Influence of Soil Fumigation on the Fusarium-Root-knot Nematode Disease Complex of Cotton in California[1]

E. C. JORGENSON, A. H. HYER, R. H. GARBER, and SHIRLEY N. SMITH[2]

Abstract: For control of the root-knot nematode, *Meloidogyne incognita*, and the pathogenic wilt fungus, *Fusarium oxysporum*, on cotton, soil fumigants were applied in the field at conventional and higher rates. Conventional rates suppressed Fusarium wilt but higher rates gave quicker early growth, better stands, less stand loss over the season, a lower percentage of plants infected with wilt, fewer plants with vascular discoloration, and fewer nematodes. The best treatment about doubled the yields of untreated controls in one experiment and quadrupled them in another. *Key Words:* Fusarium wilt, *Meloidogyne incognita*, *Fusarium oxysporum* f. sp. *vasinfectum*, nematicides.

The Fusarium wilt-root-knot nematode disease complex of cotton was recognized in the eastern and southeastern parts of the United States before the turn of the century (1). Recognition in the western U. S. was comparatively recent (2, 5). Through the years, several reports by Smith and coworkers (11, 12, 13, 14, 15) have described the interrelations of *Meloidogyne* spp. and the Fusarium wilt fungus. Two recent reviews by Sasser (9) and Ebbels (3), summarizing this and much other work, are indicative of present understanding of this important disease complex.

In California the root-knot nematode is widely distributed and commonly occurs in all cotton-growing areas (10). *Fusarium oxysporum* Schlect f. sp. *vasinfectum* (Atk.) Snyd. & Hans., the Fusarium wilt fungus that is virulent to cotton, is not known to be widely distributed in California; it has been found in only two counties (in the southern San Joaquin Valley). The wide distribution of the nematode, however, presents a potential for widespread damage from this disease. We therefore conducted studies to develop an effective means of managing this disease complex. Some observations have been presented in preliminary reports (4, 6).

MATERIALS AND METHODS

Two experiments were conducted on fields of Hesperia sandy loam (ca. 76% sand, 17% silt, and 7% clay) naturally infested with the cotton root-knot nematode, *Meloidogyne incognita* Chitwood, and the pathogenic wilt fungus. The first used a split-plot design with four replications (Table 1). The second study was in randomized complete blocks with treatments replicated four times (Table 2). Individual plots were four rows wide on 1-m centers. Row length was 18 m in one experiment (Table 1) and 43 m in the other (Table 2).

The fumigants were used as described in Tables 1 and 2: 1,3-dichloropropene and chloropicrin (1,3-D + pic); 1,3-dichloropropene (1,3-D); and 2-dibromo-3-chloropropane (DBCP). Immediately before preirrigation, 1,3-D + pic, 1,3-D, and DBCP were applied 45 cm or 30 cm deep in the row by tractor-mounted chisels. Acala SJ-1 cotton (*Gossypium hirsutum* L.) was planted 26 days after treatment when the soil was in proper condition and after the fumigants had dissipated enough to avoid phytotoxicity.

Stand counts, plant height measurements, wilt readings, and soil sampling for nematode determinations were made periodically during the season. The pretreatment population of cotton root-knot nematode was estimated by bioassay in the following manner: Soil samples were collected at random from throughout the two test areas. Thirty plastic containers (0.5 liter) were filled with soil from each test area, and a tomato was grown in each container for 6 weeks. Then the root of each plant was rated on a 0-4 scale, from no galls to completely galled. These ratings were weighted to emphasize the differences between them and converted to a 0-100 scale. The weighted nematode rating (WNR) was the average rating of the 30

Received for publication 8 December 1977.

[1] Cooperative investigations of Agricultural Research Service, U. S. Department of Agriculture and the California Agricultural Experiment Station. No endorsements are implied herein.

[2] Respectively Zoologist, Research Agronomist, and Research Plant Pathologist, U. S. Cotton Research Station, 17053 Shafter Avenue, Shafter, California 93263; and Plant Pathologist, Department of Plant Pathology, University of California, Berkeley, California 94720.

TABLE 1. Interaction of *Meloidogyne incognita* and *Fusarium oxysporum* on SJ-1 cotton as influenced by treatment with 1,3-D + chloropicrin, 1,3-D, and DBCP.

Treatment	Formulation (kg (a.i.)/liter)	Rates (liter/ha)	Plant[a] Height (cm)	Stand			Yield lint (kg/ha)	Wilt		WNR[g]	
				9 wk[b]	6 mo[c]	%[d]		%[e]	Severity[f]	Mid-season	After harvest
1,3-D + pic	1.27	140	20	207	207	100	900	33	1.1	0	56
1,3-D	1.20	140	20	126	125	97	791	34	1.4	0	35
DBCP	1.45	19	16	181	168	93	830	29	1.0	0	25
Untreated	—	0.0	13	121	76	64	216	64	4.0	82	96
LSD 0.05			6	.57	58	15	234	24	1.7	22	37

[a]Mean of 10 plants from each plot 9 weeks after planting.
[b]Plants per 37-meter row 9 weeks after planting.
[c]Plants per 37-meter row 6 months after planting.
[d]Fall stand as a percent of spring stand.
[e]Percent of plants with vascular discoloration 6 months after planting.
[f]Severity of *F. oxysporum* infection: 0 = none; 1 = light; 3 = medium; 5 = dark; 10 = dead 6 months after planting.
[g]Weighted nematode rating 0 = no galling; 100 = completely galled.

TABLE 2. Interaction of *Meloidogyne incognita* and *Fusarium oxysporum* on SJ-1 cotton as influenced by treatment with 1,3-D + chloropicrin, 1,3-D, and DBCP.

Treatment	Formulation (kg (a.i.)/liter)	Rates (liter/ha)	Yield lint (kg/ha)	Wilt		WNR[c]	
				% discolored[a]	Severity[b]	Mid-season	After harvest
1,3-D + pic	1.27	140	826	34	.8	0	10
1,3-D	1.20	140	682	41	1.0	0	18
1,3-D	1.20	94	558	45	1.3	0	38
DBCP	1.45	7	434	69	2.4	1.3	48
Untreated	—	0.0	355	83	3.00	33	71
LSD 0.05			184	25	1.1	33	39

[a]Vascular discoloration percent of 30-plant sample, mean of 4 replications.
[b]Mean of 4 replications: 0 = clean; 1 = light; 3 = medium; 5 = dark; 10 = dead.
[c]Weighted nematode rating: 0 = no galls; 100 = completely galled.

plants from each test area. Thus, the pretreatment WNR of 100 for experiment 1, and 90 for experiment 2, represent the initial population in each test area, and show that the pretreatment population was higher in experiment 1 than in experiment 2. Near midseason (June), similar bioassays were made to determine the early effectiveness of the fumigants. Soil samples were collected from all plots, and the composited samples from each plot were arranged on the greenhouse bench in the same design as in the field experiment. The effects of fumigation on the root-knot nematodes were demonstrated by the average WNR of tomato plants grown in the soils from each experiment.

At the end of the season, cotton plants in the field plots were rated for Fusarium wilt on the basis of leaf symptoms and stem and root discoloration. The cotton was machine-picked twice from the first experiment and once from the second. Immediately after harvest the tops of the cotton plants were shredded with a rotary stalk cutter, the roots were dug with a tractor-drawn lifter, and 30 plants from each plot were rated for root-knot nematode infection.

RESULTS

Generally, the plots treated with fumigants, compared with untreated plots, gave more early growth, better initial stands, less loss of stand over the season, a lower percentage of plants infected with wilt, fewer plants with vascular discoloration, and fewer nematodes, as evidenced by the WNR of tomato plants at midseason and cotton plants after harvest (Tables 1 and 2). Specifically, Fusarium wilt symptoms in the leaves of the cotton plants were greatly reduced by all treatments. Wilt percent and wilt severity decreased with a decrease in WNR. The correlation coefficients for WNR vs. wilt percent, and WNR vs. wilt severity were respectively ($r = 0.74^{**}$) and ($r = 0.59^{*}$) in the split-plot experiment (Table 1), and ($r = 0.75^{**}$) and ($r = 0.82^{**}$) in the randomized complete block experiment (Table 2). These experiments included the standard soil fumigation rates for control of root-knot nematode in California cotton (8) (Table 2). Higher than standard rates were used in the split-plot experiment (Table 1). The treatment used most commonly by growers, DBCP (7 liters/ha), and the slightly more effective but less commonly used treatment, 1,3-D (94 liters/ha), suppressed this complex disease. There was evidence, however, that the standard rates were less effective than the higher rates in controlling the disease. DBCP at the standard rate in experiment 2 (Table 2) gave only a 22% yield increase over untreated, whereas in experiment 1 (Table 1) the higher rate of DBCP gave a significant 284% yield increase. The 1,3-D high rate gave a 22% yield increase over the standard rate of 1,3-D, and 1,3-D + pic gave a significant 48% increase over the standard rate of 1,3-D. All treatments except DBCP at the low rate, resulted in lint yields significantly higher than in untreated controls. In both tests, the 1,3-D + pic gave the highest yields, these being respectively 4.2

and 2.3 times the untreated in experiments 1 and 2.

All treatments suppressed cotton root-knot nematode populations to some extent, as evidenced by the pretreatment, midseason, and postharvest WNR. The reductions in WNR, particularly those at midseason, indicate the effectiveness of these treatments, and they afford a basis for judgment in determining useful ways of controlling cotton root-knot nematode.

DISCUSSION

We identified treatments that will increase cotton yields dramatically in soils harboring Fusarium wilt fungus and root-knot nematodes. Our results support the hypothesis of a direct relation between intensity of root-knot nematode parasitism, as reflected by WNR, and the severity of Fusarium wilt.

If cotton yields are to be maintained at the present level, root-knot nematodes must continue to be controlled. If yields are to be increased, all means of control available (chemical, cultural and biological) should be used to keep nematode numbers low so that the nematodes, acting alone, do not cause yield reductions, and, as a component of the Fusarium wilt-root-knot nematode complex, do not contribute to this devastating disease. Unrelenting control of the nematode seems to be the most practical way now available of limiting the severity of the Fusarium wilt-root-knot nematode complex disease of cotton. Soil fumigation controls root-knot nematode dramatically and effectively; however, tolerant-resistant cotton cultivars can, when used properly, reduce field populations of nematodes (6) and at the same time reduce wilt (4). When fully effective, management of this disease complex will necessarily combine all available means of controlling the wilt organism and the nematodes.

LITERATURE CITED

1. ATKINSON, G. F. 1892. Some diseases of cotton. III. Frenching. Bull. Ala. Agric. Exp. Stn. No. 41, 19-20.
2. BLANK, L. M. 1962. Fusarium wilt of cotton moves west. Plant Dis. Rep. 46:396.
3. EBBELS, D. L. 1975. Fusarium wilt of cotton: a review, with special reference to Tanzania. Cotton Grow. Rev. 52:295-339.
4. GARBER, R. H., A. H. HYER, E. C. JORGENSON, and SHIRLEY SMITH. 1976. Control of Fusarium wilt-rootknot nematode complex in California. Proc. Beltwide Cotton Production Res. Conf., Las Vegas, Nevada, Jan. 5-7, 1976.
5. GARBER, R. H., and G. A. PAXMAN. 1963. Fusarium wilt of cotton in California. Plant Dis. Rep. 47:398-400.
6. HYER, A. H., and E. C. JORGENSON. 1974. Nematode reproduction on resistant and susceptible cotton strains. Agron. Abs., Nov. 10-15, 1974. pp. 54-55.
7. JORGENSON, E. C. 1970. Antagonistic interaction of Heterodera schachtii Schmidt and Fusarium oxysporum (Woll.) in sugarbeets. J. Nematol. 2:393-398.
8. RADEWALD, J. D., I. J. THOMASON, M. W. ALLEN, and W. H. Hart. 1967. Root-knot nematode on cotton. California Plant Diseases-28. University of California Agric. Ext. Serv., 5 pp.
9. SASSER, J. N. 1972. Nematode diseases of cotton, Pages 187-214 *in* J. M. Webster, ed. Economic Nematology. Academic Press, New York. 563 p.
10. SIDDIQUI, I. A., S. A. SHER, and A. M. FRENCH. 1973. Distribution of plant parasitic nematodes in California. California Dept. of Food and Agric. 324 pp.
11. SMITH, A. L. 1941. The reaction of cotton varieties to Fusarium wilt and root-knot nematodes. Phytopathology 31:1099-1107.
12. SMITH, A. L. 1948. Control of cotton wilt nematodes with a soil fumigant. Phytopathology 38:943-947.
13. SMITH, A. L. 1954. Problems on breeding cotton for resistance to nematodes. Plant Dis. Reptr. Suppl. 227:90-91.
14. SMITH, A. L. and A. L. TAYLOR. 1941. Nematode distribution in the 1940 regional cotton-wilt plots. (Abstr.) Phytopathology 31:771.
15. Smith, A. L. and J. B. Dick. 1960. Inheritance of resistance to Fusarium wilt in Upland and Sea Island cottons as complicated by nematodes under field conditions. Phytopathology 50:44-48.