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Resistance to Root-Knot Nematode in Control of Root-Knot Nematode-Fusarium Wilt Disease Complex in Cotton[1]

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ABSTRACT

To determine the efficacy of resistance to root-knot nematode in the control of the root-knot nematode-Fusarium wilt disease complex in cotton (*Gossypium hirsutum* L.), the response to natural infections with root-knot nematode, *Meloidogyne incognita* (Kofoid and White) Chitwood, and wilt fungus, *Fusarium oxysporum* Schlecht. f. sp. *vasinfectum* (Atk.) Snyd. and Hans., was studied in four cottons that varied in resistance to both organisms. 'Acala SJ-1' is susceptible to both organisms, 'Auburn 56' is tolerant to *Fusarium* and moderately resistant to root-knot nematodes, 'N6072' is susceptible to *Fusarium* but highly resistant to root-knot nematodes, and 'Delcot 277' is tolerant to *Fusarium* but susceptible to root-knot nematodes. Control of Fusarium wilt and maintenance of stands were as good in N6072 as in Auburn 56 and Delcot 277. In unfumigated plots, lint yield of N6072 exceeded those of Acala SJ-1 and Delcot 277 by more than 60% and that of Auburn 56 by 18%. The superior performance of N6072 appeared to result from its ability to resist root-knot nematodes, which helped prevent the development of the wilt disease and subsequent stand and yield losses.

Additional index words: ***Meloidogyne incognita, Fusarium oxysporum*** **f. sp.** ***vasinfectum*****, nematode resistance,** ***Fusarium*** **resistance,** ***Gossypium hirsutum*** **L.**

THE root-knot nematode--Fusarium wilt disease complex caused by the organisms *Fusarium oxysporum* Schlect f. sp. *vasinfectum* (Atk.) Synd. and Hans. and *Meloidogyne incognita* (Kofoid and White) Chitwood has long been known to be a serious disease of cotton, *Gossypium hirsutum* L. (1, 6). Atkinson (1) first described the disease complex in Alabama in 1892, and by 1914 (6) it was recognized in every cotton-producing state from North Carolina to Texas. Blank (2) in 1962 reported Fusarium wilt and root-knot nematodes in cotton fields near Mexicali, Baja California, Mexico, and in 1963 Garber and Paxman (5) reported Fusarium wilt on cotton in a single field in California. Since that time we have identified Fusarium wilt generally associated with root-knot nematodes in numerous California cotton fields. Although the percentage of cotton in California significantly affected by this disease complex is low, the potential for increase is great because root-knot nematodes commonly occur in cotton (15).

Atkinson (1) recognized in his 1892 report that the disease reaction on cotton was much more severe when *F. oxysporum* f. sp. *Vasinfectum* and *M. incognita* occurred together in a field than when they occurred separately. Subsequently, in controlled experiments numerous workers have been shown that root-knot nematodes increase the severity of Fusarium wilt disease over that from *F. oxysporum* f. sp. *vasinfectum* alone (10, 11, 12, 13). Cauquil and Shepherd (3) found increased seedling disease with the combination of the two organisms compared to that with the fungus alone.

The use of Fusarium wilt-resistant cultivars has long been recommended to control the wilt-nematode disease in cotton (6). Historically, considerable effort has been exerted in the development of such varities. Along with Fusarium wilt resistance some root-knot nematode resistance has been incorporated into the varieties, although the main criterion for selection evidently was wilt resistance (16). Root-knot nematode resistance helps control the disease complex in cotton (4, 7, 16). In recent years emphasis has been placed on the development of root-knot nematode-resistant cottons. Such cottons, with high resistance, have been developed in the Alabama (14) and California (17, 18) breeding programs.

Chemical control of the Fusarium wilt-nematode disease complex in cotton has been good. We were able to increase cotton yields fourfold by chemical fumigation in a field infested with *F. oxysporum* f. sp. *vasinfactum* and root-knot nematodes (9).

The objective of this study was to determine the efficacy of high root-knot nematode resistance in the control of the root-knot nematode-Fusarium wilt disease complex of cotton, and to compare it with the efficacy of control by chemical fumigation or the use of Fusarium wilt- resistant cultivars.

MATERIALS AND METHODS

Four cottons, 'Acala SJ-1', 'N6072', 'Auburn 56', and 'Delcot 277', were planted near Shafter, California, in fumigated and unfumigated plots naturally infested with *F. oxysporum* f. sp. *vasinfectum* and *M. incognita*. The soil was a Wasco sandy loam, formerly classed as Hesperia, a member of the coarse-loamy, mixed, nonacid, thermic Xeric Torriorthents. The experimental design was a split plot with four replicates, with fumigated and unfumigated plots as whole plots and cottons as subplots. Subplots were four rows wide (on 96.5-cm centers) and 18.3 m long. A fumigant mixture 1,3-D (1,3-dichloropropene and related chlorinated C_3 hydrocarbons), 85%, and chloropicrin (Trichloronitromethane), 15%, was applied 140 liters/ha 45 cm deep in the row by tractor-mounted chisels just before preirrigation. The unfumigated plots were also chiseled. Cotton was planted 13 April, which is a usual planting date for the area.

The four cottons were chosen because of their differing reactions to *F. oxysporum* f. sp. *vasinfectum* and root-knot nematodes. Acala SJ-1 is susceptible to both *Fusarium* and root-knot nematode, N6072 is susceptible to *Fusarium* but highly resistant to root-knot nematode, Auburn 56 is tolerant to *Fusarium* and moderately resistant to root-knot nematode, and Delcot 277 is tolerant to *Fusarium* but susceptible to root-knot nematode.

The percentage of plants showing foliar and vascular Fusarium wilt symptoms was determined on 29 July and 10 October. The wilt grade, a visual rating of disease severity ranging from 0 for no wilt symptoms to 10 for dead plants, was also deter-

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Table 1. Percent of plants showing Fusarium wilt 29 July and 10 October and wilt grade 10 October of four cottons planted 13 April in unfumigated and fumigated plots.

Cotton	Plants with wilt†					
	29 July		10 Oct.		Wilt grade 10 Oct.‡	
	Unfum.	Fum.	Unfum.	Fum.	Unfum.	Fum.
	%					
Acala SJ-1	56.9 a§	0.03*a	70.9 a	30.3 a	3.1 a	0.8 a
N6072	3.0 b	0.03 a	22.5 b	0.9 b	0.7 b	0.04 a
Auburn 56	3.7 b	0.12 a	38.0 ab	1.9*b	1.7 ab	0.1 a
Delcot 277	1.9 b	0.09 a	21.3 b	2.3 b	0.8 b	0.1 a
Mean	11.1	0.06*	37.5	5.7*	1.4	0.2*

* Denotes treatment means within a cotton that are significantly different according to the L.S.D. test at the 0.05 level of probability.
† Original data transformed to arcsine for ANOV. Retransformed means reported here. ‡ Original data transformed to log (x + 1.05) for ANOV. Retransformed means reported here. Wilt grade: 0 = no wilt symptoms to 10 = plants dead. § Within columns, values followed by the same letter are not significantly different according to Duncan's multiple range test at the 0.05 level of probability.

mined on 10 October. Stand counts were made 23 June and 4 October. After harvest on 24 November, the roots were dug and rated for galling, and a weighted nematode rating (WNR) (8) of 0 for no galls to 100 for roots completely galled was calculated. Thirty plants per plot were rated. All measurements and yield data were from plants in the center two rows of each subplot.

Analyses of variance were performed on arscine-transformed data for percent wilt, log (x + 1.05) for wilt grade, and log x for stand counts. Retransformed means are reported, but levels of significance were determined on transformed data. All other analyses were performed on the raw data.

RESULTS

Percent Fusarium wilt 29 July and 10 October and wilt grade 10 October are shown in Table 1. On 29 July in the unfumigated plots 57% of the Acala SJ-1 plants had symptoms of Fusarium filt, whereas only 2 to 4% of the other cottons had symptoms. By 10 October in unfumigated plots wilt in Acala SJ-1 had increased to 71%, whereas in the other cottons it ranged from only 21 to 38%. On 29 July wilt in the fumigated plots was 1% or less in all cottons. By 10 October wilt prevalence in fumigated plots rose to 30% in Acala SJ-1 but remained at 1 to 2% in the other cottons. In unfumigated plots the wilt grade on 10 October was significantly higher for Acala SJ-1 than for the other cottons, except Auburn 56. Differences in wilt grade among the cottons in the fumigated plots were not significant. For a given cotton, the percent wilt was always lower in fumigated plots than in unfumigated plots. Due to large error variances, these differences were not always significant, although they were relatively large.

Stand counts on 23 June and 4 October, as well as the 4 October stand expressed as a percentage of the 23 June stand, are shown in Table 2. Stands of all cottons were always higher in the fumigated plots than in the unfumigated plots. Particularly noteworthy are the large stand increases in fumigated vs. unfumigated Delcot 277 on both dates and Acala SJ-1 on 4 October. For Delcot 277, the differences were nearly fourfold and for Acala SJ-1, nearly threefold. Stand losses, in the unfumigated plots between 23 June and 4 October for Acala SJ-1, N6072, Auburn 56 and Delcot 277 were 36, 10, 15, and 11%, respectively. Stand losses

Table 2. Plant stand 23 June and 4 October, and 4 October stand as a percentage of 23 June stand, for four cottons in unfumigated and fumigated plots.

Cotton	Stand†					
	23 June		4 October		4 October/23 June	
	Unfum.	Fum.	Unfum.	Fum.	Unfum.	Fum.
	No. of plants/plot				%	
Acala SJ-1	115 ab‡	205*a	71 b	205*a	64 b	100*a
N6072	128 a	179 ab	114 a	180 ab	90 a	100 a
Auburn 56	126 ab	191 ab	106 a	179*ab	85 a	94 a
Delcot 277	38 c	137*b	33 c	129*b	89 a	94 a
Mean	92	176*	73	171*	82	97

* Denotes treatment means within a cotton that are significantly different according to the L.S.D. test at the 0.05 level of probability.
† Original data transformed to log x for ANOV. Retransformed means reported here. ‡ Within a column, values followed by the same letter are not significantly different according to Duncan's multiple range test at the 0.05 level of probability.

Table 3. Weighted nematode rating and lint yield of four cottons in unfumigated and fumigated plots.

Cotton	Weighted nematode rating†		Lint yield	
	Unfum.	Fum.	Unfum.	Fum.
			kg/ha	
Acala SJ-1	96 a‡	56 a	216 c	898*ab
N6072	48 b	4 c	663 a	944*ab
Auburn 56	77 a	20*bc	543 b	989*a
Delcot 277	97 a	35*ab	244 c	844*b
Mean	80	29*	417	919*

* Denotes treatment means within a cotton that are significantly different according to the L.S.D. test at the 0.05 level of probability.
† Weighted nematode rating: 0 = no root galls to 100 = completely galled.
‡ Within a column, values followed by the same letter are not significantly different according to Duncan's multiple range test at the 0.05 level of probability.

were minimal in the fumigated plots between count dates.

Weighted nematode ratings (WNR) and lint yields are reported in Table 3. The WNR of N6072 was considerably lower than those of the other cottons. The WNR's of all cottons were reduced by fumigation; that of N6072 was reduced nearly to zero. The lint yields of all cottons were lower in the unfumigated plots than in the fumigated plots. Yield reductions were 76, 30, 45, and 71% for Acala SJ-1, N6072, Auburn 56, and Delcot 277, respectively. In the unfumigated plots the yield of N6072 was significantly greater than those of the other cottons; it was about three times those of Acala SJ-1 and Delcot 277. The only significant difference in yield in the fumigated plots was between Auburn 56 and Delcot 277.

DISCUSSION

Until 29 July, plant resistance controlled Fusarium wilt in unfumigated plots planted to cottons that were tolerant only to *Fusarium* (Delcot 277), resistant only to root-knot nematode, (N6072), or tolerant to both organisms (Auburn 56) and row fumigation controlled the wilt in all cottons. By 10 October, fumigation no longer controlled wilt in Acala SJ-1, probably because of the build-up of root-knot nematodes. Although these nematodes probably also built-up in the fumigated plots of Auburn 56 and Delcot 277, the resist-

ance of these cottons to *F. oxysporum* f. sp. *vasinfectum* kept the disease under control. The superior resistance of N6072 to nematodes, coupled with fumigation, apparently reduced nematode reproduction and thus the development of Fusarium wilt disease late in the season. We found a significant correlation coefficient of 0.80 between root galling (WNR) and percent wilt on 10 October over the fumigated and unfumigated plots; this correlation indicates that any factor, chemical or genetic, that controls root-knot nematodes also strongly influences Fusarium wilt in cotton. Similar significant correlations between root galling and wilt were found by Cooper and Brodie (4).

We did not ascertain whether the reduction in stand of seedling plants in unfumigated plots was due solely to the Fusarium wilt-nematode complex. No doubt the Fusarium wilt-nematode complex was the major factor, as was previously reported by Cauquil and Shepherd (3). We believe that the poor stand of Delcot 277, in both unfumigated and fumigated plots, was due to poor quality of the planted seed. Of the other cottons, Fusarium-wilt-susceptible, highly nematode-resistant N6072 had a stand reduction of only 28% on 23 June in the unfumigated plots compared with the fumigated plots, whereas Fusarium-wilt and nematode-susceptible Acala SJ-1 had a reduction of 44% and wilt-resistant, moderately nematode-resistant Auburn 56 had a reduction of 34%.

The loss of stand in the unfumigated plots from 23 June to 4 October probably was due mainly to the interaction of *F. oxysporum* f. sp. *vasinfectum* with root-knot nematodes; in our experience stand loss occurs infrequently with nematodes in the absence of *Fusarium*. In the unfumigated plots, stand loss during this period was significantly greater for Acala SJ-1 than for N6072, Auburn 56, or Delcot 277.

We obtained a highly significant correlation coefficient of 0.93 between yield and stand on 4 October. The correlation coefficient between percent wilt on 10 October and stand on 4 October was a nonsignificant −0.47, while that between WNR and stand on 4 October was a significant −0.79, which indicates that nematode activity (as indicated by root galling) contributed more than Fusarium wilt to stand loss. This conclusion may help to explain the superior performance of the highly nematode-resistant N6072 in reducing stand losses. These results agree with those of other studies demonstrating that root-knot nematodes in combination with *Fusarium* greatly intensify the wilt disease (11, 12).

The high root-knot nematode resistance of N6072 is shown by its lower WNR's than in the moderately resistant Auburn 56 in both unfumigated and fumigated plots. The root galling in this study appeared to be much more severe than we had encountered in fields infested with only root-knot nematodes. For example, at the Shafter Research Station, within 1.6 km of these experimental plots and infested only with root-knot nematodes, WNR's in unfumigated plots were 78, 29 and 36% for Acala SJ-1, N6072 and Auburn 56, respectively, of the WNR's in the present test. The site for this test had not been fumigated for several years, which permitted an unusually large build-up of the nematode population.

The effect of the interaction of *F. oxysporum* f. sp. *vasinfectum* and root-knot nematodes on yield can be seen in the yield reductions in Acala SJ-1 and N6072, 76 and 30%, respectively, in unfumigated vs. fumigated plots. (In nearby fields infested with root-knot nematodes and not *Fusarium*, we have observed yield reductions of 10 to 30% for Acala SJ-1 and 5 to 10% for N6072.) The nature of the *Fusarium*-nematode interaction is not well understood. In this study, significant regression coefficient (b) of −8.25 and −13.02 were obtained for the regression of yield on WNR and percent wilt 10 October, respectively; the r^2 values were 0.84 and 0.57. Thus, the linear regression of yield on WNR accounted for 27% more of the variation in yield than did the linear regression of yield on percent wilt. A multiple linear regression analysis of yield regressed on WNR and percent wilt on 10 October gave an R^2 value of 0.84, the same as the r^2 value for the regression of yield on WNR alone. Evidently the closer relationship between WNR and yield than between percent wilt and yield is a manifestation of the predominating influence of root-knot nematodes over *Fusarium* in intensifying the effects of the disease.

In controlling yield losses from the Fusarium wilt-nematode complex, high resistance to nematodes was more effective than tolerance to wilt and moderate resistant to nematodes, as shown by the significantly higher yield of N6072 than of Auburn 56 in unfumigated plots. Cotton strains with greater root-knot nematode resistance (18) than N6072 are under development in our program. From the results of our studies, we expect that the use of such strains will control this disease complex better than does N6072.

REFERENCES

1. Atkinson, G. F. 1892. Some diseases of cotton. Alabama Agric. Exp. Stn. Bull. 44.
2. Blank, L. M. 1962. Fusarium wilt of cotton moves west. Plant Dis. Rep. 46:396.
3. Cauquil, Jean, and R. L. Shepherd. 1970. Effect of root-knot nematode-fungi combinations on cotton seedling disease. Phytopathology 60:448-451.
4. Cooper, W. E., and B. B. Brodie. 1963. A comparison of Fusarium wilt indices of cotton varieties with root-knot and sting nematodes as predisposing agents. Phytopathology 53:1077-1080.
5. Garber, R. H., and G. A. Paxman. 1963. A comparison of Fusarium wilt of cotton in California. Plant Dis. Rep. 47: 398-400.
6. Gilbert, W. W. 1914. Cotton wilt and root-knot. USDA Farmer's Bull. 625.
7. Jones, J. E., and L. D. Newsom. 1959. Resistant cotton for wilt-nematode areas. Louisiana Agric. 3:14-15.
8. Jorgensen, E. C. 1979. Granular nematicides as adjuncts to fumigants for control of cotton root-knot nematodes. J. Nematol. 11:144-150.
9. ———, A. H. Hyer, R. H. Garber, and S. N. Smith. 1978. The influence of root-knot nematode control by fumigation on Fusarium-root-knot nematode disease complex of cotton in California. J. Nematol. 10:228-231.
10. Kappelman, A. J., Jr., and W. P. Sappenfield. 1973. Development of a set of upland cotton lines for comparisons of Fusarium wilt-root-knot nematode data from several tests. Crop Sci. 13:280-281.
11. Martin, W. J., L. D. Newsom, and J. E. Jones. 1956. Relationship of nematodes to the development of Fusarium wilt in cotton. Phytopathology 46:285-289.
12. Minton, N. A., and E. B. Minton. 1966. Effect of root-knot and sting nematodes on expression of Fusarium wilt of cotton in three soils. Phytopathology 56:319-322.

13. Perry, D. A. 1963. Interaction of root-knot and Fusarium wilt of cotton. Emp. Cotton Grow. Rev. 40:41-47.
14. Shepherd, R. L. 1974. Transgressive segregation for root-knot nematode resistance in cotton. Crop Sci. 14:872-875.
15. Siddiqui, I. A., S. A. Sher, and A. M. French. 1973. Distribution of plant parasitic nematodes in California. California Dep. Food Agric., Sacramento.
16. Smith, A. L. 1941. The reaction of cotton varieties to Fusarium wilt and root-knot nematode. Phytopathology 31: 1099-1107.
17. USDA, SEA, and California Agric. Exp. Stn., Univ. California. 1978. Notice of release of a resistant cotton, non-commercial breeding stock of cotton. N6072.
18. USDA, SEA, and California Agric. Exp. Stn., Univ. California. 1978. Notice of release of three root-knot nematode resistant cottons, non-commercial breeding stocks of cotton. N9281, N9308, and N9311.