Effect of Cultivar Selection on Soil Population of Verticillium dahliae and Wilt Development in Cotton

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Abstract

A microplot study was conducted over a 3-year period to investigate the influence of planting combinations of susceptible and/or partially resistant cotton cultivars on soil population of Verticillium dahliae. Stoneville (ST) 4554B2RF was used throughout the test as a susceptible cultivar and either Associated Farming Delinting (AFD) 5065B2F or an advanced breeding line was used as a partially resistant cultivar. Microplots were augmented with field soil naturally infested with V. dahliae. ST 4554B2RF when planted in three sequential seasons increased V. dahliae population in soil by 754-fold; however, V. dahliae population in microplots planted to the partially resistant cultivars over three seasons increased by 114-fold. Disease incidence increased from 8% to 58% over 3 years for ST 4554B2RF and from 0% to 5% for AFD 5065B2F or the advanced breeding line over the same period. Yield was highest after 3 years of AFD 5065B2F or the advanced breeding line and lowest after 3 years of ST 4554B2RF. Yield correlated with the current year cultivar, pre-plant V. dahliae densities, and disease incidence. Results from this study indicate that cultivar selection can impact microsclerotia density and incidence of wilt in cotton.

Introduction

Verticillium wilt, caused by the soilborne fungus Verticillium dahliae Kleb., is an economically important disease of cotton (Gossypium hirsutum L.) (1). The fungus has a broad host range including more than 400 plant species, and is divided into different vegetative compatibility groups (3). Integrated management systems can effectively minimize losses due to Verticillium wilt (5). The most effective management option in cotton is achieved by growing adapted partially resistant cultivars and using cultural management practices known to reduce disease severity, for example, choice of planting date, plant density, and sanitation (5). The benefits derived from different management options depend largely on the density of inoculum in the soil. Disease development and symptom expression are influenced profoundly by environmental factors, including temperature and soil moisture, as well as soil nutrients and cultivar selection (5). Verticillium wilt was responsible for significant losses throughout the 1970s and 1980s in the United States (9).

Symptoms of Verticillium wilt are typified by yellowing, interveinal chlorosis, and necrosis of leaves (Fig. 1A) starting from the base of the plant and progressing upwards (8). Infection also results in fewer fruiting positions. As the season progresses, plants may become stunted and young bolls may abscise or become malformed. The ramification of fungus in the xylem vessels leads to a tan to brown discoloration of the vascular system, and plants can eventually wilt and die. Symptoms of disease in cotton plants infected by V. dahliae are variable and often influenced by the strain of the pathogen, which can be defoliating or non-defoliating (18). The pathogen is capable of infecting plant roots throughout the growing season.
Microsclerotia (ms), the survival structures of *V. dahliae*, are produced once the plant dies. Microsclerotia are composed of masses of melanized hyphae and considered the principal source of inoculum for the initial infection. Microsclerotia can survive for more than 20 years in soil (21), and root exudates stimulate germination of ms (12). *V. dahliae* primarily colonizes the rhizoplane of the host plant early in the growing season. Hyphae penetrate deep into the root cortex, and may enter the xylem vessels by direct penetration or through wounds. Microsclerotia can form in decaying plant tissues depending on temperature and moisture availability. The fungus is capable of infecting plant roots throughout the growing season between temperatures 21 to 27°C, whereas temperatures between 24 to 27°C are best suited for *V. dahliae* growth and survival in the plant (17).

Being a monocyclic disease, the inoculum density of the pathogen in field soils at planting plays a critical role in the epidemiology of Verticillium wilt (14). The incidence of Verticillium wilt is proportional to the inoculum density expressed as the number of viable ms per cm³ of soil; however, considerable variation occurs, with such a relationship depending upon crops and cultivars (7). Evans et al. (6) observed that ms density of *V. dahliae* decreased throughout the growing season, but increases at harvest time with the release of ms into soil from damaged tissues of infected cotton plants.

Understanding the relationship between soil inoculum density before planting and wilt development is essential for developing a disease risk assessment. In general, management options should be implemented at or before planting to prevent disease. Inoculum density can also be an important factor in determining the timing, nature, and duration of management practices. The objective of this study was to determine the effect of cotton cultivar selection on soil *V. dahliae* population over time, and its implications for Verticillium wilt development.
Microplot Experiment

A microplot study was conducted during 2008, 2009, and 2010 at the Texas Tech University, Quaker Research Farm in Lubbock, TX. Microplots consisted of cylindrical galvanized aluminum rings (90 cm diameter by 60 cm high), and buried at a depth of 50 cm (Fig. 1B). In 2008, the microplots were augmented with 56,780 cm³ of soil naturally infested with V. dahliae before planting. Six treatments consisting of cultivar rotation schemes over three years utilizing all possible permutations of a susceptible cultivar [Stoneville (ST) 4554B2RF], and/or a partially resistant cultivar [Associated Farming Delinting (AFD) 5065B2F (2008) or an advanced breeding line (2009 and 2010)] were used. The partially resistant advanced breeding line had been verified in Verticillium wilt field nurseries and inoculated greenhouse tests (T. A. Wheeler, unpublished data). In 2009, the resistant cultivar AFD 5065B2F was replaced with the advanced breeding line, as AFD 5065B2F was no longer available commercially. Cultivars were selected based on the results of cotton cultivar performance trials conducted in 2006 and 2007 (20). Microplots were planted at the rate of 25 seed per microplot in a circular pattern on 15 to 16 May of 2008, 2009, and 2010 resulting in a planting density of 200,000 seed/ha. Microplots were irrigated using a drip irrigation system and fertilized with urea ammonium nitrate (32-0-0, N-P-K) as needed. Weeds were controlled throughout the study using pre-and post-emergence herbicides according to local extension recommendations, and hand hoeing.

Soil Sampling and Data Collection

In April 2008, microplots were sampled to determine baseline V. dahliae inoculum densities. Subsequently, soil samples were taken in February, August, and December 2009 and April, August, and December 2010 to determine the inoculum density (ms/cm³ soil) over time. A 2.5-cm diameter auger at a depth of 20-cm was used for sampling each microplot. Each sample consisted of four cores and had a total weight of approximately 250 g of air dried soil. Inoculum density was determined using the dilution plating technique described by Nicot and Rouse (13). Soil cores from each microplot were mixed together, air dried at room temperature for 14 days, and air-dried soil was ground using a rolling pin. Subsequently, a 20% w/v soil suspension was prepared using de-ionized water and stirred for 10 min at 200 rpm using a magnetic stir plate. Sorensen’s NP-10 semi-selective medium, amended with 0.025 N NaOH, as suggested by Kabir et al. (11) was used for soil plating. This medium consisted of two parts autoclaved separately. In the first part, 5 g of Polygalacturonic acid from orange (Sigma-Aldrich, St. Louis, MO) and 0.025N NaOH were added to 500 ml of distilled water and autoclaved at 121°C for 20 min and cooled to 50°C. In the second part, 15 g of Bacto-Agar (Difco Laboratories, Detroit, MI), 1 g of KNO₃ (Sigma-Aldrich), 1 g of KH₂PO₄ (Sigma-Aldrich), 0.5 g of KCl (Sigma-Aldrich), 0.5 g of MgSO₄·7H₂O (Sigma-Aldrich), 0.5 ml of Tergitol NP-10 (Sigma-Aldrich), and 500 ml of distilled water with a magnetic stir bar were autoclaved at 121°C for 20 min and cooled to 50°C. After the second part equilibrated to 50°C, chloramphenicol (Sigma-Aldrich), streptomycin sulfate (S-6501, Sigma-Aldrich), and chlorotetracycline HCl (Sigma-Aldrich) at 50 mg/liter each were added. When the antibiotics were completely dissolved, the two parts were mixed and placed on a magnetic stirrer. This semi-selective medium was dispensed (15 ml/petri dish) into 9-cm diameter petri dishes immediately. A 1-ml aliquot was plated on each petri dish (10 replications) containing semi-selective medium.

After 14 days of incubation at room temperature and dark conditions, the soil was rinsed from the petri dishes under slow running water and air dried for approximately 2 h prior to counting. Colonies of V. dahliae from germinating ms were identified with the aid of a stereomicroscope (Nikon SMZ 800, Tokyo, Japan) at 20× magnification based on characteristic starburst-shaped colony morphology and black pigmentation (Fig. 1.C). Colonies were expressed as the number of ms/cm³ of dry soil. Microsclerotia densities were recorded for three
years. Stand counts were taken in mid June and disease incidence was assessed in late September and recorded for each season as percentage of plants that were symptomatic in each microplot. Plant height (cm) in each microplot was measured before harvesting in December 2010. Cotton was hand harvested and weighed to determine lint yields for each microplot. Lint samples were sent to the Fiber and Biopolymer Research Institute at the Texas Tech University for fiber quality analysis using a high volume instrument system.

Statistical Analysis
The six treatments were arranged in a randomized complete block design with seven replications. Percent germination, disease incidence, inoculum density, plant height, and lint yield data were analyzed using Proc MIXED (SAS v.9.2, SAS Institute Inc., Cary, NC). Data were analyzed as a split-plot in time where the sub-plots were seven sampling dates. A linear model was fitted for V. dahliae inoculum densities in soil over time. Linear change was on a monthly basis with replication and treatment as random effects. Center of the month values (0, 10, 16, 20, 24, 28, and 32) was determined as described by Draper and Smith (4). The error term was the natural error of the experiment. Regression analysis for pre-plant soil inoculum density of V. dahliae, and disease incidence was done on yield in 2010 using Proc MIXED with replication as a random effect. The method used to adjust the degrees of freedom (df) to match adjustments in the sums of square was the Satterthwaite option in the LSMEANS statement in Proc MIXED. Standard error and LSD were determined from the PDIFF option. Slopes for Stoneville 4554B2RF and AFD 5065B2F/advanced breeding line were tested by regressing pre-plant soil inoculum density of V. dahliae on disease incidence over the three year period using Proc Reg.

Cultivar Selection Effects
Soil populations of V. dahliae. At the beginning of the experiment, prior to rotations being implemented, there were 1.30 ± 0.06 ms/cm³ of soil in microplots, and V. dahliae soil densities (ms/cm³) were similar across all rotations. Stoneville 4554B2RF planted for three sequential years increased ms densities in soil significantly by 754 fold, whereas ms densities increased by 114 fold with only planting a partially resistant cultivar over the same period (Fig. 2). Soil ms densities in the microplots initially planted with a partially resistant cultivar followed by a susceptible cultivar for the next two years (RRS) were not different from those planted to ST 4554B2RF for three years (SSS) (Fig. 2). Microplots initially planted with a susceptible cultivar followed by a resistant cultivar for the next two years (SSR) had similar ms densities to those planted with a resistant cultivar for three years (RRR) (Fig. 2). The dynamics of V. dahliae population densities over the three years fitted a linear model for most cultivar rotations (Fig. 2). A linear model was significant (P < 0.01) for cultivar rotation RRS, RSS, SSS, and SSR with positive slopes (0.16, 0.34, 0.32, and 0.22, respectively) (Fig. 2). Microsclerotia densities increased by 114 fold when a partially resistant cultivar was present for two or more years and linear model for both rotations RRR and SRR were not significant at P = 0.05 level (Fig. 2). The greatest increase of ms over time occurred when a susceptible cultivar was present in a particular microplot for at least two consecutive years (RSS and SSS rotations) where ms density increased by 754 fold (Fig. 2). The models describing the dynamics of ms for these rotations were best fitted with linear models, and their slopes (0.05 and 0.03, respectively) were not significantly different from each other, but were significantly higher than the slopes associated with the RRR and SRR models (Fig. 2). Microsclerotia densities for RRS were relatively low for the first two years and then increased dramatically in 2010 with the planting of a susceptible cultivar (Fig. 2). Microsclerotia densities for SSR increased rapidly for 2008 and 2009, but slowed in 2010 when a resistant cultivar was planted (Fig. 2). A quadratic model (y = 1.46 − 0.16x + 0.01x²; P < 0.01; R² = 0.90) was significant only for RRS and had a concave shape due to the rotation of cultivars (Fig. 2).
Fig. 2. Effect of cultivar rotation on *Verticillium dahliae* inoculum density in soil over time. Data were analyzed using Proc MIXED (v. 9.2, 2008, SAS Institute Inc.) using mixed model analysis. Linear model was significant ($P < 0.01$) for cultivar rotation RRS, RSS, SSS, and SSR, whereas quadratic regression was significant only for RRS rotation. $R = $ Partially resistant (AFD 5065B2F / Advanced breeding line), $S = $ Susceptible (Stoneville 4554B2RF). RRR, RRS, RSS, SSS, SSR, and SRR represent three year rotations where the first letter refers to the cultivar grown in 2008, the second letter to the cultivar grown in 2009, and the third letter to the cultivar grown in 2010. LSD$_{0.05} = 0.26$. 

$\text{SSS; } y=0.85+0.32x; \ P<0.01; \ R^2=0.97$

$\text{RSS; } y=0.03+0.34x; \ P<0.01; \ R^2=0.91$

$\text{SSR; } y=1.76+0.22x; \ P<0.01; \ R^2=0.83$

$\text{RRR; } y=1.74+0.03x; \ P>0.10; \ R^2=0.26$

$\text{SRR; } y=1.08+0.05x; \ P>0.10; \ R^2=0.80$

$\text{RRS; } y=1.46-0.16x+0.01x^2; \ P<0.01; \ R^2=0.90$
Verticillium wilt incidence. Seed germination was similar between ST 4554B2RF and AFD 5065B2F in 2008 (98%). In 2009, ST 4554B2RF had slightly lower germination than the advanced breeding line (data not presented). In 2008, incidence of wilt was greater for microplots planted with ST 4554B2RF than in microplots planted with AFD 5065B2F (Table 1). In 2009, when a susceptible cultivar was planted for two consecutive years (SS), the disease incidence averaged 32% (Table 1). When partially resistant cultivars were planted for two consecutive years in 2009 (RR), then disease incidence averaged 2% (Table 1). When cultivars were rotated so that the partially resistant cultivar was planted in 2008 and the susceptible in 2009 (RS), then incidence of wilt was as high as two consecutive years of susceptible cultivars (31%) (Table 1). However, when a susceptible cultivar was planted in 2008, followed by a partially resistant cultivar in 2009 (SR), the disease incidence was intermediate (10%) (Table 1). The lowest disease incidence observed after three years rotation was 4.9% for the RRR rotation scheme while the greatest disease incidence observed after three years rotation was 58.0% for the SSS rotation scheme (Table 1). Overall, it was observed that in the rotations where a partially resistant cultivar was planted for at least two consecutive years, there was significantly lower disease incidence as compared to the rotations planted with a susceptible cultivar for two or more years (Table 1). An increase in disease incidence was found to be negligible (0% to 5% only) for the treatment RRR, whereas the percent disease incidence significantly increased from 8% to 59% with the treatment SSS for the same period of time; other treatments had intermediate effects (Table 1). Two years of a susceptible cultivar followed by a partially resistant cultivar (SSR) resulted in more wilt in 2010 than two years of a partially resistant cultivar followed by a susceptible cultivar (RRS) (Table 1). Microsclerotia accumulation in the soil may have a greater impact on disease incidence than cultivar selection and planting a partially resistant cultivar could have more disease than a susceptible cultivar, if greater amounts of ms had occurred because of previous susceptible cultivar rotations. Slopes obtained by regressing pre-plant V. dahliae inoculum densities in soil with disease incidence in three years were significantly different (P = 0.0001) for AFD 5065B2F/advanced breeding line (3.07) and ST 4554B2RF (6.2). The different slope values indicate that disease incidence would increase faster with per unit V. dahliae inoculum for ST 4554B2RF than for AFD 5065B2F/advanced breeding line.

Lint yield. Lint yield was significantly different among rotations in 2010 (Table 2). In 2010, lint yield for the rotation schemes planted to a partially resistant cultivar, RRR was 14% greater than SRR and 76.1% greater than SSR, whereas for rotation schemes planted to a susceptible cultivar, SSS was 22.7% lower than RSS and 33.8% lower than RRS (Table 2), suggesting that lint yield was affected by the current year cultivar and cultivar history. Microsclerotia density in April 2010 was predictive of yield for each cultivar (Fig. 3A, B). Yields were high for the partially resistant cultivar, when ms density was < 3/cm³ soil (Fig. 3A). Microsclerotia densities in April were < 3/cm³ soil for both the RRR and SRR rotations, but yield was 12.3% greater for the RRR than for the SRR rotation (Table 2). However, yield for the partially resistant cultivar declined substantially when ms density increased to > 8/cm³ soil (Fig. 3A).
Table 1. Effect of cultivar rotation on percent disease incidence in 2008, 2009, and 2010.

<table>
<thead>
<tr>
<th>Cultivar rotation scheme</th>
<th>Disease incidence (%)</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>LSD(^z) = 5.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>RRR</td>
<td>0.0 c(^w), A(^x)</td>
<td>1.4 c, A</td>
<td>4.9 e, A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RRS</td>
<td>0.0 c, B</td>
<td>2.4 c, B</td>
<td>17.8 d, A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RSS</td>
<td>0.0 c, C</td>
<td>31.1 a, B</td>
<td>39.2 b, A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSS</td>
<td>8.3 b, C</td>
<td>32.5 a, B</td>
<td>58.0 a, A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SSR</td>
<td>10.3 ab, B</td>
<td>31.9 a, A</td>
<td>30.2 c, A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRR</td>
<td>11.2 a, A</td>
<td>10.3 b, A</td>
<td>9.3 e, A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSD(^y)</td>
<td>2.2</td>
<td>7.1</td>
<td>5.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^v\) R = Resistant (AFD 5065B2F/Advanced breeding line), S = Susceptible (Stoneville 4554B2RF). RRR, RRS, RSS, SSS, SSR, and SRR represent three year rotations where the first letter refers to the cultivar grown in 2008, the second letter to the cultivar grown in 2009, and the third letter to the cultivar grown in 2010.

\(^w\) Means followed by the same lower case letter in the same column are not significantly different at \(P \leq 0.05\) level according to Fisher's LSD.

\(^x\) Means followed by the same upper case letter in the same row are not significantly different at \(P = 0.05\) level.

\(^y\) LSD for comparing cultivar rotations.

\(^z\) LSD for comparing years.

Table 2. Effect of cultivar rotation scheme on lint yield in 2010.

<table>
<thead>
<tr>
<th>Cultivar rotation scheme</th>
<th>Lint yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RRR</td>
<td>3454.1 a(^y)</td>
</tr>
<tr>
<td>SRR</td>
<td>3030.9 b</td>
</tr>
<tr>
<td>SSR</td>
<td>1962.2 c</td>
</tr>
<tr>
<td>RRS</td>
<td>1407.8 d</td>
</tr>
<tr>
<td>RSS</td>
<td>1205.7 d</td>
</tr>
<tr>
<td>SSS</td>
<td>931.9 d</td>
</tr>
<tr>
<td>LSD</td>
<td>281.1</td>
</tr>
</tbody>
</table>

\(^x\) R = Resistant (AFD 5065B2F/Advanced breeding line), S = Susceptible (Stoneville 4554B2RF). RRR, RRS, RSS, SSS, SSR, and SRR represent three year rotations where the first letter refers to the cultivar grown in 2008, the second letter to the cultivar grown in 2009, and the third letter to the cultivar grown in 2010.

\(^y\) Means followed by the same letter in the same column are not significantly different at \(P \leq 0.05\) level according to Fisher's LSD.
When ms densities were < 3/cm³ soil, yields were poor for the susceptible cultivar (Fig. 3B), though they declined even more when ms densities were > 7/cm³ soil (Fig. 3B). ST 4554B2RF typically had excellent yield potential in the county where the test was conducted, and would be expected to out yield many other cultivars in the absence of disease. It is unlikely that the advanced breeding line had as high a yield potential in the absence of disease. A negative relationship was also detected between disease incidence taken during the same growing season and lint yield for both cultivars (Fig. 4). The slope for disease incidence and lint yield was −10.44 for ST 4554B2RF and −52.95 for the advanced breeding line (Fig. 4). Yield for the susceptible cultivar was poor even when Verticillium wilt incidence was low indicating that this cultivar was intolerant of *V. dahliae*. With the partially resistant cultivar, yields were much greater at low incidences of Verticillium wilt, but the rate of yield decline per unit wilt was
Fig. 4. Effect of disease incidence on lint yield in 2010. Data were analyzed using Proc Reg (SAS v. 9.2, 2008). Advanced breeding line was partially resistant and Stoneville 4554B2RF was susceptible to *Verticillium dahliae*. Slope for the Advanced breeding line (-52.95) was significantly different from slope for Stoneville 4554B2RF (-10.44) at $P = 0.05$ level. Tabular $t$-value was 2.055, whereas observed $t$-value was 6.272.
much greater than for the susceptible cultivar. The result suggests that while the cultivar was partially resistant (i.e., it reduced the rate of reproduction of ms over time), it was also relatively intolerant of *V. dahliae* in terms of yield, when there was a high enough density of *V. dahliae* to cause significant wilt symptoms.

Disease incidence and yield could be explained through cultivar choice and pre-plant *V. dahliae* density in soil. Cultivar rotation history defined ms density. Fibers were longer for the partially resistant cultivar grown in microplots that had the least amount of wilt (RRR rotation) than for a susceptible cultivar grown in microplots where wilt was the highest (SSS rotation) *(data not presented).*

**Inoculum Density and Disease Incidence**

A correlation between inoculum density at planting and disease incidence at the end of the cropping season has previously been reported (14). In Acala cotton fields of California, the number of plants infected by *V. dahliae* at the end of the crop season was determined to be directly related to the density of ms in soil (1,16). In cotton, the role of the inoculum density on vascular infection or development of foliar symptoms changes with the cultivar tolerance and pathotypes of *V. dahliae* (2). Only a single cycle of inoculum is produced per season because with the decay of tissue the ms again disperse in the soil (14). Microsclerotia population in the soil can further contribute to soil inoculum for the next season.

**Management of Verticillium Wilt**

Management options are limited for Verticillium wilt of cotton, due to longevity of ms (21) and a broad host range. In other systems, reducing ms is usually accomplished with a combination of chemical (21) and cultural methods, such as use of resistant cultivars (7) and crop rotations (17). However, it is not economically feasible for cotton farmers to rotate for many years with other crops (non-hosts). There are limited chemical options available due to lack of efficacy at economical rates (22).

Management tactics to prevent Verticillium wilt should be aimed at preventing the increase of inoculum. The choice of cultivar is probably the single most important decision farmers can make in an integrated crop management system. The cultivar sets the framework for the level of susceptibility to disease, the tactics applied to manage the crop, and production costs. Differences in the resistance of cotton cultivars to Verticillium wilt have been identified (20). Thus, cultivar selection seems to be the cornerstone to manage the *V. dahliae* inoculum density in the soil. Planting susceptible cotton cultivars is believed to increase inoculum of *V. dahliae* in soil. The use of partially resistant cotton cultivars appears to be a promising management option. The importance of primary inoculum in Verticillium wilt development justifies the use of partially resistant cotton cultivars for effective disease management.

In the present microplot study, planting a partially resistant cultivar for three consecutive years did not increase ms density significantly, whereas planting a susceptible cultivar significantly increased ms density by 754 fold. Vallad and Subbarao (19) reported a 159-fold difference in inoculum density of *V. dahliae* per gram of root tissue between resistant and susceptible cultivars of lettuce. Joaquim et al. (10) reported a sharp increase in ms population in the second year following a susceptible crop, despite host susceptibility. These results suggest that if a susceptible cultivar is planted in soil infested with *V. dahliae*, then ms density and wilt incidence will increase, thus increasing yield losses.

There were distinct differences in the rotation schemes. With at least two consecutive years of a resistant cultivar, ms density was kept the same, wilt incidence was low, and yields were high. With even low densities of *V. dahliae* in the soil, a susceptible cultivar resulted in low yields, even if wilt incidence was relatively low. Any gains made by two years of growing resistant cultivars, would likely be lost using a susceptible cultivar in subsequent years, if they were as intolerant of wilt as ST 4554B2RF. In essence, only partially resistant cultivars
should be grown in fields with a history of Verticillium wilt. Cultivar rotation combinations were effective at manipulating density of *V. dahliae*, but the threshold ms density that caused significant damage in the partially resistant cultivar was > 3/cm³ soil and in the susceptible cultivar it was too low to be measured by the third year of this experiment.

**Summary and Implication for Producers**

This study demonstrates the importance of planting partially resistant cultivars for managing Verticillium wilt in cotton. If *V. dahliae* densities in soil are low, a resistant cultivar can help maintain low inoculum concentrations; but, if inoculum levels are already high then it may require several years to reduce the inoculum density. Adoption of a partially resistant cultivar for at least 2 years was required to negatively impact *V. dahliae* inoculum density in soil, wilt incidence, plant stunting, and low lint yield.

**Acknowledgments**

This research was funded by the Cotton Incorporated, Texas State Support Committee and the International Cotton Research Center at Texas Tech University. We would like to thank Benjamin Mullinix for the statistical analysis and Bayer Crop Science for providing seeds of the two commercial cultivars that were used in the study. The technical assistance of Mitchell Ratliff, Ira Yates, and Lindsey Thiessen is greatly appreciated.

**Literature Cited**