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Field assessment of commercial cotton cultivars for Verticillium wilt resistance and yield

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ABSTRACT

Verticillium wilt is responsible for substantial yield losses in cotton. The use of cultivars with partial resistance to Verticillium wilt is a preferred management strategy. Cotton breeders utilize rating scales based on severity of foliar symptom expression and/or defoliation when making cultivar selections. The objective of this research was to determine the yield relationship with cultivars grouped by both incidence of Verticillium wilt during the boll filling stage, and late season defoliation in fields with a history of Verticillium wilt. Small plot, replicated cultivar trials were conducted over an 11 year period in west Texas. Cultivars were divided into four classes (A–D) based on normalized wilt incidence (NW) and four classes based on normalized defoliation ratings (ND). Classes were determined through a mixed model analysis of cultivars, with *T*-test comparisons between a partially resistant check (Fibermax 2484B2F) and a susceptible check (Deltapine 0912B2RF). The A and C classes did not differ ($P = 0.05$) from the partially resistant and susceptible checks, respectively. Classes were used in a mixed model analysis with lint yield. In a model with only NW classes, lint yield decreased significantly as NW increased with least square mean values of 1421, 1385, 1284 and 1204 kg/ha, for classes A, B, C and D, respectively. In a model with both NW and ND classes, the A/A class combination of NW and ND had a significantly ($P \leq 0.05$) higher lint yield (1776 kg/ha) than any other combination. NW/ND class combinations of A/B, B/A, B/B, and C/A had intermediate yields, and ND classes of C or D had the lowest yields. Cultivars with both low wilt and defoliation incidences should result in higher yields in fields infested with *Verticillium dahliae*. Furthermore, these two rating criteria could be used to standardize the process for developing resistant cultivars.

1. Introduction

Verticillium wilt causes substantial losses in many dicotyledonous plants. The causal agent, *Verticillium dahliae* Kleb, is a soilborne fungus that has a host range of more than 300 plant species (Pegg and Brady, 2002). The fungus is capable of persisting in the soil via the production of microsclerotia (Wilhelm, 1955). Management of Verticillium wilt requires a number of different tactics, most providing only limited control. Crop rotation with non-hosts has not been very effective at reducing high *V. dahliae* microsclerotia densities (Butterfield et al., 1978; Huisman and Ashworth, 1976). Rotation with sorghum can delay initial buildup of *V. dahliae* microsclerotia (Wheeler et al., 2014), resulting in less wilt, higher cotton yields, and better economic returns (Wheeler et al., 2012; 2016). Chemical control with fumigation has been practiced, but high usage rates are required to kill microsclerotia, limiting the use to high-value crops (Ben-Yephet and Frank, 1984; Woodward et al., 2011). Fungicides have not been widely used for managing Verticillium wilt (Bell, 1992), though some have been shown to reduce severity of Verticillium wilt symptoms in field studies (Bubici et al., 2006; Kurt et al., 2003). Selection of resistant or partially resistant cultivars is the most desirable method of managing the disease; however, highly resistant commercial cultivars have not been identified in *Gossypium hirsutum* grown in the U.S.

Efforts to assess Verticillium wilt resistance include the incidence or severity of foliar symptoms and vascular discoloration (Bassett, 1974; Karademir et al., 2010; Marani and Yaacobi, 1976). An index may include both incidence of wilt and percent defoliation within the same scale (Aguado et al., 2008). Fungal reproduction or

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Abbreviations

AFD	Associated Farmers Delinting
AM	Americot
AT	All-Tex
B	Bollgard I (one-gene resistance to lepidopteran pests), Monsanto
B2	Bollgard II (two-gene resistance to lepidopteran pests), Monsanto
BCG	Beltwide Cotton Genetics
BW	Beltwide
CG	Croplan Genetics
DG	Dynagro
DP	Deltapine
F	Full season resistance to glyphosate, Bayer CropScience
FM	Fibermax
GL	Resistance to glyphosate and glufosinate, Bayer CropScience
GT	Full season resistance to glyphosate, Bayer CropScience
LL	Resistance to glufosinate, Bayer CropScience
ND	Normalized defoliation
NG	NexGen
NW	Normalized wilt
NY	Normalized yield
PHY	Phytogen
PM	Paymaster
PVP	plant variety protection (www.ars-grin.gov/cgi-bin/npgs/pvp/pvp.pl?Cotton)
RR	Resistance to glyphosate, early season application only, Monsanto
RF	Full season resistance to glyphosate, Monsanto
ST	Stoneville
T	Twinlink (two-gene resistance to lepidopteran pests, Bayer Cropscience)
W	Widestrike (two-gene resistance to lepidopteran pests), DowAgrosciences
W3	Widestrike 3 (three gene resistance to lepidopteran pests), Dow AgroSciences
XF	Resistance to glyphosate, glufosinate, and dicamba, Monsanto

growth in the plant has also been used as a direct measure of resistance (Frost et al., 2007; Pasche et al., 2013; Tsai and Erwin, 1975; Zhang et al., 2013). Chawla et al. (2012) found that microsclerotia (MS) densities increased slowly over a three-year period in soils planted with partially resistant cultivars, from 1.3 to 2.8 MS/cm^3 soil, compared to a susceptible cultivar which increased to 11.1 MS/cm^3 soil. Such relatively small changes in microsclerotia production in a cultivar within a growing season might be difficult to detect in cultivar trials due to spatial variability.

"Many cotton breeding programs have been frustrated by the fact that a cultivar might be resistant to Verticillium wilt, but is not as productive as less resistant cultivars. Therefore, the use of yield or its components associated with foliar symptoms is very important as an indicator of Verticillium wilt tolerance" (Aguado et al., 2008). The objective of this research was to represent cultivars as class values by their relative ability to reduce wilt symptoms (expressed as wilt incidence), and defoliation (expressed as percent defoliation); and determine the relationship between these class values and yield in fields infested with *V. dahliae*.

2. Materials and methods

Data sets from cultivar trials conducted in west Texas from 2005 through 2015 were used in the analysis. Trials typically consisted of 32 entries, arranged in a randomized complete block design with four replications. Plots were two-rows wide by 11.0 m in length, and 144 seeds were planted in each row. Two composite soil samples were taken at planting from all test sites and assayed for density of *V. dahliae* microsclerotia (Wheeler et al., 2014). All entries were commercially sold cultivars from regional cotton seed companies (All-Tex Cotton, Americot [Americot and NexGen brands], Bayer CropScience [Associated Farmers Delinting, Fibermax, and Stoneville brands], Beltwide Cotton Genetics, Croplan Genetics, DowAgrosciences [Phytogen brand], DynaGro, Monsanto [Deltapine brand], or Paymaster). All trial sites were irrigated, 39 sites with center pivot irrigation, 10 sites with subsurface drip irrigation, and 3 sites were furrow irrigated.

Data collected from each plot included disease incidence of wilt and lint yield. All emerged plants were counted from both rows after stands were established (typically 35–60 days after planting). Sites were monitored for wilt symptoms and the number of plants with wilt symptoms was counted, typically two or three times during the growing season. The incidence of wilt was calculated as the number of plants with wilt symptoms/total number of plants in the plot, times 100. The timing that resulted in the best statistical separation of wilt between cultivars was used in the analysis. Sites that averaged <4% incidence of wilt were omitted from the analysis.

Starting in 2009, a defoliation rating was made between 15 and 25 September. At approximately 1 m intervals, the plants from each row were inspected for defoliation and given a rating. The scale was 0 for no defoliation, 1 = 1–33% defoliation; 2 = 34–66% defoliation; and 3 = 67–100% defoliation. Approximately 20 locations were evaluated in each plot. The defoliation ratings were converted into % defoliated by taking the midpoint of each rating i.e. 0 = 0; 16.5 for those with a 1 rating; 49.5 for those with a 2 rating; and 83.5 for those with a 3 rating, and averaged to obtain the % defoliation in a plot. In several cases, there was almost no defoliation, or defoliation was due to extreme drought stress, so a decision was made not to measure this parameter at those sites.

Plots were harvested with a two-row cotton stripper modified to catch the harvested material in a "cage" that was supported by load cells. A subsample of harvested cotton (approximately 1 kg) containing lint, seed, bracts, some branches, etc. was collected and ginned to determine the percentage of the harvested weight that was lint for each cultivar. Two replicates were ginned per cultivar for a location.

Fibermax (FM) 2484B2F (tested in 23 trials from 2010 to 2015) was used as the partially resistant comparison cultivar and Deltapine (DP) 0912B2RF (tested in 28 trials from 2009 to 2015), was the susceptible comparison cultivar. Incidence of wilt, and % defoliation were normalized so that a combined analysis could be conducted across all cultivars and trial sites. The scaling was conducted for each plot by subtracting the minimum value for that test site (X_{min}) from a plot rating (X_i), and then dividing by the range of values (X_{max}-X_{min}). All values were thusly converted to a 0 to 1 scale.

A mixed model analysis (SAS version 9.3, Cary, NC) was conducted with the Y-variable as normalized wilt (NW) or defoliation (ND) = cultivar. The Satterthwaite (1946) option was used to determine the degrees of freedom. The random statement contained the terms: year, site, replication(year), and replication(site).