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Resistance of Cotton Cultivars to Verticillium Wilt and Its Relationship to Yield[1]

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ABSTRACT

Twenty-eight to 35 upland cotton cultivars (*Gossypium hirsutum* L.) representing a wide range of resistance to the fungus *Verticillium albo-atrum* (microsclerotial form) were grown in six tests spanning a 3-year period on moderately to severely infested fields. Various assessments of foliar or vascular damage to each of the cottons were made during the course of the season.

Ratings based on visual estimates of foliar damage made in either August or September were most closely related to yield performance, accounting for 35 to 65% of the yield variation among the cottons in five of the six tests. Percentages of plants showing early season foliar symptoms were less well correlated with yield, while postharvest vascular ratings showed virtually no yield correlation.

***Additional index words:* *Gossypium hirsutum* L., *Verticillium albo-atrum*, Disease ratings, Genetic tolerance, Physiological tolerance.**

VERTICILLIUM wilt of cotton (*Gossypium hirsutum* L.) is caused by a soil-borne fungus *Verticillium albo-atrum* (MS) which penetrates the vascular system of the roots and spreads throughout the plant, causing damage to both the vascular system and the foliage. Since the first reported field discovery on cotton in 1928 (12) it has become a major disease in much of the cotton-growing area of the United States and in many other countries. Because of its economic importance, there have been numerous investigations of the disease as it relates to the cotton plant. These

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have included studies of the fungus itself (9), methods of invasion and mechanisms of resistance (4, 7), environmental factors affecting its development (9), and the genetics of resistance (2, 17, 19). These subjects have recently been covered in a series of reviews by Ranney et al. (16).

The inheritance of Verticillium wilt resistance is unclear though it appears that different types of gene action are involved (2, 14, 15, 17, 19). Complexities arise from the extreme sensitivity of genetic expression to environmental factors, particularly temperature (3), and also from differences in pathogenicity of various strains and isolates (11). In spite of intensive applied breeding programs which have been carried on in several states (6, 14), J. R. Cotton (5) in a review in 1965 stated that no upland cotton approached immunity to the disease. This probably still holds true today though much progress has been made and a wide range of resistance exists among the many current strains and varieties. A number of these are highly tolerant except under the most severe infestations.

It has been pointed out that conclusions derived from certain genetic studies are influenced by the system used to measure disease expression (17). Any evaluation method, particularly as it relates to applied breeding endeavors, should not only differentiate between varying intensities of disease reaction but should also be indicative of the effect of the disease on yield. Different investigators have measured resistance on the basis of the percentage of plants showing foliar symptoms (1, 10), percentage or degree of vascular discoloration (8, 9, 18), recovery of the organism from the tissues of exposed plants (18), or a combination of these methods. A more subjective method is a grading system based on visual estimates of foliar damage (13, 14, 17).

The purpose of this study was to systematically compare different times and methods of rating for disease as expressed by different cotton genotypes under natural field infestations and to relate these measurements to the ability to set and mature fruit. For several years cultivars, derived from breeding programs from across the United States that have an extremely wide range of resistance to Verticillium wilt, have been compared in replicated field trials and evaluated for yield and quality in the San Joaquin Valley.

The six tests reported in this study were in fields sufficiently infested with the disease to cause extensive damage, severely limit production in the susceptible cottons, and to cause varying degrees of damage in the more resistant lines.

MATERIALS AND METHODS

From 28 to 35 widely different genotypes were grown in each of the 3 years of this study. These were predominantly newly developed experimental lines but also included some of the major commercial cultivars representative of different areas of the Cotton Belt. The locally developed 'Acala SJ-1' cultivar was a standard entry in all of the tests.

The tests were planted in a randomized block design with four replications, each plot consisting of four rows 97 cm apart and 18.3 m long. To avoid border effects only the two inside rows were harvested for yield.

Near the beginning of flowering in late June or early July, the percentage of plants in each cultivar showing foliar symptoms was determined on one full row in each replication. This is termed "early-season wilt percentage." No attempt was made to rate severity of infection at this time. Near the end of the boll setting period about the middle of August, termed "mid-season," a visual estimate was made of foliar damage in each plot. The rating scale from 1 to 10 (for convenience this is expanded to a 10 to 100 rating in the tabulation) ranged from no observable external symptoms at 10 to complete defoliation or desiccation of all plants at 100. About mid-September, termed "late-season," another rating was made in the same manner. Finally, following harvest the base of the stems from 25 randomly selected plants in each plot was cut to determine the percentage of plants showing vascular discoloration. In the last 2 years of the study the cut stems were also individually graded, based on the intensity and extent of the darkening. This ranged from no vascular discoloration at a rating of 1 to intense darkening of the entire cross section at a rating of 5.

For every date within a test, correlation coefficients were computed between the mean readings of each of the cultivars and the corresponding mean yields. For each test, correlation coefficients were likewise computed between the different times and methods of disease evaluation. Mean values of the four replications were used in all calculations.

RESULTS AND DISCUSSION

The correlation of yield with the various times and methods of rating for disease resistance are shown in Table 1 for each of the six tests together with the range in yield and range in wilt reactions of the cottons. All six tests showed highly significant yield differences among cultivars. As one might expect, the correlations of yield with wilt reaction are mostly negative, i.e., increased severity of symptoms is associated with decreased yields. However, the closeness of this association varies greatly with the time and method of estimating plant damage.

A significant buildup of the disease often occurs in May or June in the San Joaquin Valley, but this is usually suppressed with the onset of prolonged hot weather in July. In three of the tests there was a measurable amount of wilt appearing by late June. The percentage of plants showing foliar symptoms at this time was not closely related to final yield, even though in two of the instances the correlation coefficients were statistically significant. In the one test where the correlation failed there were no significant differences among the cultivars in percentage infection.

Cultivar differences with respect to visual estimates of foliar damage made in August and in September (mid-season and late-season) were highly significant in all tests, and these estimates in turn were best related to yield of any of the ratings. They were significantly and inversely correlated with yield in five of

Table 1. Correlation (r) of lint yield of cotton cultivars with various indices of Verticillium wilt infection.

			June-July foliar symptoms†		August foliar ratings‡		September foliar ratings‡		Postharvest vascular discoloration§	
Location	Year	Cultivar yield range	Range	r	Range	r	Range	r	Range	r
		kg/ha	%						%	
Woodville	1968	(594-1109)**	(6-23)**	-.49**	(29-64)**	-.78**	(55-98)**	-.71**	(73-98)*	-.24
Woodville	1969	(280-930)**	(18-62)ns	-.12	(46-88)**	-.81**	(59-88)**	-.73**	(78-100)	-.01
Woodville	1970	(370-1142)**	<1	---	(12-63)**	-.72**	(39-95)**	-.75**	(75-100)*	.04
Arvin	1968	(728-1714)**	----	---	(33-73)**	-.68**	(40-90)**	-.66**	(33-94)	.11
Madera	1969	(784-1277)**	(0-7)**	-.52**	(10-54)**	-.61**	(11-75)**	-.59**	---	---
Madera	1970	(605-941)**	<1	---	(10-34)**	-.19	(15-72)**	.03	(67-94)	.21

*, ** Significant at the 5 and 1% probability levels, respectively. † Percentage of plants showing soliar symptoms. ‡No observable foliar symptoms at rating of 10, increasing to complete defoliation or desiccation of all plants at rating of 100. § Percentage of plants showing vascular discoloration.

the six tests and accounted for 35 to 65% of the yield variation among the cultivars. The remaining variation indicates that genetic factors not directly related to wilt resistance are responsible for much of the yield performance, even in heavily infested fields where disease is a major factor limiting production. These two visual ratings were about equally correlated with yield even though the earlier one (in August) was made while the wilt symptoms were still increasing and before the disease had reached its maximum expression. A better relationship might therefore have been expected on the later date but may have been complicated to a greater degree by leaf senescence normally associated with advanced maturity and in some instances by nutritional symptoms, particularly potash deficiency.

The percentage of plants showing vascular discoloration was not strongly influenced by cultivar differences, reaching significance in only two of five tests. Furthermore, disease ratings based on this criterion were not good indicators of field tolerance as evidenced by the very low and nonsignificant correlation coefficients, some of them positive as well as negative. When this became evident it seemed likely that a rating based upon the intensity of discoloration as well as the percentage of plants thus affected would provide a better measure of resistance. The rating system did indeed magnify the cultivar differences and increased their significance, as shown in Table 2. However, comparison of the two methods shows that although the correlation with yield appeared to improve slightly by using the grading system it did not approach the degree of correlation based on foliar symptoms nor did it reach significance in any instance. This would imply that foliar damage is a better indicator of adverse yield effects than vascular damage. In another study not reported here a cultivar of *G. barbadense* which approached complete resistance based on foliar symptoms showed nearly the same percentage of plants with vascular discoloration as the upland cottons, although of a much lower intensity. One unpublished report has actually shown an inverse relationship between vascular discoloration and other indicators of resistance of several cultivars (R. H. Garber, personal communication).

Indirectly, all of this supports some evidence from the laboratory and greenhouse that resistance is not related primarily to the ability of the roots to withstand invasion of the organism but rather to the ability to suppress colonization throughout the plant once it does enter the vascular system (4, 7). Wilhelm, Sagen, and Tietz (18) have successfully used a vascular rating system in combination with other measurements to differentiate between levels of resistance, but many of the lines they worked with were *G. barbadense* and possessed a higher order of resistance than is found in most upland cottons. Results of the present study would not necessarily preclude the usefulness of vascular ratings in upland cotton as an indicator of the general level of infestation in a field.

In addition to yield relationships, correlations were made between the different dates and methods of measuring wilt reaction. Theoretically, if each of the ratings were equally correlated with yield then these ratings in turn would of necessity bear a high, positive correlation with each other. In all instances there was a positive relationship between the different readings taken throughout the season but many of these were nonsignificant (Table 3). Only the mid-season and late-season visual ratings made in August and September were consistently well correlated with each other. These two ratings in turn did not correlate as well with either of the vascular ratings and were inconsistently correlated with the early season percentage infection, a possible indication of recovery, and subsequent reinfection. This further indicates that the relative response of a cotton to early infection is not always indicative of its eventual wilt reaction after it has set most of its bolls.

There were individual instances of fruitful cottons exhibiting a high level of resistance early in the season, but which showed a greater than average breakdown of the leaves after the crop had been set. This suggests that a heavy fruit load of itself contributes to greater plant damage than would otherwise be the case. Conversely, as has commonly been observed, unfruitful types tended to be associated with fewer symptoms and less breakdown (5), a possible manifestation of physiological rather than true genetic resistance.

Staten (14) used the term "physiological tolerance" to signify progenies which maintained a large leaf area per unit of fruit, but which tend to be late maturing, "leafy," and unproductive. Genetic tolerance was used to describe a strain which endured the disease without being greatly damaged and which was not excessively late and leafy. This might also be termed agronomic or field tolerance, and implies an ability to re-

Table 2. Correlation (r) of yield of cotton cultivars with Verticillium wilt as measured by two methods of evaluating vascular damage.

Location	Year	Discolored stems: Range	Discolored stems: r	Intensity rating†: Range	Intensity rating†: r
		%			
Woodville	1969	(78-100)	-.01	(3.0-4.7)**	-.18
Woodville	1970	(75-100)*	.04	(2.2-4.0)**	-.26
Madera	1970	(67-94)	.21	(1.9-3.3)**	-.12

*,** Significant at the 5 and 1% probability levels, respectively. † No vascular discoloration at rating of 1, increasing to intense darkening of entire cross-section of the stem at rating of 5.

Table 3. Correlation between different dates and methods of evaluating Verticillium wilt on cotton.

		Percent symptoms in June-July vs:				August foliar rating vs:			September foliar rating vs:		
Location	Year	Aug. foliar rating	Sept. foliar rating	Post-harvest vascular %	Post-harvest vascular rating	Sept. foliar rating	Post-harvest vascular %	Post-harvest vascular rating	Post-harvest vascular%	Post-harvest vascular rating	Vascular % vs vascular rating
Woodville	1968	.73**	.48**	.41**	---	.84**	.34*	---	.30	---	---
Woodville	1969	.16	.24	.66**	.68**	.92**	.01	.31	.15	.43**	.66**
Woodville	1970	---	---	---	---	.87**	.16	.28	.11	.53**	.79**
Arvin	1968	---	---	---	---	.79**	.37*	---	.28	---	---
Madera	1969	.76**	.72**	---	---	.93**	---	---	---	---	---
Madera	1970	---	---	---	---	.87**	.42*	.59**	.31	.42*	.77**

*,** Significant at the 5 and 1% probability levels, respectively.

main reasonably productive in the presence of a certain amount of foliar or vascular damage. As more is learned of the nature of the genetic mechanisms involved, more rapid progress toward development of a truly resistant cotton may be possible. In the meantime these results suggest a continuing need for breeding programs to develop strains which can better endure the disease without excessive foliar damage while maintaining good productivity combined with acceptable earliness.

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