Published March, 1963

# Fusarium Wilt-Root Knot Nematode and Verticillium Wilt Resistance in Cotton: Possible Relationships and Influence on Cotton Breeding Methods[1]

W. P. Sappenfield[2]

THE breeding of cotton *(Gossypium hirsutum)* resistant to the verticillium wilt disease, caused by *Verticillium alboatrum* Reinke and Berth, has become increasingly necessary because of the increased incidence of this disease in the upper Mississippi delta and the lack of resistant varieties adapted to the area. The available evidence indicates that transferring resistance or tolerance from the late-maturing unadapted strains to early-maturing adapted varieties will be difficult. Explorations of new breeding methods and procedures are required.

The performance of varieties and strains of Upland cotton in tests in southeast Missouri have indicated that some relationship exists between resistance to the fusarium wilt-root knot nematode disease complex, caused by *Fusarium oxysporum f. vasinfectum* (Atk.) Synder and Hansen, and *Meloidogyne incognita* var. *acrita* Chitwood, 1949, and tolerance to verticillium wilt.

Smith (1) obtained significant negative correlations between the percentage of plants showing fusarium wilt-root knot nematode symptoms and lint yield. Root-knot nematode severity and the percentage of fusarium wilt infected plants were positively correlated. Staffeldt and Fryxell (2) found that verticillium wilt percentage was not a good measure of tolerance to verticillium wilt under New Mexico conditions. However their ratings, based on the percent of functioning photosynthetic area and plant stunting by verticillium infection, gave significant negative correlations with yield. Their studies also indicated that early season ratings were more meaningful than late season ratings. Waddle et al. (3) reported differences in tolerance to verticillium wilt based on the percentage of plants showing wilt symptoms. Wiles (4) reported differences in verticillium wilt tolerance based on the percentage survival of inoculated seedlings thirty days after inoculation.

Blank,[3] Smith,[4] and Wiles (4) have also suggested that some cotton strains are resistant or tolerant to both verticillium and fusarium wilt.

In 1954, Acala 49–149, a cotton strain tolerant to verticillium wilt in New Mexico, was also resistant to fusarium wilt in the regional fusarium wilt screening tests at Tallassee, Alabama. Inheritance studies by Smith[4] indicates that Acala 49–149 possesses one dominant factor for resistance to fusarium wilt comparable to the resistance factor found in current fusarium wilt-resistant varieties. These results suggest that one of the factors involved in tolerance to verticillium wilt also confers fusarium resistance to a level comparable to that of the major factor for resistance. This gene does not appear identical to the gene for fusarium resistance occurring in certain fusarium-resistant varieties which possess little or no tolerance to verticillium. Blank[4] reported similar results from the regional fusarium wilt screening tests at Tallassee for verticillium wilt tolerant Acala strains developed in Arizona.

Wiles (4), using the seedling inoculation-seedling survival method of selection, developed strains of Upland cotton that possessed seedling tolerance to verticillium wilt. These verticillium wilt-tolerant strains were selected from the fusarium wilt resistant Alabama strains 56–M, 257–202, and 81–41. These three Alabama strains are known to have very high fusarium-root knot resistance. They apparently possess genes giving resistance additive to that of the major gene.

## MATERIALS AND METHODS

Cotton varieties and experimental strains were tested at Diehlstadt, Mo., (1958–60) on light sandy soil heavily infested with the fusarium wilt organism and root-knot nematodes, and at Dorena (1958–59) and Sikeston (1960) on clay loam soils infested with the verticillium wilt organism.

Field plot designs were randomized blocks or lattice squares. Each entry was grown in 4-row plots replicated 6 times. Only the

---

[1] Contribution from the Department of Field Crops, Missouri Agricultural Experiment Station. Journal Series Number 2407. Approved by the Director, Feb. 1, 1962. Received July 30, 1962.

[2] Professor of Field Crops, Missouri Agr. Exp. Sta., Delta Center, Portageville, Mo.

[3] Blank, L. M. Report of the verticillium wilt committee. Proc. 18th Cotton Disease Council, 12, 1957.

[4] Smith, A. L. Report of the verticillium wilt committee. Proc. 18th Cotton Disease Council, 6, 1957.

middle two rows were harvested for yield. Lint yield data were analyzed by the randomized block method for the analysis of variance, whereas yield differences required for significance are expressed as the minimum and maximum mean values obtained by Duncan's Multiple Range Test.

Stand counts in rows designated for harvest were made. Numbers of plants showing fusarium or verticillium wilt symptoms were recorded at 2-week intervals beginning on or about July 1 and continuing until August 29 in 1958 and 1960. During 1959, only 1 reading was made for fusarium wilt (August 26) and for verticillium wilt (August 29). Disease severity estimates were based on the percentage of plants showing wilt symptoms. Since root-knot ratings can be positively correlated with fusarium wilt reactions (1), ratings for root-knot infection were not made.

The fusarium wilt-root knot nematode disease estimates for 1959 were calculated from differences between initial and final stand counts assuming that stand losses, following thinning, were caused by fusarium wilt and root-knot nematode attack. Final counts also included living plants showing fusarium wilt symptoms. Although good negative correlations with lint yields were obtained by this method, the accuracy was not comparable to that obtained previously by actual periodic counts. This method was not used in 1960.

Simple correlations were calculated to determine relationships between host reaction and lint yield, including lint yields obtained from fusarium wilt-root knot nematode and verticillium wilt infested soils. Correlations also were made between the relative percentages of fusarium wilt and verticillium wilt.

Table 1—Lint yields and wilt percentages for cotton varieties grown on wilt-infested soil, 1958, 1959, 1960.

| Variety or *strain* | Fusarium wilt infested* | | | Verticillium wilt infested† | | | |
|---|---|---|---|---|---|---|---|
| | Lint, lb./acre | | Wilt, %‡ | Lint, lb./acre | | Wilt, % | |
| | Total | 1st. pick | | Total | 1st. pick | Early§ | Final§ |
| | | | Tests in 1958 | | | | |
| 1. Auburn 56 | 872 | 645 | 2 | 475 | 297 | 18 | 31 |
| 2. Rex | 817 | 690 | 3 | 564 | 392 | 17 | 36 |
| 3. Coker 100A | 605 | 386 | 20 | 389 | 221 | 19 | 36 |
| 4. Fox 4 | 478 | 374 | 45 | 484 | 301 | 26 | 45 |
| 5. Delfos 9169 | 412 | 303 | 53 | 259 | 162 | 26 | 45 |
| 6. Deltapine-SL | 187 | 172 | 74 | 516 | 383 | 22 | 44 |
| 7. Fox | 106 | 106 | 78 | 497 | 359 | 24 | 51 |
| 8. Deltapine 15 | 67 | 54 | 80 | 528 | 361 | 19 | 39 |
| Mean | 444 | 341 | 45 | 464 | 310 | 17 | 37 |
| Min. M.D. (.05) | 114 | 160 | 12 | 75 | 60 | 7 | 12 |
| Max. M.D. (.05) | 138 | 193 | 14 | 91 | 73 | 8 | 14 |
| | | | Tests in 1959 | | | | |
| 1. Rex | 864 | 656 | 33 | 744 | - | - | 38 |
| 2. Auburn 56 | 856 | 611 | 30 | 666 | - | - | 36 |
| 3. Dixie King 6 | 803 | 557 | 43 | 697 | - | - | 30 |
| 4. Mo. 58-A56 | 787 | 607 | 32 | 690 | - | - | 31 |
| 5. Coker 100A | 756 | 509 | 28 | 456 | - | - | 37 |
| 6. All-in-one | 730 | 463 | 32 | 431 | - | - | 38 |
| 7. Dixie King 319B | 727 | 497 | 39 | 502 | - | - | 37 |
| 8. Coker 124B | 722 | 482 | 44 | 523 | - | - | 38 |
| 9. Mo. 17-521 | 722 | 576 | 47 | 571 | - | - | 44 |
| 10. CLH60M | 719 | 508 | 43 | 509 | - | - | 37 |
| 11. Empire W.R. | 696 | 474 | 29 | 496 | - | - | 35 |
| 12. Delfos 9169 | 692 | 435 | 46 | 301 | - | - | 52 |
| 13. Fox 4 | 684 | 489 | 53 | 533 | - | - | 35 |
| 14. Hale 33 | 680 | 496 | 52 | 463 | - | - | 41 |
| 15. Deltapine-SL | 458 | 355 | 93 | 573 | - | - | 40 |
| 16. Deltapine 15 | 400 | 314 | 76 | 479 | - | - | 33 |
| Mean | 706 | 502 | 45 | 540 | | | 38 |
| Min. M.D. (.05) | 97 | 66 | 20 | 72 | | | ns |
| Max. M.D. (.05) | 119 | 80 | 24 | 87 | | | ns |
| | | | Tests in 1960 | | | | |
| 1. Mo. 58-432 | 731 | 731 | 5 | 855 | 764 | 28 | 49 |
| 2. Mo. 58-463 | 710 | 528 | 3 | 678 | 571 | 28 | 49 |
| 3. Mo. 58-449 | 610 | 497 | 6 | 777 | 649 | 27 | 49 |
| 4. Auburn 56 | 589 | 445 | 7 | 645 | 504 | 35 | 65 |
| 5. Rex | 576 | 459 | 9 | 810 | 722 | 32 | 52 |
| 6. Dixie King 6 | 541 | 422 | 26 | 831 | 640 | 25 | 48 |
| 7. Mo. 58-1750 | 467 | 403 | 21 | 794 | 720 | 25 | 56 |
| 8. Fox 4 | 401 | 298 | 33 | 798 | 670 | 42 | 62 |
| 9. Coker 124 | 392 | 278 | 27 | 743 | 548 | 33 | 56 |
| 10. Stoneville 7 | 280 | 192 | 66 | 911 | 570 | 38 | 61 |
| 11. Mo. 58-140 | 205 | 174 | 57 | 624 | 580 | 60 | 83 |
| 12. Delfos 9169 | 186 | 105 | 68 | 548 | 320 | 40 | 59 |
| 13. Mo. 58-321 | 131 | 111 | 72 | 863 | 758 | 18 | 42 |
| 14. Deltapine-SL | 100 | 90 | 72 | 750 | 561 | 33 | 49 |
| 15. Deltapine 15 | 88 | 71 | 76 | 806 | 605 | 18 | 40 |
| 16. Mo. 58-138 | 81 | 73 | 88 | 689 | 546 | 53 | 72 |
| Mean | 380 | 294 | 40 | 758 | 615 | 34 | 56 |
| Min. M.D. (.05) | 136 | 111 | 18 | 174 | 174 | 13 | 17 |
| Max. M.D. (.05) | 163 | 133 | 22 | 210 | 210 | 16 | 20 |

* Sandy soil, Diehlstadt, Mo. † Clay loam soil, Dorena, Mo., 1958 and 1959; Sikeston, Mo. 1960. One picking only in 1959. ‡ On Aug. 28, 1959; Aug. 26, 1959; Aug. 29, 1960. § Early = Aug. 15, 1958; Aug. 8, 1960. Final = Aug. 29.

Table 2—Correlations between wilt percentages and yield of lint cotton, 1958–60.

| Observation | r, fusarium wilt | r, verticillium wilt | |
|---|---|---|---|
| | Final | Early | Final |
| Tot. var. lint yields, fusarium wilt tests, 1958 | -.87 | | |
| 1959 | -.80 | | |
| 1960 | -.97 | | |
| Average | -.90 | | |
| Tot. var. lint yields, verticillium wilt tests, 1958 | | -.33 | -.14 |
| 1959 | | - | -.59 |
| 1960 | | -.52 | -.52 |
| Average | | -.43 | -.42 |
| 1st pick var. lint yields, verticillium wilt tests, 1958 | | -.39 | -.14 |
| 1960 | | -.34 | -.34 |
| Average | | -.36 | -.24 |

## EXPERIMENTAL RESULTS

Lint yields and wilt percentages for cotton varieties and strains are given in Table 1. Correlation analyses show that fusarium wilt percent, is highly but negatively correlated (r = —.90) with lint yields of varieties grown on sandy soils infested with the fusarium wilt organism and root-knot nematodes (Table 2). The same criterion used to express tolerance to verticillium wilt, gave a negative correlation with lint yields of the same varieties when grown on verticillium wilt-infested soils. These latter correlations (r = —.42) indicate that wilt percent alone is not a true measurement of verticillium wilt tolerance. The validity of using the percentage of plants showing wilt symptoms, when used as a measurement of verticillium wilt tolerance, was further confused by an apparent positive relationship between increased boll load and wilt expression. Young et al. (5) reported that during years with above-normal seasonal temperatures verticillium wilt was depressed. Many infected plants partially recovered during the high temperature periods. The verticillium wilt organism appeared most virulent at cooler temperatures. This may have accounted for a moderately high verticillium wilt infection of the tolerant Stoneville 7 variety (Table 1) and also may partially explain the less significant correlation values obtained when percentage of plants showing wilt symptoms was used as a measurement of tolerance to verticillium wilt. Although an increased wilt incidence usually was noted as boll load increased, the higher temperatures that normally accompany seasonal advance, coinciding with fruiting intensity, may have been instrumental in reducing the total effect of verticillium wilt, permitting plant recovery and subsequent fruiting. Staffeldt and Fryxell (2) observed similar responses of cotton strains in yield trials in New Mexico. Their studies also indicate that early season disease ratings result in more accurate measurement of tolerance to verticillium wilt than late season ratings. These data (Table 2) indicate that only in 1958 the early counts and wilt percentages were better correlated with total lint yield than were later readings. These data, however, are not conclusive and with the less significant correlation values obtained illustrate the need of better techniques for measuring resistance to verticillium wilt.

Varieties expressing the highest resistance to the fusarium wilt-root knot nematode disease complex have frequently produced good lint yields when grown on verticillium wilt infested soils in Missouri. Rex, Auburn 56, Auburn 56 derivatives (Mo. 58–A56, Mo. 58–432, Mo. 58–449) and Dixie King 6, all resistant to the fusarium wilt-root knot nematode disease complex, have demonstrated tolerance to verticillium wilt. In Table 3 this positive relationship is indicated by correlation analyses of lint yield of varieties designated as highly resistant to the fusarium wilt-root knot nematode disease complex and varieties susceptible to both the fusarium wilt-root knot nematode disease complex and verticillium wilt. The average correlation value for these variety yields produced on fusarium wilt and root-knot nematode infested soils when compared with yields of the same varieties on verticillium wilt infested soils was $r = +.61$. When yields of all varieties were compared the average correlation value was only $r = -.01$. When lint yields of only the verticillium wilt tolerant varieties and strains were compared under both disease conditions, the average correlation value was $r = +.27$. These latter data indicate that varieties which show tolerance to verticillium wilt in Missouri are not necessarily resistant or even tolerant to the fusarium wilt-root knot nematode disease complex.

Data mentioned previously indicates that wilt percent alone is not a true measure of verticillium wilt tolerance. However, assuming that the lower verticillium wilt percentages are, at least, partial measures of verticillium wilt tolerance, correlations were obtained to determine the relationship between varietal percentages of verticillium wilt and fusarium wilt (Table 4). The relatively good average relationship ($r = +.84$) between the fusarium wilt percentages and the verticillium wilt percentages for fusarium wilt-resistant varieties and strains was significant. This further indicates that factors for resistance or tolerance to both diseases might be found in cotton varieties or strains that express maximum resistance to the fusarium wilt-root knot nematode disease complex.

Table 3—Correlations between variety lint yields in fusarium wilt tests and variety lint yields in verticillium wilt tests, 1958–60.

| Observation | | r |
|---|---|---|
| Total lint yield, all entries, 1958 | | -.52 |
| 1959 | | +.41 |
| 1960 | | +.07 |
| Average | | -.01 |
| Tot. lint yields of varieties highly resistant to fusarium wilt and varieties susceptible to both wilts* | 1958 | +.31 |
| | 1959 | +.90 |
| | 1960 | +.62 |
| | Average | +.61 |
| Total lint yields of varieties tolerant to verticillium wilt and varieties susceptible to both wilts† | 1958 | +.06 |
| | 1959 | +.52 |
| | 1960 | +.24 |
| | Average | +.27 |

*With high fusarium resistance:

1958: Auburn 56, Rex.
1959: Rex, Auburn 56, Dixie King 6, Mo.58-A56,
1960: Mo.58-432, Mo.58-463, Mo.58-449, Auburn 56, Rex

*Susceptible to both wilts

1958: Delfos 9169, Fox
1959: Delfos 9169, Hale 33
1960: Mo.58-140, Delfos 9169, Mo.58-138

†Tolerant to verticillium wilt:

1958: Auburn 56, Rex, Fox 4, Deltapine-SL, Deltapine 15.
1959: Rex, Auburn 56, Dixie King 6, Mo.58-A56, Mo.17-521, Fox 4, Deltapine-SL, Deltapine 15.
1960: Mo.58-432, Mo.58-449, Auburn 56, Rex, Dixie King 6, Mo.58-1750, Fox 4, Stoneville 7, Mo.58-321, Deltapine-SL, Deltapine 15.

Table 4—Correlations between final percent of wilt in fusarium wilt tests and percent of wilt (early and final) in verticillium wilt tests, 1958–60.

| Observation | | r, early | r, final |
|---|---|---|---|
| % wilt, all entries, 1958 | | +.54 | +.77 |
| 1959 | | - | +.13 |
| 1960 | | +.24 | +.16 |
| Average* | | +.39 | +.42 |
| % wilt of varieties highly resistant to fusarium wilt and varieties susceptible to both wilts (See Table 3) | 1958 | +.89 | +.98 |
| | 1959 | - | +.48 |
| | 1960 | +.80 | +.70 |
| | Average* | +.85 | +.84 |
| % wilt of varieties tolerant to verticillium wilt and varieties susceptible to both wilts (See Table 3) | 1958 | +.50 | +.75 |
| | 1959 | - | +.01 |
| | 1960 | +.20 | +.12 |
| | Average* | +.35 | +.44 |

* Averages include 1958 and 1960 only, since no early counts were made in 1959.

## DISCUSSION

The data presented suggest that genetic interrelationships may exist among factors conditioning resistance to the fusarium wilt-root knot nematode disease complex and verticillium wilt. Varieties that demonstrated the highest levels of resistance to the fusarium wilt-root knot nematode disease also showed some degree of tolerance to verticillium wilt. Some varieties or strains that were tolerant to verticillium wilt were not resistant to the fusarium wilt-root knot nematode disease.

These interrelationships could be important in breeding new cotton varieties having increased tolerance, or perhaps resistance, to verticillium wilt. Positive relationships of resistance to the two diseases would suggest the utilization of sources possessing the highest levels of fusarium wilt-root knot resistance as indicators for the presence of additional minor factors for verticillium wilt tolerance in early-maturing varieties of cotton since genetic tolerance to verticillium wilt appears to be polygenic in nature. The interaction of accumulated genetic factors from different sources, possessing maximum resistance to the fusarium wilt-root knot nematode disease complex and verticillium wilt, may result in lines possessing verticillium wilt resistance that is not associated with late maturity and inefficient fruiting characteristics of the most tolerant or resistant current varieties.

It is not known if a relationship exists between verticillium wilt and root-knot nematode tolerance similar to the known fusarium wilt-root knot nematode resistance association. This needs attention since verticillium wilt may not always be confined to soils free of nematodes. Additional information concerning the inheritance of root-knot nematode resistance and improved techniques for measuring resistance to verticillium wilt also would be of value.

## SUMMARY

Varietal resistance, as measured by the percent of plants showing fusarium wilt symptoms, was highly but negatively correlated with lint yields of cotton ($r = -.90$). The severity of verticillium wilt was also negatively correlated with lint yields but its use to determine varietal resistance was not so precise ($r = -.42$). Varieties that possessed the highest levels of resistance to the fusarium wilt-root knot nematode disease complex also showed a degree of tolerance to verticillium wilt. Interactions of genetic factors conditioning resistance or tolerance to the fusarium wilt-root knot nematode disease complex and verticillium wilt may lead to higher levels of verticillium wilt tolerance or resistance.

## LITERATURE CITED

1. SMITH, A. L. Resistance to fusarium wilt and root-knot nematode in Upland cotton varieties. Phytopath. 44:333. 1954.
2. STAFFELDT, E. E., and FRYXELL, P. A. A measurement of disease reaction of cotton to verticillium wilt. Plant Dis. Rep. 39: 690–692. 1955.
3. WADDLE, B. A., FULTON, N. D., and YOUNG, V. H. Verticillium wilt disease of cotton. Arkansas Farm Res. 4:2. 1955.
4. WILES, A. B. Evaluation of cotton strains and progencies for resistance to verticillium wilt. Plant Dis. Rep. 44:419–422. 1960.
5. YOUNG, V. H., FULTON, N. D., and WADDLE, B. A. Factors affecting the incidence and severity of verticillium wilt disease of cotton. Arkansas Agr. Exp. Sta. Bul. 612:1–26. 1959.