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ECONOMICS AND MARKETING

Analysis of Returns above Variable Costs for Management of Verticillium Wilt in Cotton

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ABSTRACT

A large-plot study located in Halfway, TX, was conducted from 2007 to 2013 in an irrigated field infested with Verticillium wilt. Management options (crop rotation, irrigation amount, variety selection) and combinations of options that can reduce this disease were compared using returns above variable costs (RVC) analysis. A continuous cotton system was compared with a crop rotation system (2-yr cotton and 1-yr sorghum). Irrigation rates consisted of a base (1.0B), base + 50% (1.5B), and base - 50% (0.5B) rates. From 2007 to 2009, 1.0B targeted 80% of the evapotranspiration (ET) needs of cotton, and from 2010 to 2013, 1.0B targeted 60% ET. Varieties planted were tolerant or susceptible to Verticillium wilt. Data collected included wilt incidence, cotton lint yield, loan value for lint, sorghum yield, fertilizer types and amounts, and total irrigation applied. Cotton prices were approximately $1.15 and $1.54/kg lint ($0.52 to $0.70/lb) (adjusted up or down by actual loan value of cotton fiber), and sorghum was valued at $0.185/ kg ($8.40/cwt). Crop rotation generally resulted in higher RVC than continuous cotton, although higher cotton prices, and ET = 60% (drier conditions) could result in both systems having similar RVC. The 1.5B rate had higher RVC, but as irrigation increased above 80% of cotton needs, RVC was reduced compared with 1.0B. The 0.5B rate resulted in lower RVC than the 1.0B rate, except when ET = 80% and a susceptible variety was grown. The 1.5B rate combined with a tolerant variety always had higher RVC than growing a susceptible variety. The combinations of 1.5B rate and growing continuous cotton resulted in the most Verticillium wilt. Conditions that aggravated Verticillium wilt resulted in lower RVC.

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Verticillium wilt, caused by the soil-borne fungus *Verticillium dahliae* Kleb., is one of the most important diseases of cotton worldwide. Substantial losses have been reported in many countries including Australia, China, Greece, Turkey, U.S., and Uzbekistan (Bell, 1992). The disease results in blockage of the xylem and symptoms include chlorotic or necrotic discoloration of leaves, brown-streaked vascular system, defoliation, substantial yield reduction, and occasional plant death. The fungus persists by producing specialized structures called microsclerotia that survive long term in the soil (Wilhelm, 1955). The density of microsclerotia in soil has been correlated positively with incidence of wilt and subsequent yield loss (Paplomatas et al., 1992).

The development of Verticillium wilt is sensitive to environmental conditions and disease severity is greater when cool and wet conditions occur during the flowering and boll-filling stages of plant development (Garber and Presley, 1971; Talboys and Wilson, 1970; Wheeler and Woodward, 2014). There is evidence that excessive moisture, either from rainfall or irrigation, can lead to increased severity of Verticillium wilt (Cappaert et al., 1992; Wheeler et al., 2012). Excessive moisture also can lead to high densities of microsclerotia in soil (Wheeler et al., 2014).

Verticillium-wilt management in cotton is challenging, and an integrated approach is recommended. Examples of management tactics include crop rotation, particularly with high densities of *V. dahliae* (El-Zik, 1985); planting cultivars with good Verticillium-wilt tolerance (Paplomatas et al., 1992; Wei et al., 2015); and not over watering (Cappaert et al., 1992; Wheeler, et al., 2012). In addition, practices that do not cool the soil, such as raised beds, can minimize wilt severity (El-Zik, 1985; Leyendecker, 1950). Fumigation of soil with metam sodium is practiced in high-value crops such as potatoes to manage Verticillium wilt (Rowe and Powelson, 2002), but rates used in such crops are cost prohibitive in cotton. Woodward et al. (2011) found that lower rates have not been effective at reducing high microsclerotia densities sufficiently. In general, commercial upland cotton cultivars are all susceptible to Verticillium wilt, though variety differences exist in how quickly or severely symptoms are expressed (Wheeler and Woodward, 2014) and in microsclerotia production in soil (Chawla et al., 2012).

Use of these various management practices have been shown to reduce Verticillium wilt and in some cases improve cotton lint yield and quality. However, most of these practices come with an added cost or might negatively impact cotton yield. Crop rotation, for example, requires additional farm equipment and might have less competitive prices for the alternative crop. Reduced irrigation might result in reduced yield. A management practice should result in increased net returns, rather than just reduced disease.

Calculation of economic returns in general is not widely practiced in the field of plant pathology; rather, most studies focus on disease reduction and yield response. However, in some cases there is an effort to include economic factors to test whether fungicide management treatments are cost effective (Te Beest et al., 2013; Wegulo et al., 1997). Fungicide treatments generally do not have negative effects (unlike insecticides that might trigger secondary pest problems), so a cost/benefit analysis is fairly simple. However, other management tactics can result in more complicated inputs and returns. Reis et al. (1983) considered the impact of soybean varieties, crop sequences (i.e., corn and soybean rotations), nematicide usage, and fertilization for fields infested with the soybean cyst nematode. Management of this organism presents some similarities to those for *V. dahliae*. Reis et al. (1983) noted that no single set of experiments is likely to combine all the relevant factors involved with managing a pathogen that once present, is likely to remain forever at that site. The approach of trying to integrate multiple studies was used to predict which combinations of soybean cyst nematode management factors would result in optimal whole-farm economics. The team working on the system presented in this paper decided an experimental approach containing the most relevant management options was superior to trying to integrate various published studies.

Returns above variable costs (RVC) is a widely used tool to compare enterprises that use the same set of resources. RVC is total income less variable costs for that enterprise. In this study, RVC analysis is used to estimate relative profitability of various management options of Verticillium wilt in cotton. Agronomic and disease severity aspects of some of this work have been published previously (Wheeler et al., 2012, 2014).

MATERIALS AND METHODS

The experiments described in this study were initiated in 2007 and terminated after 2013 in a field located near Halfway, TX. The test area covered 48.6 ha irrigated by center pivot and divided into six equally sized wedges. One wedge has been in continuous cotton since 2001. Three wedges were in a 2-yr cotton and 1-yr sorghum rotation from 2007 to 2013 and were previously in a 2-yr cotton and 1-yr grain (sorghum or corn) rotation since 2001. The design of the rotation treatment permitted yield for all three parts of the rotation to be available every year of the study (i.e., sorghum yield; cotton in the first year following sorghum, and cotton in the second year following sorghum). However, there was no randomization of the two cropping systems. In 2010, two additional wedges that previously had been in continuous cotton for 9 yr were placed in a 1-yr cotton and 1-yr sorghum rotation (SCSC). Verticillium wilt was identified as a problem in the field for the first time in 2007 and has continued to be observed since.

Three irrigation treatments were imposed on the outside four spans of the eight-span pivot and remained in the same locations throughout the experiment. Irrigation rate (IR) was randomized and replicated four times along the four-span length, although in most years only three replications were used in the experiment. In some years, one replicate was used for other purposes. The base irrigation treatment (1.0B) was managed to meet approximately 80% of the evapotranspiration rate (ET) for cotton (Howell et al., 2004) when pumping capacity was sufficient during 2007 to 2009. Pumping capacity available to the pivot declined over time, so the 1.0B IR was reduced to provide ET of 60% for 2010 to 2013. The other IRs were 50% above and below the base treatment (i.e., 1.5B and 0.5B, respectively).

Within each IR there was a recommended tolerant variety to Verticillium wilt and one considered more susceptible to Verticillium wilt. These designations were determined based on multiple small-plot variety trials in Verticillium-wilt fields (Wheeler, 2007; Wheeler and Woodward, 2008, 2009, 2011, 2013). Variety was randomized within IR. An effort was made to select tolerant and susceptible varieties that had good yield potential in the absence of disease. The tolerant variety during 2007 was ‘Paymaster 2140B2RF’, and during 2008 and 2009 was ‘Deltapine (DP) 104B2RF’. The susceptible variety from 2007 to 2009 was ‘Stoneville 4554B2RF’. The tolerant variety from 2010 to 2013 was ‘Fibermax (FM) 9180B2F’ and the susceptible variety from 2010 to 2013 was ‘DP 0912B2RF’. In the

SCSC system, only wilt-tolerant varieties were used in the analysis from 2010 to 2013. In 2010, the tolerant variety was 'FM 9063B2F'; and in 2012 and 2013, the varieties were 'FM 9170B2F', 'FM 1944GLB2', 'FM 9250GL', and 'FM 2484B2F'. All these varieties in the SCSC rotation were considered tolerant to Verticillium wilt (Wheeler and Woodward, 2011, 2013).

To start the season, the irrigation amount was uniform for all irrigation treatments until plants were established, and then different rates were applied for the rest of the growing season. The irrigation amounts applied for each wedge and IR were recorded. Soils were assayed for nutrient needs during the winter, and differential amounts applied each year depending on nutrient test results and targeted irrigation levels. In general, nitrogen applied through the center pivot was proportional to irrigation amount as recommended (Morrow and Krieg, 1990). Plots were harvested with a four-row cotton stripper and weighed using a load-cell system on a boll buggy. Samples were taken of harvested cotton, ginned to determine turnout of lint, and lint was sent for HVI testing at the Texas Tech University Fiber and BioPolymer Research Institute (Lubbock, TX).

A loan value (base = $1.15/kg lint [$0.52/lb]) was obtained for each of the treatments each year (Anonymous, 2007, 2008, 2009, 2010, 2011, 2012, 2013). Loan values differ from the base value depending on the fiber properties of the lint. If the properties (micronaire, length, uniformity, elongation, strength, percent reflectance, degree of yellowness, leaf grade, and color grade) all fall into a base range, then the cotton is valued at $1.15/kg. However, for fiber properties above or below the base range, there are premiums and/or discounts used to adjust the loan value from its base quality value. These adjusted values above or below the base loan value were used to change the cotton prices accordingly, in the budget spreadsheet calculations. Two cotton prices were arbitrarily chosen for the analysis: $1.15/kg ($0.52/lb) lint and $1.54/kg ($0.70/lb) lint and these values were adjusted by the actual loan value differences. If for example, the loan value of a treatment combination was $1.16/kg lint ($0.01 higher than the base loan value), then the lint yield was multiplied by $1.16/kg and 1.55/kg lint to calculate revenue. Revenue was calculated as lint yield x price, plus $252.56/metric ton of cottonseed produced.

The RVC was calculated on an Excel spreadsheet (http://SouthPlainsProfit.tamu.edu) for each of 72 different treatment combinations representing 6 yr x two cropping systems x three IR x two varieties, at two different cotton prices (sorghum price was kept constant at $0.1852/kg [$8.40/cwt]). The yield for each treatment (averaged over 3-4 replications), turnout, and loan value for each treatment combination as well as fertilizer amounts, seeding rate, and irrigation applied for each treatment were used to calculate RVC. An example of production costs and income used in the calculation of RVC is presented in Table 1 for cotton and Table 2 for sorghum. The cropping system RVC for rotated cotton was calculated by adding the RVC for the two wedges of cotton plus the sorghum wedge for each year and then dividing by three.

A statistical analysis using a mixed model analysis with Proc Mixed (SAS version 9.3, SAS Institute, Cary, NC)was conducted with year being the replication factor and cropping system (CS), IR, and variety (V) and their interactions (IR x V) being independent factors. After examination of the initial results, the data sets were separated into 2007 to 2009 (when 1.0B had an ET = 80%) and 2010 to 2013 (when 1.0B had an ET = 60%). Due to a historic deviation from the normal weather patterns for this region, data from the 2011 year were excluded from any analysis. The dependent variables analyzed were yield; price adjustments due to lint quality (i.e., actual loan value: $1.15/kg lint); RVC for the cotton part of the system (i.e., cotton in continuous cotton system versus cotton in a rotation with sorghum); RVC for the continuous cotton versus the sorghum part of the system; and RVC for the entire system (continuous cotton versus cotton/cotton/sorghum). The analysis for each dependent variable was conducted separately for the two cotton prices and ET values. The model tested was Y = CS + IR + V + (IR x V), and year was the random factor. An additional analysis was conducted for 2010 to 2013 (minus 2011) where CS had three treatments (ET = 60%) and only using the tolerant variety. The model tested for this comparison was Y = CS + IR, and year was the random factor. Treatments were significant at p = 0.10 using the PDIFF option.

Wilt incidence was measured in each treatment combination for each year on three different areas in the plot. Each area rated was 10.7 m in length, and wilt incidence was counted on approximately 20 August each year. Incidence was calculated as the number of plants exhibiting symptoms of wilt/total number of plants in the 10.7-m row. The three ratings for each plot were averaged. Wilt incidence was analyzed with a mixed model. The model tested was similar to that for yield, except that years consisted of 2008 to 2010 and 2012 to 2013. Wilt incidence was not obtained in 2007, because the disease was not discovered until September, when it was too late to obtain wilt incidence accurately.

Table 1. An example of estimated income and variable costs per hectare for cotton (yield = 1788 kg lint/ha)

Variable factors	Quantity	Unit	Price	Total/ha
INCOME				
Cotton lint harvested[v]	1788 (1596)	kg/ha (lbs/a)	$1.596	$2854.34
Cotton seed harvested[v]	2.55 (1.133)	metric tons/ha (tons/a)	$252.56	$644.03
Total Income		/ha		$3498.37
VARIABLE COSTS				
Planting seed[z]	138.4 (56.0)	1000 kg (1000/a)	$0.63	$87.18
Technology fee[z]	138.4 (56.0)	1000 kg (1000/a)	$0.78	$107.94
Boll Weevil Assessment[u]	1.0	ha	$2.47	$2.47
Fertilizer - N dry[y]	67.2 (60.0)	kg/ha (lbs/a)	$1.18	$78.97
Fertilizer – P dry[y]	112.0 (100.0)	kg/ha (lbs/a)	$1.25	$140.18
Fertilizer – N liquid[y]	100.0 (89.3)	kg/ha (lbs/a)	$1.28	$127.58
Preplant herbicide & application[u]	1.0	ha	$21.62	$21.62
At-plant herbicide[u]	1.0	ha	$14.21	$14.21
Post-emergence herbicide & application[u]	1.0	ha	$66.10	$66.10
Fertilizer application[u]	1.0	ha	$11.74	$11.74
Insecticide & application[u]	1.0	ha	$29.65	$29.65
Harvest aids[u]	1.0	ha	$61.78	$61.78
Strip & module[x]	1788 (1596)	kg/ha (lbs/a)	$0.18	$315.50
Ginning[x]	21.3 (46.9)	100 kg (cwt)	$16.89	$359.59
Hoeing[u]	0.49 (0.2)	ha (acre)	$15.00	$7.41
Scouting[u]	1.0	ha	$22.24	$22.24
Spot spraying[u]	0.49 (0.2)	ha (acre)	$15.13	$7.41
Crop insurance[u]	1.0	ha	$98.84	$98.84
Operator labor & hand labor[u]	3.95	hours/ha	$11.76	$46.46
Irrigation labor[u]	2.22	hours/ha	$11.76	$26.14
Diesel fuel for tractors[u]	37.42 (4.0)	L/ha (gal/a)	$0.86	$32.12
Gasoline for pickup[u]	18.71 (2.0)	L/ha (gal/a)	$0.85	$15.81
Irrigation fuel[w]	50.9 (8.11)	cm/ha (ac-in)	$3.54	$180.27
Repair & maintenance for above-ground irrigation[w]	50.9	cm/ha	$0.39	$20.04
Repair and maintenance - other[u]		/ha		$45.72
Interest-operating capital[t]	6.00	%		$35.71
Total Variable Costs		/ha		1962.68
Returns above variable costs:				$1535.69

[z] Planting density changed between years and varieties, so the value was not uniform across all budget work sheets.

[y] Fertilizer type and amount changed between irrigation treatments, years, and occasionally between cropping systems. The amount listed is just an example from one treatment combination.

[x] The stripping, moduling, and ginning costs are based on the average lint yield (kg/ha) for each treatment.

[w] Based on amount of water applied.

[v] Income generated from cotton lint and seed changed as yield changed for each treatment.

[u] The quantity and price were uniform across all budget sheets.

[t] The same interest rate on operating costs used over all budgets.

Table 2. An example of estimated income and variable costs per hectare for sorghum

Variable factors	Quantity	Unit	Price	Total/ha
INCOME				
Harvested sorghum grain[v]	**8977 (80.15)**	**kg/ha (cwt/a)**	**$0.19**	**$1663.63**
VARIABLE COSTS				
Planting seed[w]	**5.04 (4.5)**	**kg/ha (lbs/a)**	**$5.30**	**$26.69**
Fertilizer - N dry[z]	**123.2 (110.0)**	**kg/ha (lbs/a)**	**$1.175**	**$144.78**
Fertilizer – P dry[z]	**56.0 (50.0)**	**kg/ha (lbs/a)**	**$1.252**	**$70.10**
Fertilizer – N liquid[z]	**100.0 (89.3)**	**kg/ha (lbs/a)**	**$1.275**	**$127.53**
Preplant herbicide & application[w]	**1.0**	**ha**	**$52.19**	**$52.19**
Fertilizer application[w]	**1.0**	**ha**	**$29.04**	**$29.04**
Insecticide & application[w]	**1.0**	**ha**	**$10.60**	**$10.60**
Custom harvest & haul[y]	**36.36**	**100 kg**	**$3.27**	**$118.83**
Crop insurance[w]	**1.0**	**ha**	**$71.66**	**$71.66**
Operator labor & hand labor[w]	**3.21**	**hours**	**$11.75**	**$37.76**
Irrigation labor[w]	**2.22**	**hours**	**$11.75**	**$26.02**
Diesel fuel for tractors[w]	**29.93 (3.2)**	**L/ha (gal/a)**	**$0.86**	**$25.70**
Gasoline for pickup[w]	**18.71 (2.0)**	**L/ha (gal/a)**	**$0.85**	**$15.81**
Irrigation fuel[x]	**57.05 (9.09)**	**cm-ha (ac-in)**	**$3.54**	**$202.16**
Repair & maintenance for above-ground irrigation[x]	**57.05**	**cm-ha**	**$0.39**	**$22.46**
Repairs & maintenance - other[w]		**ha**		**$40.16**
Interest-operating capital[u]	**6.00%**	**ha**		**$27.08**
Total Variable Costs		**ha**		**$1048.57**
Returns above variable costs:				**$615.06**

[z] Fertilizer type and amount did change between irrigation treatments, years, and occasionally between cropping systems. The amount listed is just an example from one treatment combination.

[y] The custom harvest and hauling was an example for one treatment based on yield.

[x] Based on amount of water applied.

[w] The quantity and price were uniform across all budget sheets.

[v] Income generated from sorghum grain. The quantity changed as yield changed, but price was consistent across all budget work sheets.

[u] The same interest rate on operating costs used over all budgets.

RESULTS

Wilt Incidence. The main effects of cropping system, IR, and variety all had significant effects on wilt incidence. Continuous cotton had a higher wilt incidence (20%) than the rotated cotton system (8%). Wilt incidence increased as IR increased (3.4%, 10.7%, and 28.0% incidence wilt, for 0.5B, 1.0B, and 1.5B rates, respectively). The susceptible cotton variety exhibited higher wilt incidence (16%) than the tolerant variety (12%). The IR x V term was not significant in the analysis.

Yield. Cropping system had a significant effect on yield for both ET = 80 and 60%. The continuous cotton (CCC) had consistently lower yields than the 1-yr sorghum rotated with 2-yr cotton (ROT) (CCC = 1145 and ROT = 1275 kg of lint/ha, when ET = 60% [10% reduction]; CCC = 1090 and ROT = 1307 kg lint/ha when ET = 80% [17% reduction]). For ET = 60%, IR significantly affected yield (0.5B = 852, 1.0B = 1309, and 1.5B = 1466 kg lint/ha), but variety did not ($p = 0.103$). For ET = 80%, there was an interaction between IR and variety (Table 3). For both ET = 60 and 80%, the 0.5B rate had the lowest yields for both tolerant and susceptible varieties, and yields were similar between tolerant and susceptible varieties. At ET = 80%, the 1.0B and 1.5B rates had similar yields within a variety, but the tolerant variety yielded higher than the susceptible variety. With ET = 60% and 1.5B rate, the tolerant variety yielded more than the susceptible variety, and the 1.5B rate yielded more than the 1.0B rate (with a tolerant variety). However, with the susceptible variety and ET = 60%, the 1.0B and 1.5B rates yielded similarly.

Table 3. Effect of irrigation rate and variety on cotton yield (averaged over cropping system[w])

IR[z]	ET=60%[z]		ET = 80%[z]	
	T[y]	S[y]	T	S
	kg lint/ha			
0.5B	839 cz[x]	866 bz	935 bz	988 bz
1.0B	1337 bz	1281 az	1416 az	1262 ay
1.5B	1586 az	1347 ay	1430 az	1160 ay

[z] IR = irrigation rate, where 1.0B = base IR, and the low (0.5B) and high (1.5B) IRs were decreased or increased by 50% of the base rate. The base rate targeted 80% of the crop evapotranspiration (ET) needs in 2007 – 2009, and 60% from 2010 onwards.

[y] T = a tolerant variety to Verticillium wilt and S = a susceptible variety to Verticillium wilt.

[x] Within a column, the same letter (a, b, c) indicated that IR means were not significantly different at p = 0.10; whereas within an ET level, the same letter (y, z) indicated that the varieties were not significantly different (p = 0.10) for that IR.

[w] The combinations of IR and varieties were averaged over two cropping systems (continuous cotton, and a crop rotation consisting of 2-yr of cotton and 1-yr of sorghum).

When cropping system was expanded to three treatments (2010 and later) and variety effect was eliminated (tolerant varieties only), then yield was affected by IR, but not by cropping system. The sorghum/cotton alternation, 1-yr sorghum and 2-yr cotton rotation, and continuous cotton averaged 1353, 1288, and 1221 kg lint/ha, respectively. Yield for each IR differed significantly, and yields averaged 867, 1370, and 1625 kg lint/ha for the 0.5B, 1.0B, and 1.5B rates, respectively.

Adjusted Price. The adjustments from the loan value due to lint quality were affected by IR at both target ET values. With ET = 80%, the highest valued cotton was associated with 0.5B (adjustment of $0.037/kg of lint over loan value), which was significantly higher than with 1.0B (adjustment of $-0.007/kg of lint below the loan value), which was higher than 1.5B (adjustment of $-0.104/kg of lint below the loan value). With ET = 60%, the 0.5B and 1.0B rates had similar price adjustments ($0.053 and $0.062/kg lint above loan value, respectively) and higher than the 1.5B rate ($0.022/kg of lint above loan value). The results were similar at ET = 60% when cropping system was expanded to three treatments (data not presented). Variety effect on loan value was marginally significant at ET = 60% (p = 0.09). The tolerant variety was valued higher ($0.053/kg lint over the loan value) than the susceptible variety ($0.037/kg lint over the loan value).

RVC for Cotton. This included cotton produced in cotton/sorghum rotation and in continuous cotton system. Rotated cotton had a higher RVC than continuous cotton (Table 4) under both lint prices and ET levels, when averaged over the three IRs and the tolerant and susceptible varieties. When the third system (rotated cotton every other year) was added and only the tolerant varieties were used in the comparison, continuous cotton had marginally (p = 0.09) lower RVC than cotton from the 1:1 sorghum/cotton rotation, although only with the higher cotton price. When lint was valued at $1.15/kg, the cropping systems had similar RVC as continuous cotton. In this reduced model (no variety component), there were no differences in RVC from the rotated 2-yr of cotton and the continuous cotton at either cotton price.

Table 4. Effect of cropping system (CS) on the returns above variable costs for the cotton part of the cropping systems

CS[z]	[w]Approximate price of cotton					
	$1.15/kg		$1.54/kg		$1.15/kg	$1.54/kg
	ET[y] = 60% T,S[v]	ET = 80% T,S	ET = 60% T,S	ET = 80% T,S	ET = 60% T only	
	Returns above specified costs ($/ha)					
CCC	115 b[x]	-104 b	565 b	329 b	209 a	689 b
ROT	275 a	150 a	777 a	669 a	299 a	806 ab
SCSC	-------	-------	-------	-------	372 a	909 a

[z] Cropping system where CCC = continuous cotton and ROT = 1-yr sorghum rotated with 2-yrs cotton. SCSC = cotton rotated every other year with sorghum (only at ET = 60% and with a tolerant variety).

[y] ET = The returns above variable costs were averaged over three irrigation rates (IR). The middle IR targeted 80% of the crop evapotranspiration (ET) needs in 2007 – 2009, and 60% from 2010 onwards.

[x] Within a column the different letters indicate treatments were significantly different at p = 0.10.

[w] Cotton was assigned a loan value each year based on HVI testing of lint. The base loan value ($1.15/kg lint) was subtracted from the actual loan value for each year-treatment combination, and the difference was added (or subtracted if negative) from the cotton prices of $1.15 and $1.54/kg lint.

[v] Returns above variable costs were averaged over a tolerant (T) and susceptible (S) variety, when T, S is specified; or averaged over just tolerant variety when T only is specified. The SCSC crop rotation only included a tolerant variety.

Irrigation rate effects were highly significant ($p < 0.001$) for the four combinations of lint price and ET on RVC. Variety effects were significant ($p < 0.056$) for all combinations of lint prices and ETs, and in some cases there were significant interactions between IR and variety. Under the wetter conditions (ET = 80%), 1.5B had lower RVC than 1.0B IR at both prices (Table 5). However, under drier conditions overall (ET = 60%), the RVC for both 1.0B and 1.5B were similar within a variety. Under most combinations of lint price, ET, and variety, the 0.5B had lower RVC than 1.0B. However, at ET = 80% and a susceptible variety, 1.0B and 0.5B had similar RVC (though numerically higher for 1.0B).

For all lint price and ET combinations, the tolerant variety had a higher RVC than the susceptible variety at the 1.5B IR. However, varieties did not have significantly different RVC at the 0.5B and 1.0B IRs. The combination of too much water (1.5B at ET = 80%) and a susceptible variety significantly reduced RVC for cotton.

RVC for Sorghum Versus Continuous Cotton. When the price of cotton was near loan value, then the continuous cotton system had a lower RVC than sorghum, for both ET levels (Table 6). When the price of cotton lint was near $1.54/kg, then the continuous cotton system had a similar RVC as growing sorghum.

Table 5. Effect of irrigation rate and variety on returns above variable costs ($/ha) for the cotton part of the cropping systems[v]

IR[z]	Approximate price of cotton[w]							
	$1.15/kg lint				$1.54/kg lint			
	ET = 60%[z]		ET = 80%[z]		ET = 60%		ET = 80%	
	T[y]	S[y]	T	S	T	S	T	S
	Returns above variable costs ($/ha)							
0.5B	-68 bz[x]	-50 bz	63 bz	28 az	261 bz	290 bz	309 cz	420 az
1.0B	388 az	302 az	287 az	131 az	915 az	806 az	850 az	632 az
1.5B	442 az	156 ay	21 bz	-266 by	1067 az	686 ay	589 bz	193 by

[z] IR = irrigation rate, where B = base IR, and the low (0.5B) and high (1.5B) IRs were decreased or increased by 50% of the base rate. The base rate was designed to meet 80% of the crop evapotranspiration (ET) needs in 2007 – 2009, and 60% of the ET needs from 2010 onwards.

[y] T = a tolerant variety to Verticillium wilt and S = a susceptible variety to Verticillium wilt.

[x] Within a column, the same letter (a, b, c) indicated that IR means were not significantly different at $p = 0.10$; whereas within an ET level, the same letter (y, z) indicated that the varieties were not significantly different ($p = 0.10$) for that IR.

[w] Cotton was assigned a loan value each year based on HVI testing of lint. The base loan value ($1.15/kg lint) was subtracted from the actual loan value for each year-treatment combination, and the difference was added (or subtracted if negative) from the cotton prices of $1.15 and $1.54/kg lint.

Table 6. Comparison between returns above variable costs for sorghum in a 2-yr cotton and 1-yr sorghum rotation and cotton in a continuous cotton system

CS[z]	Approximate price of cotton[w]			
	$1.15/kg		$1.54/kg	
	ET[y] = 60%	ET = 80%	ET = 60%	ET = 80%
	$/ha			
CCC	115 b[x]	104 b	565 a	329 a
Sorghum	434 a	474 a	434 a	474 a

[z] Cropping system where CCC = continuous cotton and sorghum was the sorghum component of a 3-yr rotation with 1-yr sorghum and 2-yr cotton. Sorghum was valued at $0.1852/kg. The cropping system returns were averaged over three IRs and two varieties.

[y] ET = the medium IR targeted meeting an evapotranspiration (ET) of 80% in 2007 – 2009 and 60% after 2009.

[x] Within a column the different letters indicate cropping system means were significantly different at $p = 0.10$.

[w] Cotton was assigned a loan value each year based on HVI testing of lint. The base loan value ($1.15/kg lint) was subtracted from the actual loan value for each year-treatment combination, and the difference was added (or subtracted if negative) from the cotton prices of $1.15 and $1.54/kg lint.

RVC for the Entire System. The rotated system (ROT) had a higher RVC at both ET levels, when cotton lint was priced near \$1.15/kg (Table 7). When cotton lint was near \$1.54/kg, then ROT had a higher RVC than continuous cotton at ET = 80%, but RVC was similar in both systems at ET = 60%. ROT and SCSC had similar RVC at both cotton lint prices. Irrigation rate affected RVC in all ET and price scenarios tested (Table 8), similar to what was already described in the cotton RVC. The 1.0B rate had significantly higher RVC than the 0.5B rate, except for the combination of a susceptible variety/ET = 80% (both cotton lint prices). However, the relative relationship between 1.0B and 1.5B was strongly affected by ET. For ET = 80%, the RVC for 1.5B were lower than 1.0B for both varieties and cotton prices. With ET = 60% the 1.0B and 1.5B rates had similar RVC for both varieties and both lint prices. The 1.0B and 1.5B RVC were also similar when the third cropping system (SCSC) was included in the analysis (tolerant varieties only) at the lower cotton price (Table 9). However, at the higher cotton price, the 1.5B IR had marginally higher RVC (p = 0.084) than the 1.0B IR with a tolerant variety.

Table 7. Effect of cropping system (CS[z]) on returns above variable costs for the entire system

CS[z]	Averaged over both tolerant and susceptible varieties				Tolerant variety only	
	Approximate cotton lint price[w]					
	\$1.15/kg		\$1.54/kg		\$1.15/kg	\$1.54/kg
	ET[y] = 60%	ET = 80%	ET = 60%	ET = 80%	ET = 60%	
	(\$/ha)					
CCC	115 b[x]	-104 b	565 a	329 b	209 b	689 a
ROT	328 a	258 a	662 a	604 a	344 a	682 a
SCSC	-------	-------	-------	-------	393 a	751 a

[z] Cropping system where CCC = continuous cotton and ROT = 1-yr sorghum and 2-yr cotton rotation. SCSC = 1-yr sorghum alternated with 1-yr cotton. Returns above variable costs were averaged over three IRs.

[y] ET = There were three IRs in the test, and the middle rate targeted meeting an evapotranspiration (ET) of 80% in 2007 – 2009 and 60% after 2009.

[x] Within a column the different letters indicate cropping system means were significantly different at p = 0.10.

[w] Cotton was assigned a loan value each year based on HVI testing of lint. The base loan value (\$1.15/kg lint) was subtracted from the actual loan value for each year-treatment combination, and the difference was added (or subtracted if negative) from the cotton prices of \$1.15 and \$1.54/kg lint. Sorghum was valued at \$0.185/kg.

Table 8. Effect of irrigation rate and cotton variety (averaged over cropping systems) on returns above variable costs for the entire cropping system[z]

IR[y]	Approximate price of cotton[v]							
	\$1.15/kg lint				\$1.54/kg lint			
	ET = 60%[y]		ET = 80%[y]		ET = 60%		ET = 80%	
	T[x]	S[x]	T	S	T	S	T	S
	Returns above variable costs (\$/ha)							
0.5B	-36 bz[w]	-27 bz	-15 bz	52 az	238 bz	254 bz	293 cz	374 abz
1.0B	393 az	305 az	313 az	176 az	830 az	718 az	774 az	585 az
1.5B	472 az	221 ay	84 bz	-148 by	989 az	654 ay	546 bz	227 by

[z] There were two cropping systems, a continuous cotton system and crop rotation consisting of 2 yr of cotton and 1 yr of sorghum.

[y] IR = irrigation rate, where 1.0B = base IR, and the low (0.5B) and high (1.5B) IRs were decreased or increased by 50% of the base rate. The base rate was designed to meet 80% of the evapotranspiration (ET) needs of the crop in 2007 – 2009, and 60% ET from 2010 onwards.

[x] T = a tolerant variety to Verticillium wilt and S = a susceptible variety to Verticillium wilt.

[w] Within a column, the same letter (a, b, c) indicated that IR means were not significantly different at p = 0.10. Within an ET and cotton price combination, the same letter (y, z) indicated that the varieties were not significantly different (p = 0.10) for that IR.

[v] Cotton was assigned a loan value each year based on HVI testing of lint. The base loan value (\$1.15/kg lint) was subtracted from the actual loan value for each year-treatment combination, and the difference was added (or subtracted if negative) from the cotton prices of \$1.15 and \$1.54/kg lint. Sorghum was valued at \$0.185/kg.

Table 9. Effect of irrigation rate on returns above variable costs for Verticillium wilt tolerant varieties when averaged across three cropping systems[w]

IR[z]	Approximate price of cotton[y]	
	$1.15/kg lint	$1.54/kg lint
	($/ha)	
0.5B	-5 b[x]	260 c
1.0B	424 a	842 b
1.5B	526 a	1020 a

[z] IR = irrigation rate, where 1.0B = base IR, and the low (0.5B) and high (1.5B) IRs were decreased or increased by 50% of the base rate. The base IR targeted meeting 60% of the evapotranspiration needs of the crop.

[y] Cotton was assigned a loan value each year based on HVI testing of lint. The base loan value ($1.15/kg lint) was subtracted from the actual loan value for each year-treatment combination, and the difference was added (or subtracted if negative) from the cotton prices of $1.15 and $1.54/kg lint. Sorghum was valued at $0.185/kg.

[x] Within a column, the same letter (a, b, c) indicated that IR means were not significantly different at $p = 0.10$.

[w] Cropping systems consisted of a continuous cotton system; a rotation with 2 yr of cotton and 1 yr of sorghum; and a rotation of cotton and sorghum every other year.

The variety response was complicated by IR. At the 0.5B IR, the tolerant and susceptible variety had similar RVC, though the susceptible variety always had a higher numerical RVC (average of 25% higher) than the tolerant variety (Table 8). At the 1.0B IR, again the tolerant and susceptible variety had similar RVC, though now the tolerant variety always had numerically higher RVC (average of 28% higher) than the susceptible variety. At the 1.5B IR, the tolerant variety always had a significantly higher RVC (61% higher at ET = 60% and 808% higher for ET = 80%) than the susceptible variety.

CONCLUSIONS

The objective of this work was to provide economic evaluation of management options for Verticillium wilt. Management options using crop rotation and IR result in complicated dynamics, beyond simple disease management. Disease management that involves fungicide applications can be simpler to evaluate economically, because the fungicide usually will either reduce disease and increase yield, or have no impact. The economic impact then can be evaluated for a range of disease scenarios (Hollingsworth et al., 2008; Te Beest et al., 2013; Wegulo et al., 1997). Disease management options that have both negative and positive attributes are more difficult to use for disease recommendations.

Verticillium wilt was first observed in 2007 at the test site, and quickly developed into a yield-limiting factor, particularly in continuous cotton and under higher IR. The rotated cropping system of 2-yr cotton and 1-yr sorghum produced a higher RVC, at the prices tested, than did continuous cotton. The use of varieties with tolerance to Verticillium wilt also produced higher RVC than varieties susceptible to Verticillium wilt at the highest IR. An IR that targeted a crop ET replacement rate of 60 to 80% resulted in consistently better RVC than lower IRs. Irrigation rates that targeted ET rates of substantially greater than 80% could result in much lower RVC and are not recommended. Disease was much higher at this site under the 1.5B IR and with continuous cotton.

An integrated approach of crop rotation and planting a tolerant variety resulted in higher RVC than the alternatives of continuous cotton or planting a susceptible variety. Irrigation rates that reduced disease had to be balanced with the water needs of the crops for adequate yield. The best IR appeared to be one that met approximately 80% of the crop water requirements. As IR was reduced to meeting less than 60% of the crop water requirements, yields were reduced dramatically, although disease was also less; and as IR was increased substantially above 80% of the crop water requirements, yields were also reduced, in part due to severe Verticillium wilt and other factors related to over watering.

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