Effects of Management Practices on Nematode and Fungi Populations and Okra Yield[1]

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Abstract: Okra was grown in field plots of Tifton loamy sand naturally infested with the nematodes *Meloidogyne incognita* and *Criconemoides ornatus* and the pathogenic fungi *Fusarium oxysporum, F. solani, F. roseum,* and *Pythium* spp. Plots were treated with various soil pesticides and left exposed or covered with biodegradable paper film mulch under trickle irrigation. Soil was assayed for nematodes and fungi, and plant roots were examined for root-rot and insect damage. Fewer nematodes and fungi generally were recovered from soil treated with DD-MENCS (with and without film mulch) or methyl bromide-chloropicrin (2:1) (MBC) and film mulch than from nontreated soil. Fumigation with DD-MENCS or MBC suppressed populations of *M. incognita, C. ornatus, F. oxysporum, F. solani, F. roseum,* and *Pythium* spp. Ethoprop (alone or combined with other pesticides), sodium azide, and chloroneb were less effective than DD-MENCS and MBC. Plant growth and yield were greatest when nematodes and pathogenic fungi were controlled. Yield was increased 3-fold by DD-MENCS + film mulch or MBC + film mulch in comparison with the average yield of okra produced in Georgia. The root-knot nematode-*Fusarium* wilt complex was most severe in nonfumigated soil. *Key Words: Abelmoschus esculentus,* multiple-pest control.

The use of mulches in crop production has been studied (1), but the use of polyethylene or biodegradable film mulches on high value vegetable crops has only recently become commercially feasible. Research on strawberries (14) and tomatoes (3, 10) indicated that soil fumigation under plastic film mulch to control pests could be used on a large scale.

The influence of the southern root-knot nematode, *Meloidogyne incognita* (Kofoid & White) Chitwood, on *Fusarium* infection of okra (*Abelmoschus esculentus* (L.) Moench) in the Georgia coastal plain was recognized by others (4, 13). *Fusarium oxysporum* Schlecht f. *vasinfectum* (Atk.) Snyd. & Hans. is pathogenic to both okra and cotton (6). Okra and cotton have been grown in Georgia for decades, and most fields now used for okra production are naturally infested with the wilt fungus. Nematodes and *Fusarium* wilt are limiting factors in okra production in Georgia. In 1972, the nematode-wilt complex and drought reduced commercial production more than 25% (personal communication, R. O. Corbett, Senior Agricultural Representative, Joseph Campbell Co., Cairo, Georgia).

Research in the Georgia coastal plain showed that nematodes, soilborne fungi, and weeds could be controlled with soil fumigation (5); however, single-row raised beds were studied almost exclusively, information on disease control was limited, and when film mulch was used, it was removed prior to planting.

Methods are now available to monitor populations of soilborne fungi and to determine their influence on root diseases and yield. Also, equipment is available to lay film mulch and to direct seed through the mulch. If irrigation is necessary, trickle or drip irrigation tubing can be laid under the film mulch as it is unrolled.

The research presented here examined the effects of management practices on nematode and fungi populations on okra.

METHODS AND MATERIALS

The experiment was conducted in 1974 on Tifton loamy sand (ca. 85% sand, 10% silt, and 5% clay) infested with natural populations of the southern root-knot nematode, *Meloidogyne incognita* Chitwood, *Pratylenchus* spp., *Criconemoides ornatus* Raski, *Trichodorus christiei* Allen, and several pathogenic fungi including *Fusarium oxysporum* Schlecht, emend Snyd. & Hans., *F. solani* (Mart.) Appel & Wr. and *F. roseum* (Lk.) Fr., *Pythium* spp., and *Rhizoctonia solani* Kühn. In 1972 and 1973,

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the test areas had been planted with okra as a summer cover crop and with hairy vetch (*Vicia villosa* Roth) as a winter cover crop. During both years, 75% or more of the initial okra stand was killed by the root-knot nematode—*Fusarium* wilt complex within the first 45 days after planting. The test crop was okra cv. 'Clemson Spineless'.

The experimental plot contained a single bed, 101 cm x 12.2 m, with two plant rows 75 cm apart on each bed. The experimental design was a randomized complete block with treatments replicated four times. The following pesticides were used as described in Table 1: nematicide-ethoprop; soil fungicides-chloroneb and sodium azide; soil fumigants—20% methyl-isothiocyanate + 80% chlorinated C_3 hydrocarbons (DD-MENCS), and 67% methyl bromide + 33% chloropicrin (MBC); and a herbicide-trifluralin. Fertilizer (2240 kg/ha, 7-14-7, N-P-K) was broadcast on the surface of the soil and supplemental soluble $CaNO_3$ and KNO_3 were added in irrigation water as previously described (8). All chemical treatments were applied to all plots at the same time. In nonmulched plots, the fertilizer was applied just before planting. Soil fumigants were injected 25 cm deep into the soil with chisels 20 cm apart and the soil surface was sealed by compaction with a bed-shaper attachment. Granules of sodium azide and ethoprop and a water suspension of chloroneb were spread on the soil surface and incorporated into the top 15-cm soil layer with a tractor-mounted rototiller. Trifluralin was sprayed on the soil surface and incorporated into the top 5-cm soil layer as described previously.

Soil moisture was near or slightly below field capacity (8-10% oven-dry weight). Viaflo® trickle irrigation tubing was laid and all mulched plots were covered immediately after soil fumigation and were not disturbed for 7-10 days. Holes (6-cm diam.) were cut 30 cm apart in the mulch in 2 rows (75 cm apart to allow aeration) and 3 seeds/hill were hand planted through the holes 1 week later.

Soil was assayed for parasitic nematodes 39 and 145 days after planting and for soil-borne fungi before or 14 to 17 days after planting and periodically thereafter. Ten cores (2.5 x 15 cm) of soil were collected from the center 6 m of each plot and mixed thoroughly. A 150-cm^3 soil aliquant was processed by a centrifugal-flotation method (9) for the nematode assay. Fungi from 2-5 gm of moist soil were assayed on selective media. Fungal population densities were expressed as propagules/gm of oven-dry soil. Media used were modified peptone-PCNB for *Fusarium* spp. (11), gallic-acid medium for *Pythium* spp. (2), and gallic-acid medium modified with 0.1 ml Pyroxychlor 2-chloro-6-methoxy-4-(trichloromethyl) pyridine/liter for *Rhizoctonia solani*.

When seedlings were 17 days old, plants from near the ends of the plots were evaluated for root and hypocotyl discoloration and decay caused by fungi. Root and hypocotyl tissues were surface disinfected for 15 sec. in 0.5% NaOCl, rinsed under running tap water (10-25 C for 30 min. to 2 h.), blotted dry on sterile filter paper, and transferred to water agar. Fungi growing from the tissues after 2-5 days at 25-30 C were transferred to potato-dextose agar (PDA) and identified. Plants were indexed for galls caused by root-knot nematodes 50 and 146 days after planting. Individual plants were rated on a 1-5 scale (1 = no galls, 2 = 1-25%, 3 = 25-50%, 4 = 50-75%, and 5 = 75-100% roots galled). After the final harvest, all plants were uprooted and rated for root galls. Stand counts, plant height, and yield (only marketable quality) were recorded from the center 6 m of each plot.

RESULTS

Nematodes: Populations of *M. incognita* and *C. ornatus* were uniformly distributed in the experimental area before treatment, but numbers of *T. christiei* and *Pratylenchus* spp. were low and were not uniformly distributed. Therefore, only data of *M. incognita* and *C. ornatus* are reported here. Root-gall indices of plants from plots treated with DD-MENCS + film mulch and MBC + film mulch were significantly less 50 and 146 days after planting than those of plots treated with herbicide + film mulch (Table 1). In addition, after the final harvest (146 days after planting), root-gall indices of plants in plots treated with DD-MENCS + trifluralin were significantly less than those of controls regardless of

TABLE 1. Number of *Criconemoides ornatus*/150 cm^3 soil, root-gall indices, and root discoloration of okra seedlings as influenced by film mulch and soil chemical treatment.

Treatment		Root-gall index (days after planting)[a]		*C. ornatus* (days after planting)[a]		Percent roots with (>10% discoloration 17 days after planting[a])
Chemical	Rates [Kg (a.i.)/ha]	50	146	39	146	
Nonmulched						
Trifluralin (T)-Control	0.56	3.03 a	4.01 a	13 a	83 a	96 a
DD-MENCS + T	376.3 + 0.56	1.25 bc	2.20 c	0 b	5 c	50 bc
Film Mulch						
Trifluralin (T)-Control	0.56	2.23 ab	3.63 a	3 b	10 c	88 a
DD-MENCS	376.3	1.00 c	1.30 d	0 b	0 c	51 b
Sodium azide (SA)	33.6	2.68 a	3.38 ab	0 b	13 c	35 bc
Chloroneb + T	26.9 + 0.56	2.83 a	3.99 a	0 b	20 b	84 a
SA + ethoprop	33.6 + 8.96	1.78 bc	3.15 ab	3 b	33 b	37 bc
Ethoprop	8.96	2.28 b	2.85 bc	10 a	33 b	93 a
MBC	336.0	1.00 c	1.01 d	0 b	68 a	24 c

[a]Numbers followed by the same letter within each column of data are not significantly different, ($P = 0.05$) according to Duncan's multiple range test.

mulch. Indices of plants in mulched plots treated with ethoprop were not affected 50 days after planting, but were significantly lower than controls 146 days after planting.

Numbers of *C. ornatus* were suppressed below a detectable level early in the growing season in plots treated with DD-MENCS + trifluralin, DD-MENCS + film mulch, chloroneb + trifluralin + film mulch, sodium azide + film mulch, and MBC + film mulch (Table 1). Numbers of *C. ornatus* continued to increase in all plots except those treated with DD-MENCS + film mulch, but numbers in nonmulched plots treated with DD-MENCS + trifluralin were lower than numbers in control plots. Numbers of *C. ornatus* in mulched plots treated with chloroneb + trifluralin, sodium azide + ethoprop, ethoprop, and MBC were greater than numbers in control plots.

Populations of soil borne fungi: Numbers of propagules/gm soil of *F. oxysporum, F. solani, F. roseum,* and *Pythium* spp. were suppressed by DD-MENCS + T without mulch and DD-MENCS, SA + ethoprop, and MBC with film mulch 25 days before planting (Table 2). At 103 days after planting, numbers of *F. solani* propagules were suppressed by nonmulched DD-MENCS and T, DD-MENCS + film mulch, and MBC + film mulch. In addition, numbers of *Pythium* spp. propagules were suppressed in film mulched plots treated with DD-MENCS, chloroneb + T, and MBC. Populations of *R. solani* were low (0.5/gm of soil), and there were no significant differences among soil treatments in March. Populations of soilborne fungi were suppressed most when a combination of soil fumigation and film mulch was used. Total numbers of *Fusarium* spp. were lower both before planting and 103 days after planting in plots treated with sodium azide + ethoprop + film mulch than in plots treated with either sodium azide + film mulch or ethoprop + film mulch. Chloroneb had no effect on populations of *Fusarium* spp.

Root discoloration: Root discoloration was significantly reduced in all treated plots, except those treated with ethoprop + film mulch and chloroneb + trifluralin + film mulch (Table 1). Correlation coefficients indicated a significant correlation between root discoloration recorded 17 days after planting and root-gall indices recorded 50 days after planting ($r = 0.39^*$). There was a significant correlation between root discoloration 17 days after planting and numbers of *C. ornatus* in the soil at planting ($r = 0.42^*$) and 39 days after planting ($r = 0.41^*$). Root discoloration was also correlated with the number of propagules of *F. oxysporum* ($r = 0.58^{**}$), *F. solani*

TABLE 2. Influence of film mulch and soil pesticides on population densities of soilborne fungi (propagules/g oven dry soil—1974).

Treatment		25 days before planting				103 days after planting			
		Fusarium[z]			Pythium[z]	Fusarium[z]			Pythium[z]
Chemical	Rates [Kg (a.i.)/ha]	*oxysporum*	*solani*	*roseum*	spp.	*oxysporum*	*solani*	*roseum*	spp.
Nonmulched									
Trifluralin (T)-Control	0.56	2,266 a	1,617 a	1,118 a	62 a	23,198 a	5,708 a	1,903	34 a-c
DD-MENCS + T	376.3 + 0.56	665 b	317 b	272 b	5 bc	1,498 b	2,146 bc	1,053	4 cd
Film mulch									
Trifluralin (T)-Control	0.56	2,477 a	1,314 a	921 a	55 a	10,445 ab	4,251 ab	729	65 a
DD-MENCS	376.3	45 b	15 b	30 b	1 c	3,725 b	122 c	244	2 d
Sodium azide (SA)	33.6	1,964 a	378 b	211 b	63 a	5,223 b	1,700 bc	729	77 a
Chloroneb + T	26.9 + 0.56	2,540 a	1,284 a	1,662 a	61 a	7,652 b	4,615 ab	1,700	24 b-d
SA + ethoprop	33.6 + 8.96	710 b	166 b	151 b	20 b	3,057 b	1,457 bc	1,012	51 ab
Ethoprop	8.96	2,734 a	1,646 a	1,088 a	94 a	8,988 ab	3,198 a-c	1,984	73 a
MBC	336.0	106 b	0 b	45 b	0 c	1,457 b	648 c	284	18 b-d

[z]Numbers followed by the same letter within each column of data are not significantly different, according to Duncan's multiple range test ($P=0.05$).

(r=0.73**), and *Pythium* spp. (r=0.39*) in the soil 25 days before planting. *F. oxysporum* was the fungus isolated most frequently from seedlings, but *R. solani, F. roseum, P. irregulare* Buis, and *F. solani,* in that order, were occasionally isolated. Root discoloration was less in seedlings from plots where control of nematodes and soilborne fungi was most effective.

Plant growth, survival, and yield: The greatest plant growth and survival occurred when populations of *M. incognita, C. ornatus,* and soilborne fungi were suppressed to low levels by soil fumigation (Table 3). Plant height recorded 31, 52, and 86 days after planting in plots treated with DD-MENCS + film mulch and MBC + film mulch was greater than height of plants in other plots. There was a significant ($P=0.05$) negative relationship between plant height and root-gall indices, number of *C. ornatus* in soil, and populations of *F. oxysporum, F. solani,* and *F. roseum* in the soil early in the growing season. Variation in plant height 31 days after planting was related more to the population of *F. solani* before planting ($R^2=0.23$) than to any other factor measured. More plants survived over a longer period of time in plots treated with DD-MENCS + trifluralin, DD-MENCS + film mulch, and MBC + film mulch than survived in the other plots. The number of live plants/plot after the final harvest was negatively correlated with number of propagules of *Pythium* spp. (r=−0.51**), *F. oxysporum* (r=−0.48*), and *F. roseum* (r=−0.33*), and root-gall indices (r=−0.65**) recorded early during the growing season. Damage to seedlings by soil insects was not significant.

Yields ranged from 3.96 to 17.36 metric ton/ha (Table 3). The greatest yield came from plants in plots treated with DD-MENCS + trifluralin, DD-MENCS + film mulch, and MBC + film mulch. When DD-MENCS and MBC were used under film mulch, total yield was more than double that of the control and late season yields were particularly high (Fig. 1). There were significant ($P=0.05$) negative relationships between total yield and populations of *F. oxysporum, F. solani, F. roseum, Pythium* spp., and *C. ornatus* before planting and root-gall indices throughout the growing season. On the basis of the value of R^2, populations of *F. oxysporum* and *C. ornatus* before planting and root-gall indices 6 weeks after planting accounted for 68% of the variation in total yield.

Pods were harvested for 9 weeks. When yields were analyzed at 2-week intervals, populations of *F. oxysporum* contributed more to the decline of yield during the first half of the growing season than during the last half. The root-gall indices caused more

TABLE 3. Influence of film mulch and soil pesticides on plant height, survival, and yield of okra.

Treatment		Plant ht. (cm) (days after planting)[z]			No. live plants/12.2 m of row (days after planting)[z]		Yield (metric ton/ha)[z]
Chemical	Rates [Kg (a.i.)/ha]	31	52	86	65	117	
Nonmulched							
Trifluralin (T)-Control	0.56	7 e	25 e	88 d	48 bc	25 ab	3.96 e
DD-MENCS + T	376.3 + 0.56	12 d	51 d	119 c	60 ad	38 a	10.86 b
Film mulch							
Trifluralin (T)-Control	0.56	17 bc	57 cd	96 d	55 ab	10 b	5.18 de
DD-MENCS	376.3	24 a	81 a	163 a	58 ab	35 a	17.36 a
Sodium azide (SA)	33.6	19 a-c	67 a-c	132 bc	63 a	12 b	8.10 c
Chloroneb + T	26.9 + 0.56	16 cd	64 b-d	113 c	56 ab	11 b	5.92 c-e
SA + ethoprop	33.6 + 8.96	20 a-c	60 b-d	129 bc	43 c	15 b	6.81 c-e
Ethoprop	8.96	18 bc	67 a-c	123 c	49 bc	15 b	7.14 cd
MBC	336.0	21 ab	74 ab	151 ab	58 ab	37 a	15.98 a

[z]Numbers followed by the same letter within each column of data are not significantly different, ($P=0.05$) according to Duncan's multiple range test.

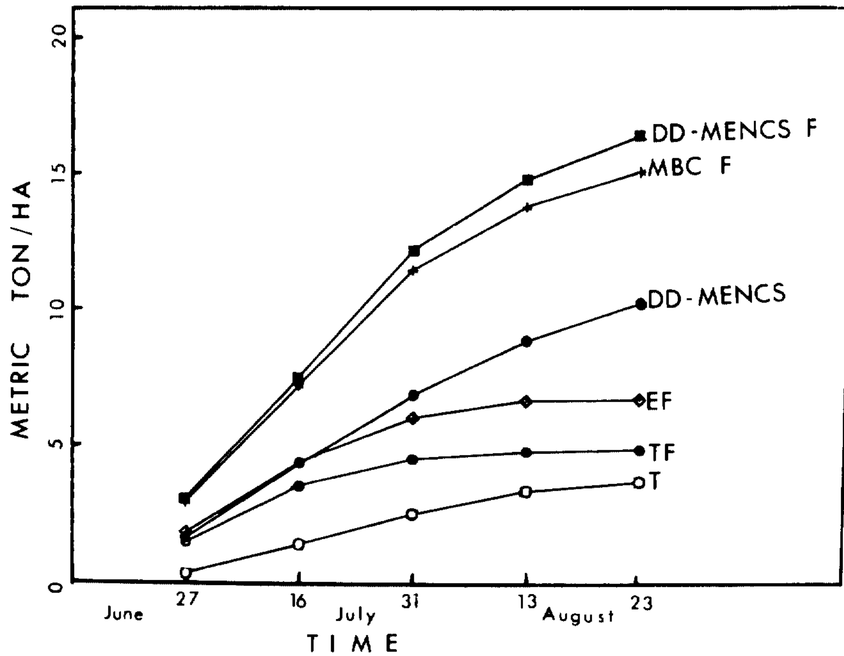

FIG. 1. Cumulative yields of okra in soil treated with (from top to bottom); DD-MENCS + film mulch (DD-MENCS F); methyl bromide-chloropicrin + film mulch (MBC F); DD-MENCS no film (DD-MENCS); ethoprop + film mulch (EF); trifluralin + film mulch (TF); and trifluralin, no film (T)-control.

of the midseason reduction in yield than any other factor, and the relationship of the root-gall indices to yield reduction was always greatest late in the growing season. Population levels of *Pythium* spp. before planting caused more of the reduction of yield late in the growing season than any other factor ($R^2 = 0.50$).

DISCUSSION

Our data indicated that root-knot and ring nematodes and soilborne fungi limited yield potential of okra. Nonvolatile nematicides and fungicides increased yield, but only soil fumigation with film mulch controlled both nematodes and fungi adequately to produce yields similar to those of crops not under stress from nematodes and soilborne disease organisms. Others reported that potassium azide alone gave good pest control (12), but our studies indicated that, for good control in soils heavily infested with root-knot nematodes, a nematicide must be used in combination with sodium azide. Sodium azide alone did not suppress populations of fungi in the soil as well as the soil fumigants, but it was as effective as the fumigants in protecting seedlings from root-rotting fungi. This suggested that the chemical was fungistatic, rather than fungicidal. Because neither nematodes nor soil fungi were suppressed to very low levels in plots treated with sodium azide, the decline in yield during the harvest period and the high mortality rate among mature plants in these plots may have resulted from a loss of the fungistatic effect and from the seasonal increase in population densities of root-knot and ring nematodes.

Jackson reported that *F. solani* caused seedling root-rot of okra in the Georgia coastal plain (7). Our research showed that reduced plant growth and root discoloration were related to populations of *F. solani* in the soil; however, *F. oxysporum* was the fungus most commonly isolated from okra seedlings, and populations of *F. oxysporum, C. ornatus,* and *M. incognita,* as indicated by the root-gall indices, caused the most significant reduction in total yields. Our data also indicated that *Pythium* spp. and *F. roseum* contributed to yield reduction.

Under conventional crop management, many field-grown vegetables have shallow root systems, 30-90 cm deep, but root systems of vegetables grown under film mulch tend to be even more shallow and confined to only the top 15-20 cm of soil (8). Thus, control of pathogens in top soil is more critical for crop culture under mulch than for crop culture by conventional methods. A crop, such as okra, that is harvested for several weeks is especially vulnerable to continuous attack by nematodes and soilborne fungi that kill root tips and root hairs of secondary and tertiary roots and decay cork and cortical tissues of older roots. Other investigators have found that soil temperature increases under mulch, especially before foliage covers the mulch (1), and our data in coastal plain soils show similar increases. Higher temperatures accelerate root growth and possibly make the root tissues more susceptible to root decay than slower growing roots of plants grown without mulch.

Although nematodes and soilborne fungi can be destructive pathogens when acting alone, their combined pathogenic potential can be far greater than the sum of their individual effects. Disease complexes of this sort present special problems for disease control. Attention must be focused on two or more interacting pathogens that differ greatly in their behavior, rather than on a single kind of pathogen. Hence, a satisfactory control program could involve the use of broad-spectrum soil fumigants rather than specific pesticides. In okra, such a control program in combination with film mulch and trickle irrigation would provide more uniform plants, increase land use efficiency, and facilitate mechanical harvesting.

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