Effect of Film Mulch, Trickle Irrigation, and DD-MENCS on Nematodes, Fungi, and Vegetable Yields in a Multicrop Production System

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ABSTRACT

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Field plots of Tifton loamy sand were treated with various rates of DD-MENCS (20% methyl isothiocyanate + 80% chlorinated C_3 hydrocarbons) and covered with black polyethylene film mulch. Trickle irrigation under the film mulch was used when cucumber, squash, and cucumber were grown in succession in these plots. The soil was assayed for nematodes and fungi, and the plant roots were evaluated for root-knot nematode and fungal damage. Soil treatments with DD-MENCS at 107, 161, 215, 269, 322, and 376 kg/ha reduced nematode and fungal populations on cucumber and on squash early in the growing season. Growth and yield of cucumber were greatest when nematodes and fungi were controlled. Nematode control based on root-gall indices in plots treated with DD-MENCS at 215 kg/ha was significantly greater than in untreated plots 54 days after the third crop (cucumber) was planted. The recommended rate of DD-MENCS (376 kg/ha) for control of nematodes and fungi under conventional production practices can be reduced by 43% and still maintain adequate pest control and yield increase of vegetable crops under the film-mulch and trickle irrigation production system.

Additional key words: Cucumis sativus, Cucurbita pepo, multiple cropping.

Trickle irrigation in conjunction with soil fumigation and plastic-film mulch has significantly increased yields of many high value vegetable crops (1,4,5,7,8,11,12). Because of the high initial costs of this production system, there is considerable interest in multiple cropping (growing three crops in sucession) and reducing the amount of fumigant. Although double cropping has been successful with film mulching, trickle irrigation, and soil fumigation (9), the concurrent reduction of fumigation rate under that system has not been studied. In this study, we evaluated DD-MENCS at various rates, determined the potential advantages of multiple cropping with film mulching and trickle irrigation, and identified possible production problems.

MATERIALS AND METHODS

The experiment was conducted on Tifton loamy sand (~85% sand, 10% silt, and 5% clay) infested with *Meloidogyne incognita* (Kofoid & White) Chitwood, *Macroposthonia ornata* (Raski) de Grisse, *Pratylenchus* spp., and several potentially pathogenic fungi including *Pythium* spp., *Fusarium oxysporum* Schlecht., *F. solani* (Mart.) Appel & Wr., *F. roseum* Lk. ex Fr., and *Rhizoctonia solani* Kuehn. The test area was planted to root-knot-susceptible vegetable crops in the summers and to hairy vetch (*Vicia villosa* Roth) as a winter cover crop prior to planting of the test crops.

Each experimental plot consisted of a single preformed 1.7×9.1-m bed with one row. Treatments were arranged in a randomized complete block design with four replications. The soil fumigant, DD-MENCS (20% methyl isothiocyanate + 80% chlorinated C_3 hydrocarbons), was applied at 107, 161, 215, 269, 322, and 376 kg/ha. It was injected 25 cm deep with chisels 20 cm apart, and the soil was sealed by compaction with a bed-shaper attachment. Soil moisture tension was approximately 0.3 bar when the chemical treatments were applied, and the soil temperature at 15 cm was 14 C.

Fertilizer application and placement were as follows: Film-mulched plots received 39-48-33 (N-P-K) kg/ha broadcast and incorporated preplant into the upper 15 cm of soil with a tractor-mounted rototiller. Also, 146-0-409 (N-P-K) kg/ha was applied preplant in double bands 46 cm apart, with each band 23 cm from the plant row. Nonmulched plots received similar fertilization except that the 146-0-409 (N-P-K) kg/ha was applied as sidedress during the final cultivation. All plots received 2.4 and 2.8 kg/ha/day of N and K applied as $Ca(NO_3)_2$ and KNO_3, respectively, applied twice a week in the irrigation water beginning 2 wk after each crop was planted.

Biwall (Anjac Plastics, Inc., El Monte, CA 91731) trickle irrigation tubing was laid on the soil surface in all plots; after fumigation mulched plots were completely covered with black polyethylene film mulch (0.152 mm thick) as previously described (5). Two weeks after plots were covered, holes (6 cm diameter) were cut 30 cm apart in the film (a single row per bed) to allow aeration. Four weeks later (April, 1975), cucumber (*Cucumis sativus* L. 'Gemini 353') was planted (three seeds per hill) 2–4 cm deep through the holes in the mulch. Nonmulched plots were treated with bensulide [*O,O*-diisopropyl phosphorodithioate *S*-ester with *N*-(2-mercaptoethyl) benzenesulfonamide] at 6.7 kg a.i./ha, sprayed on the soil surface and incorporated into the top 15 cm of soil for weed control, and then planted and irrigated as described for film mulched plots.

The cucumbers were hand-harvested and graded 15 times at 3- to 4-day intervals. Only marketable yields according to USDA standards (13) are reported. After the final harvest in July, the vines were cut near the soil surface and removed from the plots. Spaces between plots were sprayed with paraquat (1,1′-dimethyl-4,4′-bipyridinium ion) at 0.56 kg a.i./ha for weed control. Plots remained undistrubed for 18 days.

The second crop was squash (*Cucurbita pepo* L. 'Zapallo-Dixie Hybrid') planted (four seeds per hill) on 4 August 1975 as described for cucumbers and thinned to three seedlings per hill 2 wk later. The fruit were hand-picked and weighed 11 times during the experiment. After the final harvest in October, the vines were cut and removed from the plots. One week later all plots were sprayed with paraquat and cabbage (*Brassica oleracea* 'Market Prize') was planted. Because low temperatures during the winter damaged the cabbage, the plants were cut and removed from the plots which remained undisturbed until 30 March 1976, when the film mulch (which had deteriorated beyond usefulness) was removed from all plots. The plots were fertilized with 45-90-135 (N-P-K) kg/ha applied broadcast and rototilled into the top 15-cm of the soil and sprayed with paraquat for weed control. Cucumber was planted on 21 April 1976 and a single trickle irrigation tube was laid on each plot, but all plots remained uncovered for the duration of the test.

Soil was assayed for plant-parasitic nematodes 14, 72, and 53 days after cucumber, squash, and cucumber, respectively, were planted. Ten cores of soil, 2.5 × 15-cm deep, were collected from each plot, composited, and thoroughly mixed. A 150-cm^3 sample was processed by the centrifugal-flotation method (6).

Moist soil (25 g) was assayed for selected fungi 14 and 22 days after cucumber and squash, respectively, were planted and 6 days preplant and 103 days after the planting of the last crop of cucumber. The selective media used for assay were modified peptone-PCNB for *Fusarium* spp. (10), gallic acid medium for *Pythium* spp. (3), and tannic-acid medium for *Rhizoctonia solani* (2). Populations of fungi were expressed as propagules per gram of oven-dried soil, except that *R. solani* was expressed as propagules per 100 g of oven-dried soil.

When seedlings of all crops were 14–22 days old, plants were evaluated for root and hypocotyl discoloration and decay. Sections of diseased root and hypocotyl tissues from cucumber and squash seedlings were washed 30–45 min in running tap water at 10–15 C, blotted dry on sterile filter paper, and plated on water agar. Fungi growing from the tissues after 2–5 days at 25–30 C were transferred to potato-dextrose agar (PDA) and identified.

Data representing plant growth and yield were recorded from plants in the center 6-m of row in each plot. Plant growth was rated on a 1 to 5 scale in which 1 = plants small, chlorotic, and nonvigorous and 5 = plants large, dark green, and vigorous. Yields (kg) of successive cucumber or squash harvests were totaled and converted to metric tons per hectare. Plant roots were indexed for galls induced by root-knot nematodes 22–54 days after planting and after the final harvest. Twenty plants selected at random were uprooted and rated for galls on a 1–5 scale: 1 = no galls, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% of the roots galled.

RESULTS

Nematodes. *Meloidogyne incognita, Macroposthonia ornata,* and *Pratylenchus* spp. were present in the experimental area before treatment. Population densities of *M. ornata* and *Pratylenchus* spp. were low and failed to increase in untreated plots during the test. Therefore, only data on *M. incognita* are reported here. Populations of *M. incognita* usually were higher in film mulched control plots than in nonmulched control plots (Table 1). Numbers of *M. incognita* were low and variable in all plots 14 days after cucumbers were planted, but these increased in all plots 85 days after planting. Then numbers of root-knot nematodes in all treated plots were lower than those in film mulched control plots. The numbers of root-knot nematodes were variable in the second and third crop, and differences among most soil fumigation treatments were not significant ($P = 0.05$).

Root-gall indices were much more consistent and indicative of root-knot control than were numbers of nematodes (Table 2). Root-gall indices in DD-MENCS-treated plots 25 and 85 days after the planting of cucumber and 22 days after the planting of squash were lower than those in untreated plots. Root-gall indices of squash 70 days after planting and cucumber 54 days after planting in plots treated with DD-MENCS at 215 kg/ha were significantly lower than in untreated plots. Root-gall indices increased rapidly on cucumber 82 days after planting and were reduced only by DD-MENCS (376 kg/ha) compared with the untreated control.

Populations of soil-borne fungi. Numbers of fungal propagules per gram of soil were highly variable, but were reduced by all rates of DD-MENCS 22 days after application (19 days before cucumbers were planted) (Table 3). Propagule counts of *Pythium* spp. and *F. solani* were lower in treated plots than in untreated plots 87 days after planting, but the numbers of *F. oxysporum* and *F. roseum* propagules were not significantly affected by soil chemical treatments. Six days before the third crop (cucumber) was planted, propagule counts of *Pythium* spp. and *F. roseum* were similar in all film-mulched plots. Populations of *F. oxysporum* were lower in all treated plots, and populations of *F. solani* were lowest in plots treated with the higher rates of DD-MENCS. Later (103 days after planting) in the third crop, numbers of *Pythium* spp., *F. solani,* and *F. roseum* propagules were not significantly affected by soil chemical treatments, but propagules of *F. oxysporum* were lower in DD-MENCS-treated plots than in untreated plots. No propagules of *R. solani* were recovered on soil plates from initial collections in fumigated soil in April 1975, but in untreated soil there were 8 to 11 propagules per 100 g soil. In later

TABLE 1. Post planting population densities of *Meloidogyne incognita* in soil from untreated field plots and from plots treated with various rates of DD-MENCS[y] under black polyethylene film mulch and planted to three crops in succession

Treatment and DD-MENCS dosage (kg/ha)	Pretreatment	Nematodes/150 cm^3 soil			
		Cucumber		Squash	Cucumber
		14 days	85 days	72 days	53 days
Nonmulched					
Control	28	0	630 ab[z]	743	35 ab
Film-mulched					
Control	98	10	1,273 a	1,238	10 b
107	38	5	55 c	1,343	25 b
161	88	0	60 c	725	33 ab
215	93	18	285 b	1,358	40 ab
269	30	0	13 c	333	5 b
322	115	3	98 c	480	83 a
376	15	3	13 c	220	20 b

[y]DD-MENCS (20% methyl isothiocyanate + 80% chlorinated C_3 hydrocarbons).
[z]Numbers followed by the same letter within each column are not significantly different ($P = 0.05$) according to Duncan's multiple-range test. No letters indicate that the differences were not significant.

TABLE 2. Root-gall indices from three crops grown in succession in untreated field plots and plots treated with various rates of DD-MENCS[y] under film mulch

Treatment and DD-MENCS dosage (kg/ha)	Root-gall indices[z]					
	Cucumber (days after planting)		Squash (days after planting)		Cucumber (days after planting)	
	25	85	22	70	54	82
Nonmulched						
Control	1.24 b	4.58 a	1.74 b	4.66 a	2.13 ab	3.65 a
Film-mulched						
Control	2.89 a	4.35 a	2.28 a	4.23 ab	2.13 ab	3.68 a
107	1.05 b	1.75 b	1.25 c	3.01 bc	1.63 bc	2.65 ab
161	1.00 b	1.25 bc	1.04 c	3.03 bc	1.56 bc	3.13 ab
215	1.00 b	1.03 a	1.03 c	2.53 cd	1.44 c	2.70 ab
269	1.00 b	1.00 c	1.11 c	2.29 cd	1.25 c	2.28 ab
322	1.00 b	1.03 c	1.18 c	1.75 cd	1.25 c	2.45 ab
376	1.00 b	1.00 c	1.04 c	1.45 d	1.25 c	2.03 b

[y]DD-MENCS (20% methyl isothiocyanate + 80% chlorinated C_3 hydrocarbons).
[z]Root-gall index 1–5 scale: 1 = no galls; 2 = 1–25%; 3 = 26–50%; 4 = 51–75%; and 5 = 76–100% roots galled. 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.

samplings, populations of *R. solani* propagules varied from three to 13 propagules per 100 g soil, and there were no differences among treatments. Populations of *Penicillium* spp. + *Paecilomyces* spp., *Aspergillus* spp., and *Trichoderma* spp. were reduced by soil fumigation in the first sampling, but in later samplings differences among soil treatments were rare.

Root discoloration and root-disease indices. Generally, more seedlings survived in DD-MENCS-treated plots than in untreated plots. There was little root discoloration in 2- to 3-wk-old seedlings of each crop, and there were no significant differences in root-disease indices among treatments. In the first crop of cucumbers, significantly fewer total cultures of *Pythium* spp., *Fusarium* spp., *Rhizoctonia solani* (AG-4), and *Rhizoctonia* spp. (binucleate) were isolated from plants grown in fumigated soil (except those in plots treated at the 107 and 269 kg/ha) than from plants in nonfumigated soil. In the squash and second cucumber crops the results were erratic, but fewer cultures of the three genera of fungi were consistently isolated from plants grown in the fumigated plots than in those grown in the nonfumigated plots. *Rhizoctonia solani* and *Pythium* spp. frequently were isolated from discolored and decayed roots, and *R. solani*, *Rhizoctonia* spp. (binucleate), *Pythium aphanidermatum* (Edson) Fitzp., and *P. irregulare* Buis. were the most virulent on cucumber seedlings of any of the fungi tested in pathogenicity tests conducted in a

TABLE 3. Populations of selected fungi from the rhizosphere of cucumber plants grown in plots treated with various rates of DD-MENCS[v] under film mulch (crop 1) or following a planting of squash (crop 2) and without film mulch (crop 3)

Treatment and DD-MENCS dosage (kg/ha)	Propagules per gram of soil[w]							
		Fusarium spp.				*Fusarium spp.*		
	Pythium spp.	*F. solani*	*F. oxysporum*	*F. roseum*	*Pythium* spp.	*F. solani*	*F. oxysporum*	*F. roseum*
Cucumber (crop 1)	22 days after fumigation[x]				87 days after planting			
Nonmulched								
Control	37 a[y]	1,127 a	591 a	985 a	59 a	2,084 b	1,281	3,582
Film-mulched								
Control	55 a	1,521 a	339 b	919 a	112 a	9,509 a	738	1,129
107	3 b	722 b	132 c	339 b	16 b	1,151 b	369	6,666
161	8 b	164 c	77 c	153 b	4 b	586 b	22	8,402
215	2 b	44 c	0 c	22 b	40 b	3,583 b	239	6,752
269	8 b	22 c	0 c	121 b	21 b	674 b	348	9,227
322	0 b	66 c	0 c	143 b	25 b	978 b	348	6,795
376	7 b	11 c	0 c	66 b	2 b	1,303 b	131	6,644
Cucumber (crop 3)[z]	6 days preplant				103 days post plant			
Nonmulched								
Control	81 a	1,467 a	1,536 a	817 a	10	4,570	1539 a	1,669
Film-mulched								
Control	34 b	1,006 ab	1,003 a	232 b	8	2,461	1,472 a	1,298
107	9 b	912 ab	350 b	163 b	6	3,319	726 ab	1,386
161	1 b	511 bc	208 b	233 b	3	1,296	506 b	527
215	3 b	210 c	47 b	140 b	2	3,967	330 b	857
269	2 b	140 c	23 b	139 b	1	1,844	242 b	990
322	2 b	117 c	139 b	139 b	8	2,029	836 ab	1,252
376	3 b	116 c	69 b	186 b	0	330	483 b	1,362

[v] DD-MENCS (20% methyl isothiocyanate + 80% chlorinated C_3 hydrocarbons).
[w] Oven-dry basis.
[x] 19 days before planting.
[y] Numbers followed by the same letter within each column are not significantly different ($P = 0.05$) according to Duncan's multiple range test. Absence of letters indicates the differences were not significant.
[z] Film mulch had deteriorated and was removed from all plots in March 1976 before crop 3 was planted.

TABLE 4. Growth and yield of three vegetable crops grown in succession in untreated field plots and plots treated with various rates of DD-MENCS[x] under film mulch

Treatment and DD-MENCS dosage (kg/ha)	Cucumber		Squash		Cucumber	
	Plant height (cm) (14 days after planting)	Yield (metric tons/ha)	Growth index[y] (31 days after planting)	Yield (metric tons/ha)	Growth index (23 days after planting)	Yield (metric tons/ha)
Nonmulched						
Control	6.8 b[z]	42.2 c	1.25 d	1.8 b	5.00	2.7 b
Film-mulched						
Control	8.3 b	43.6 bc	4.75 a	10.5 a	4.00	1.9 b
107	10.8 a	54.4 abc	3.75 b	10.4 a	4.00	3.4 b
161	10.8 a	58.5 a	3.00 bc	9.2 a	4.00	3.2 b
215	11.3 a	55.9 ab	3.00 bc	8.8 a	4.25	5.0 ab
269	10.0 a	59.1 a	2.75 c	8.6 a	5.00	2.5 b
322	10.5 a	56.8 a	3.25 bc	9.5 a	4.50	4.2 ab
376	10.5 a	57.1 a	3.75 b	10.1 a	4.75	6.5 a

[x] DD-MENCS (20% methyl isothiocyanate + 80% chlorinated C_3 hydrocarbons).
[y] Scale 1–5: 1 = plants small, chlorotic, and nonvigorous; 5 = plants large, dark-green, and vigorous.
[z] Numbers followed by the same letter within each column are not significantly different ($P = 0.05$) according to Duncan's multiple-range test. No letters indicate that the differences were not significant.

greenhouse.

Growth and yield. The first crop (cucumbers) produced the best growth and highest yields when populations of root-knot nematodes and soilborne fungi were low (Table 4). Plant heights recorded 14 days after planting in plots treated with DD-MENCS + film mulch were 20–36% greater than those from untreated mulched plots and 47–66% greater than those from nonmulched control plots. Yields from plants in DD-MENCS-treated mulched plots were 25–36% greater than those from untreated or from nonmulched control plots. A summary of marketable yields in Table 4 indicates a significant yield increase from DD-MENCS-treated plots (161, 269, 376 kg/ha) over untreated plots, but no differences in yield among DD-MENCS-treated plots. Correlation coefficients indicate a significant negative correlation among total marketable yield and number of root-knot nematodes in the soil after the final harvest (R = −0.74**), and root-gall indices 25 days (r = 0.55**) and 85 days (r = −0.70**) after planting. The stepwise regression analyses (R^2 value) indicated that 55% of the variation in total marketable yield was related to the number of root-knot nematodes in the soil 85 days after planting.

Growth and yield of the second crop (squash) were poor in nonmulched control plots and were greatest in mulched control plots. Yield was not significantly affected by dosage levels of DD-MENCS, but was inversely correlated with root-gall indices (r = −0.39*) 70 days after planting.

Growth of the third crop (cucumber) recorded 23 days after planting was not affected by soil fumigation treatments. However, yield was greatest from plots that had received the highest rate of DD-MENCS. Total marketable yield was inversely correlated with root-gall indices 54 days (r = −0.52**) and 82 days (r = −0.55**) after planting.

DISCUSSION

Film mulches offer several advantages in crop production: increased efficiency of soil fumigants by serving as a sealant, decreased reinfestation of the treated soil with contaminated soil by wind and water erosion, prevented leaching of nutrients, prevented soil compaction, provide weed control, conserve moisture, and (at times) maintain soil temperatures favorable for plant growth. Our data indicated that plastic film mulch in a multicrop production system was effective for two crops, but that it deteriorated and was not effective for the third crop.

Control of root-knot nematodes and soilborne fungi, and increased plant growth and yield in the first crop (cucumber) were similar to results from tests with DD-MENCS at 376 kg/ha with other crops (1,5,7–9,11,12). Yields of squash in DD-MENCS-treated plots were not significantly different from those in untreated mulched plots, which indicated that squash may be more tolerant than cucumber to root-knot nematodes. Squash, however, supported large numbers of nematodes, and may be more affected by conditions under film mulch or less inhibited by pathogenic soil fungi than were cucumbers. The yield of the third crop (cucumber) was low. The deteriorated plastic film mulch was removed from plots prior to planting, and benefits of the mulch were not realized. Furthermore, there was a distinct increase in numbers of root-knot nematodes, soilborne fungi, and weeds during the third crop.

The degree of nematode control, based on root-gall indices, in the second and third crop in film-mulched plots treated with DD-MENCS (215 kg/ha) was favorable. This indicates that the rate of DD-MENCS (376 kg/ha) presently recommended for control of root-knot nematodes and soilborne fungi under conventional production practices, can be reduced by 43% and maintain effective pest control and increase yield of cucumber in a multiple cropping production system that utilizes film mulch and trickle irrigation. Reduction in pesticide usage lowers unit production costs. Dosages of DD-MENCS greater than 215 kg/ha may be required for maximum pest control and yield in three consecutive crops grown in soil heavily infested with root-knot nematodes and pathogenic fungi.

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