incidence in late August for all trials (Table 4).

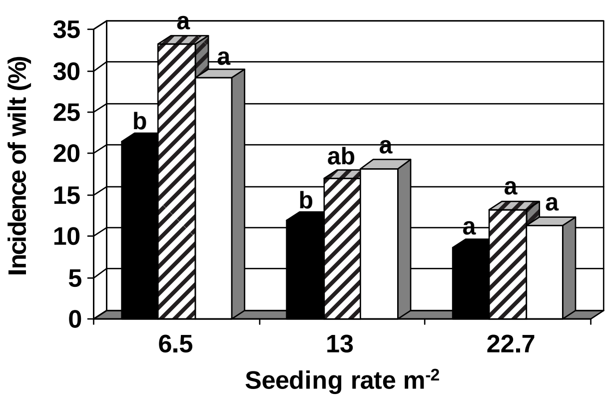

Figure 2. The effect of seeding rate and cultivar on incidence of Verticillium wilt in late August, averaged across four locations. Cultivars were AFD 5065B2F (■), Americot 1532B2RF (▨), and Fibermax 9063B2F (□). Cultivars within a seeding rate with different letters (a, b) are significantly different at $P \leq 0.05$.

Lint yield was increased by increased seeding rate ($P < 0.001$) but did not differ among cultivars in the combined analysis (Table 4). However, in the individual trials, lint yield was significantly affected by both cultivar and seeding rate at all locations (Table 4). Cultivars performed differently at different sites, whereas seeding rates affected lint yields more consistently at all sites (Fig. 3AB). The cultivar FM 9063B2F was the top yielding cultivar at Floyd08, Floyd09, and Slat09, however, FM 9063B2F had the lowest average yields at the Lock09 site (Fig. 3B). AM 1532B2RF had the lowest yields at all sites except Lock09, and AFD 5065B2F yielded higher than AM 1532B2RF at all sites (Fig. 3B). In contrast to the inconsistencies with cultivars, the lowest seeding rate always resulted in lower yields than the intermediate and highest seeding rate at all sites (Fig. 3A). The highest seeding rate always had numerically higher yields than the intermediate seeding rate, although at some sites the means were not significantly different at $P = 0.05$ (Fig. 3A).

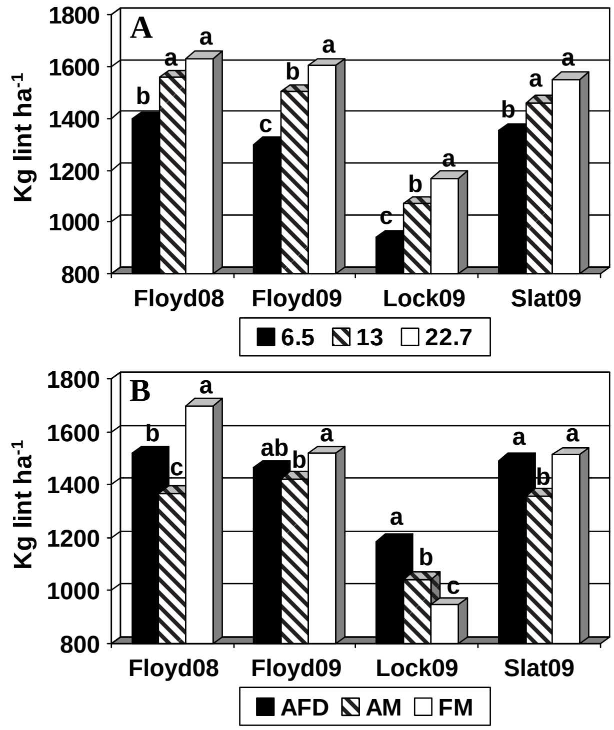

Figure 3. The effect of seeding rate (A) and cultivar (B) on lint yield in four fields infested with *Verticillium dahliae*. The seeding rates tested were 6.5, 13.0, and 22.7 m^{-2}, and the cultivars tested were AFD 5065B2F (AFD), Americot 1532B2RF (AM), and Fibermax 9063B2F (FM). Cultivars or seeding rates within a site with different lower case letters are significantly different at $P \leq 0.05$.

Plant stand, which was a function of seeding rate (Table 1), was tested as a covariate in the combined lint yield analysis with linear and quadratic functions. The quadratic function was significant ($P = 0.023$) and adjusted lint yields by the values of 47.31 X (stand-M) – 1.95 X (stand-M)^2, where M was the average number of plants m^{-2} across all trials (M=9.18). Seeding rates of 6.5, 13, and 22.7 m^{-2} resulted in 4.6, 8.6, and 14.3 plants m^{-2}, and the effects on lint yield based on the quadratic relationship would result in -258, -26, and +191 kg lint ha^{-1}, for the low, intermediate, and high seeding rates.

Loan values for the Floyd08 and Slat09 sites were averaged individually for all nine cultivar/seeding rate combinations (Table 3) because either both cultivar and seeding rate were significant (Floyd08) or there was a significant interaction between the two (Slat09) (Table 4). At the Floyd09 site, loan values were affected by cultivar ($1.118, $1.102, and $1.169 kg^{-1} lint for AFD 5065B2F, AM 1532B2RF, and FM 9063B2F, respectively), but not by seeding rate. At Lock09, loan values were affected by seeding rate ($0.999, $1.021, and $1.076 kg^{-1} lint, for 6.5, 13, and 22.7 seed m^{-2}, respectively), but not by cultivar (Table 3).

The value ha^{-1} (combination of yield x loan value minus seed costs) combined across all sites was affected by seeding rate (P = 0.042), but was not affected by cultivar or their interaction (Table 4). Value ha^{-1} for the low seeding rate was less ($1260 ha^{-1}) than the intermediate ($1381 ha^{-1}) and high seeding rate ($1360 ha^{-1}). There was a more consistent effect of seeding rate than cultivar across individual sites, although at Slat09, seeding rate did not affect value ha^{-1} (Fig. 4A). Cultivars did not perform consistently across all sites (Fig. 4B), with FM 9063B2F having higher value ha^{-1} than AM 1532B2RF at three of the four sites, but having a lower value ha^{-1} at Lock09 (Fig. 4B).

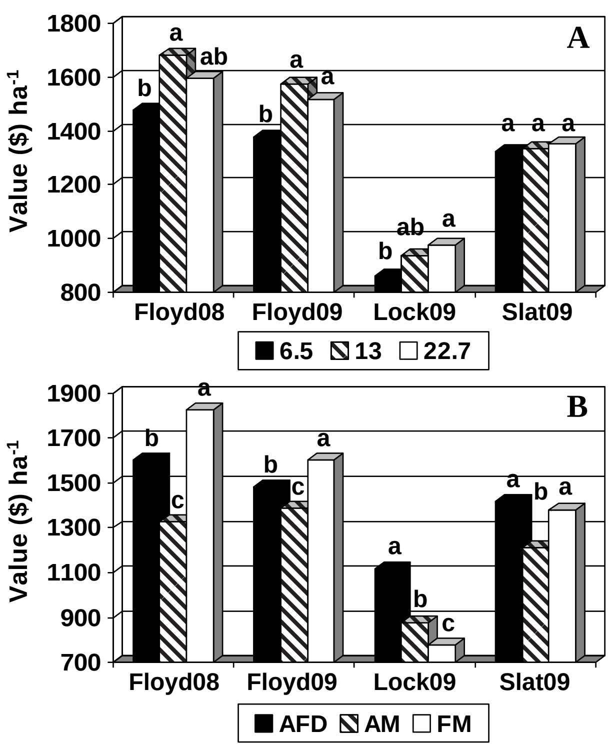

Figure 4. The effect of seeding rate (A) and cultivar (B) on value of cotton lint yields ((loan values x lint yields) – seed costs) in four fields infested with *Verticillium dahliae*. The seeding rates tested were 6.5, 13.0, and 22.7 m^{-2}, and the cultivars tested were AFD 5065B2F (AFD), Americot 1532B2RF (AM), and Fibermax 9063B2F (FM). Cultivars or seeding rates within a site with different lower case letters are significantly different at $P \leq 0.05$.

Increasing seeding rate was consistently beneficial in reducing wilt incidence and increasing yield. This result is consistent with findings in other studies (Blank et al., 1953; Brody et al. 1990; Leyendecker, 1950; Minton et al., 1972); however, the most important measurement in this study was crop value, which incorporated lint quantity and quality, as well as applicable seed and technology fees. These results show an economic benefit from planting 13.0 or 22.7 seed m^{-2} compared to 6.5 seed m^{-2} when Verticillium wilt caused significant crop damage; however, a seeding rate to 22.7 seed m^{-2} provided no additional benefit compared to 13 seed m^{-2}. On the Southern High Plains of Texas, adverse environmental conditions such as drought, hail, and wind are common and these conditions result in many hectares of cotton replanted each year or lost before the crop can be harvested, so if the cotton plants are destroyed before harvest, the loss in input expenses will be greater for the higher seeding rate.

This study is the first to couple economic analysis with the yield measurements and also the first to use transgenic cotton cultivars, which have a much higher seed cost than cultivars grown in previous decades. Based on this research, our recommendation for the Southern High Plains of Texas is to use an intermediate (13 seed m^{-2}) seeding rate to optimize the balance between achieving the maximum value ($) ha^{-1} while minimizing economic risk.

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