# Effects of Film Mulch and Soil Pesticides on Nematodes, Weeds, and Yields of Vegetable Crops[1]

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*Abstract:* Field plots in Tifton loamy sand were treated with various soil pesticides in 1973 and 1974 and either left exposed or covered with biodegradable film mulch. Test crops were cantaloup, slicing and pickling cucumber, squash, and sweet corn. Overhead sprinkler irrigation was used in 1973, and trickle irrigation under the film mulch was used on sweet corn in 1974. Soil was assayed for nematodes, and roots of plants were evaluated for damage by root-knot nematodes. Nematode populations were reduced by soil treatment with an organic phosphate or carbamate nematicide-herbicide-fungicide combination (NHF), DD-MENCS, methyl bromide-chloropicrin (MBR-CP), ethoprop, carbofuran, and sodium azide + ethoprop or carbofuran. Sodium azide, sodium azide + ethoprop or carbofuran, ethoprop, and carbofuran were less effective than DD-MENCS, MBR-CP, and the NHF combination. The NHF combination controlled grasses and broadleaf weeds as effectively as the herbicide alone. Growth and yield were greatest when nematodes and weeds were controlled. Yields of marketable vegetables were highest from plants in plots treated with DD-MENCS with a film mulch. *Key words: Meloidogyne incognita, Macroposthonia ornata,* multiple pest control.

Most fields currently used for growing vegetables in Georgia are infested with nematodes, weeds, and pathogenic soil fungi which limit production (6,7,19). Use of film mulch in conjunction with soil fumigation and trickle irrigation has greatly increased vegetable yields (1,5,9,13,14,16,17,18), and this combination of practices is increasing rapidly in the southeastern United States. However, information is limited on the influence of nematodes and weeds in the production of vegetable crops under the film-mulch, trickle-irrigation system. Research was therefore initiated on the role of nematodes and weeds in the production of high-value vegetable crops using film mulch, soil pesticides, and irrigation.

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## MATERIALS AND METHODS

The experiments were conducted in 1973 and 1974 on Tifton loamy sand (85% sand, 8% silt, and 7% clay) with natural populations of *Meloidogyne incognita* (Kofoid & White) Chitwood, *Macroposthonia ornata* (Raski) De Grisse & Loof, and *Paratrichodorus minor* (Colbran) Siddiqi. To increase nematode populations, the test areas had been planted with vegetable crops susceptible to root-knot nematodes in the previous spring and summer, and with hairy vetch (*Vicia villosa* Roth) in the fall and winter. In the summer, large crabgrass (*Digitaria sanguinalis* (L.) Scop.) and Florida pusley (*Richardia scabra* L.) were distributed uniformly over the entire test areas. Other weeds present in scattered stands were yellow nutsedge (*Cyperus esculentus* L.) and purslane (*Portulaca oleracea* L.). Biodegradable film mulch (brown paper coated with clear polyethylene film 51 $\mu$m thick) was used on all crops. Overhead sprinkler irrigation was used in 1973, but the moisture resulting under the film mulch was adequate only when the surface of the mulch was perforated. Trickle irrigation under the film mulch was used on sweet corn in 1974.

Complete dry fertilizer was broadcast and rototilled into the top 15 cm of soil in both years, and in 1974 additional $Ca(NO_3)_2$ and $KNO_3$ were banded on the bed surface (4). Fertilization was the same for all treatments within each experiment. Trickle water application was uniform within the sweet corn test, with water applied when soil-moisture-tension readings reached 25 centibars.

A randomized complete block design with four replications was used. Each plot was a raised bed of 1.7 × 12.2 m. The pesticides used, and their rates in kg/ha of active ingredient, were as follows: (A) nematicides—ethoprop, 8.96; carbofuran, 8.96; (B) nematicide + fungicide + herbicide combinations—ethoprop, 8.96, + 80% PCNB + 20% ethazole, 6.72, + butylate, 3.36; and ethoprop, 8.96, + 80% PCNB and 20% ethazole, 6.72, + bensulide, 6.72; (C) soil fungicide—sodium azide, 33.6; (D) soil fumigants—20% methylisothiocyanate + 80% chlorinated $C_3$ hydrocarbons, 376.3, (DD-MENCS); and 67% methyl bromide + 33% chloropicrin, 336, (MBR-CP); and (E) herbicides—bensulide, 6.72, on cucurbits, and butylate, 3.36, on sweet corn. Soil fumigants were injected 25 cm deep with chisels 20 cm apart, and the soil surface was sealed by compaction with a bed-shaper attachment. Granules of ethoprop, carbofuran, sodium azide, and the nematicide-herbicide-fungicide (NHF) combination were spread on the soil surface and incorporated into the top 15-cm layer with a tractor-mounted rototiller. Herbicides were sprayed on the soil surface and incorporated into the top 5-cm layer.

Soil moisture was near or slightly below field capacity during chemical application. Trickle-irrigation tubing was laid (1974 only), and all mulched plots were covered immediately after soil fumigation and were not disturbed for 7–10 d. One week after chemical application, holes of 6-cm d were cut in the mulch to allow aeration, and the seeds were hand-planted through the holes 1–3 wk later, depending on the soil temperature. The crops planted were cantaloup (*Cucumis melo* L. 'Planters Jumbo'), cucumber (*Cucumis sativus* L. 'Gemini-7' for slicing and 'Explorer' for pickling), summer squash (*Cucurbita pepo* L. var. *melopepo* L. Alefi 'Dixie'), and sweet corn (*Zea mays* L. 'Seneca Chief'). Sweet corn was planted in the spring of 1973 and 1974, and cantaloup, cucumber, and squash were planted in the spring of 1973. Cantaloup and cucumber were planted in a single row in hills, respectively 30 and 76 cm apart. Squash and sweet corn were planted in two rows/plot in hills 23 cm apart. Seeds of all crops were planted 2–4 cm deep, three seeds/hill, and the squash and sweet corn were thinned to one seedling/hill 2 wk after planting. Foliar pesticides were used as needed to prevent damage by insects, leaf spot fungi, and bacteria.

Soil was assayed for plant-parasitic nematodes at planting and 60–85 d after planting. Ten cores (2.5 × 15 cm) of soil were collected from each plot and mixed thoroughly. A 150-$cm^3$ aliquant was processed by a centrifugal-flotation method (10) for the nematode assay. The plants were indexed for galls caused by root-knot nematodes 5 wk after planting and again after the final harvest. Individual plants were rated on a

1–5 scale (1 = no galls, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% roots galled).

Percent weed control was recorded as relative ratings based on total weed growth in untreated, unmulched control plots.

Plant growth and yields were measured in the center 6 cm of each plot. Seedling growth was recorded 25–55 d after planting. First yields were taken when 90% or more of the fruit was of marketable size. Cantaloup, squash, and the slicing cucumber 'Gemini-7' were harvested several times; the pickling cucumber 'Explorer' was harvested once. Sweet corn was harvested as needed.

## RESULTS

*Nematodes:* Nematode data are presented as number/150 $cm^3$ soil. Numbers of *Macroposthonia ornata, Paratrichodorus minor,* and *Meloidogyne incognita* were less than 25/150-$cm^3$ soil in all plots at planting and 45 d after planting. The effects of nematicide treatment on the nematode populations were most evident 60–110 d after planting. The numbers of *M. incognita* were greater in film-mulched plots than in unmulched plots of cantaloup (269 vs 32), cucumbers (slicing, 524 vs 255 and pickling, 282 vs 72), and squash (143 vs 40), but not sweet corn (62 vs 12). After the final harvest of cantaloup, pickling cucumber, and squash, the numbers of *M. incognita* in unmulched plots were lowest in plots treated with the NHF combination (range 0–18). In similar plots of slicing cucumber, *M. incognita* numbered 63 in plots treated with DD-MENCS + herbicide. In film-mulched plots, the numbers of *M. incognita* were lower in plots treated with DD-MENCS and the NHF combination in cantaloup (0, 33), slicing (98, 28) and pickling (45, 13) cucumbers, and squash (33, 43) than in other plots. Numbers of *P. minor* did not increase above 25 on any crop; therefore, data are not included. *M. ornata* numbered 37 on cucurbits and 319 on sweet corn.

In 1973, populations of *M. ornata* on sweet corn were reduced below detectable levels by DD-MENCS in unmulched plots 110 d after planting. In film-mulched plots, the number of *M. ornata* in the soil 110 d after planting was lower in plots treated with DD-MENCS (13) and the NHF combination (158) than in untreated plots (508). In 1974, DD-MENCS + H reduced the numbers of *M. ornata* and *M. incognita* below detectable levels in unmulched plots 85 d after planting (Table 1). In film-mulched plots, numbers of *M. ornata* and *M. incognita* were below detectable levels in plots treated with DD-MENCS and MBR-CP.

*Root-gall indices:* Film mulch did not affect root-gall indices on the cucurbits (Table 2). Root-gall indices were lower from plots treated with the NHF combination and DD-MENCS than those in untreated plots on most sampling dates. No galls were observed on roots of sweet corn.

*Weed control:* In unmulched plots, the herbicides alone or with other pesticides controlled grasses ($\bar{x}$ 95%) more effectively than broadleaf weeds ($\bar{x}$ 54% control). Excellent control (90–100%) of grasses in herbicide-treated plots was still evident in cantaloup 70 d after planting. In most crops, DD-MENCS controlled grasses and weeds less effectively than the herbicides, but gave better control than in untreated plots. Weed and grass control was 80% or greater in all film-mulched plots.

Since it proved unfeasible to grow vegetables in untreated, unmulched plots, that treatment was deleted after 1973. In 1974, butylate was used on unmulched plots and on designated film-mulched plots of sweet corn, and weed control was > 85% in all plots.

*Plant growth and yield:* Plant height and yield (Table 3) were greatest when nematode populations were reduced to low levels by soil chemical treatments. In most tests, plant heights were greater in film-mulched plots than in unmulched plots given similar soil treatments. In 1973, the height of cantaloup, slicing cucumber, and sweet corn was greater in plots treated with DD-MENCS + film mulch than in other treatments. The trend was similar in sweet corn in 1974 in plots treated with MBR-CP + film mulch, sodium azide, sodium azide + nematicide + film mulch, and DD-MENCS + film mulch. Cantaloup height was related inversely to root-gall indices 35 d ($r$ = −0.42**) and 95 d after planting ($r$ = −0.36*) and to the number of *M. ornata* ($r$ = −0.42**) in the soil 95 d after planting.

Table 1. Number of nematodes and yield as influenced by film mulch and soil chemical treatments on sweet corn, 1974.

| Treatments | Nematodes/150 cm³ soil 85 d after planting: *M. ornata* | | *M. incognita* | | Yield (metric tons/ha) | |
|---|---|---|---|---|---|---|
| Unmulched | | | | | | |
| 1. Herbicide (H)* | 30 | | 55 | | 2.6 | |
| 2. DD-MENCS + H | 0 | | 0 | | 5.9 | |
| Film mulch | | | | | | |
| 3. H | 25 | | 428 | | 7.3 | |
| 4. DD-MENCS | 0 | | 0 | | 7.6 | |
| 5. Sodium azide (SA) | 3 | | 90 | | 6.0 | |
| 6. Nematicide (N)† | 3 | | 363 | | 8.2 | |
| 7. SA + N | 0 | | 58 | | 5.9 | |
| 8. MBR-CP | 0 | | 0 | | 7.3 | |
| 9. Chloroneb + H | 195 | | 388 | | 7.2 | |
| Comparisons | | | | | | |
| 1,3 (vs) 2,4 | 28 | 0‡ | 242 | 0 | 5.0 | 6.8 |
| 1 (vs) 3 | 30 | 25 | 55 | 428 | 2.6 | 7.3 |
| 2 (vs) 4 | 0 | 0 | 0 | 0 | 5.9 | 7.6 |
| 4 (vs) 5 | 0 | 3 | 0 | 90 | 7.6 | 6.0 |
| 5 (vs) 7 | 3 | 0 | 90 | 58 | 6.0 | 5.9 |
| 7 (vs) 6 | 0 | 3 | 58 | 363 | 5.9 | 8.2 |
| 8 (vs) 3 | 0 | 25 | 0 | 428 | 7.3 | 7.3 |
| 9 (vs) 3 | 195 | 25 | 388 | 428 | 7.2 | 7.3 |

*Butylate 3.36 kg/ha active ingredient.

†Carbofuran 8.96 kg/ha active ingredient.

‡The test for mean differences for comparisons is based on the results from least squares analysis on transformed data (Log n + 1) or square root where appropriate. Means underlined by contiguous line are not significantly ($P = 0.05$) different.

The heights of slicing cucumber and squash were related inversely to root-gall indices ($r = -0.54$** and $r = -0.43$**, respectively) 35 d after planting. Growth of sweet corn in 1974 was related inversely to numbers of *M. ornata* ($r = -0.36$*) in the soil 85 d after planting.

Cantaloup yields were low but were increased significantly by DD-MENCS in film-mulched and unmulched plots. The yield was related inversely ($r = -0.32$*) to root-gall indices 95 d after planting. Yields of slicing cucumber were greatest from plants in plots treated with DD-MENCS, and were related inversely to root-gall indices 35 d ($r = -0.54$**) and 95 d ($r = -0.50$**) after planting. The root-gall indices 35 d after planting accounted for 30% of the total variation in yield. The yields of pickling cucumber were greater from unmulched than from film-mulched plots. Yields of squash were greater from film-mulched and unmulched plots treated with DD-MENCS than from unmulched and film-mulched control plots. The yield was related inversely to root-gall indices 35 d ($r = -0.45$**) and 75 d ($r = 0.40$**) after planting. The value of $R^2$ indicated that root-gall indices 35 d after planting accounted for 20% of the total variation in yield.

Yield of sweet corn in all plots was lower in 1973 than in 1974. In 1973, DD-MENCS, and the NHF combination increased yields over those from the untreated film-mulched and unmulched plots. The yield of marketable ears was related inversely ($r = -0.45$**) to the number of *M. ornata* in the soil 110 d after planting. The number of *M. ornata* accounted for 21% of the total variation in weight of marketable ears. In 1974, the yield of sweet corn was increased by film mulch and DD-MENCS compared with unmulched and untreated plots, but was not significantly

Table 2. Root-gall indices of vegetable crops as influenced by film mulch and soil chemical treatments.

| Treatments | Cantaloup Days after planting 35 | Cantaloup Days after planting 95 | Slicing cucumber Days after planting 35 | Slicing cucumber Days after planting 95 | Pickling cucumber Days after planting 35 | Pickling cucumber Days after planting 60 | Squash Days after planting 35 | Squash Days after planting 75 |
|---|---|---|---|---|---|---|---|---|
| **Unmulched** | | | | | | | | |
| Control | 3.60* | 3.01 | 4.62 | 4.38 | 5.00 | 4.32 | 3.61 | 4.51 |
| Herbicide (H)† | 2.63 | 4.00 | 4.63 | 4.52 | 5.00 | 3.62 | 3.25 | 3.79 |
| DD-MENCS | 2.29 | 2.62 | 3.46 | 3.69 | 1.25 | 2.51 | 1.46 | 2.61 |
| DD-MENCS + H | 2.67 | 2.95 | 3.49 | 2.65 | 1.20 | 3.17 | 1.63 | 2.87 |
| Nematicide (N)‡ + H + PCNB + ethazole | 1.04 | 1.11 | 1.00 | 2.31 | 1.15 | 1.00 | 1.43 | 2.25 |
| **Film mulch** | | | | | | | | |
| Control | 2.98 | 3.50 | 4.93 | 4.73 | 4.73 | 4.18 | 2.82 | 3.79 |
| Herbicide | 3.08 | 3.57 | 4.64 | 4.27 | 4.10 | 3.33 | 3.53 | 4.53 |
| DD-MENCS | 1.00 | 1.17 | 3.50 | 2.60 | 1.30 | 2.78 | 1.18 | 1.64 |
| N + H + PCNB + ethazole | 1.37 | 1.87 | 1.18 | 2.57 | 1.03 | 1.87 | 1.25 | 1.76 |
| **Main effects** | | | | | | | | |
| Unmulched (vs) mulched | 2.39 2.11§ | 2.69 2.53 | 3.43 3.55 | 3.73 3.54 | 3.10 2.79 | 2.86 3.04 | 2.44 2.20 | 3.29 2.93 |
| Control (vs) N + H + PCNB + ethazole | 3.29 1.21 | 3.26 1.49 | 4.78 1.07 | 4.56 2.44 | 4.87 1.09 | 4.25 1.44 | 3.22 1.34 | 4.15 2.01 |
| Control (vs) DD-MENCS | 3.29 1.65 | 3.26 1.90 | 4.78 3.48 | 4.56 3.15 | 4.87 1.28 | 4.25 2.65 | 3.22 1.32 | 4.15 2.13 |
| Control (vs) herbicide (H) | 3.29 2.86 | 3.26 3.79 | 4.78 4.64 | 4.56 4.40 | 4.87 4.55 | 4.25 3.48 | 3.22 3.39 | 4.15 4.16 |

*Root-gall indices 1-5 scale: 1 = no galls, 2 = 1-25%, 3 = 26-50%, 4 = 51-75%, and 5 = 76-100% of roots galled.
†Bensulide, 6.72 kg/ha active ingredient.
‡Ethoprop, 8.96 kg/ha active ingredient.
§The test for mean differences for comparisons is based on the results from least squares analysis on transformed data (Log n + 1) or square root where appropriate. Means underlined by contiguous line are not significantly ($P$ = 0.05) different.

Table 3. Influence of film mulch and soil pesticides on yield (metric tons/ha).

| Treatments | Cantaloup | Cucumber Slicing | Cucumber Pickling | Squash | Sweet corn 1973 |
|---|---|---|---|---|---|
| Unmulched | | | | | |
| 1. Control | 0.49 | 0.44 | 2.81 | 2.81 | 0 |
| 2. Herbicide (H)* | 0 | 1.61 | 3.63 | 3.63 | 0.13 |
| 3. DD-MENCS | 0.73 | 5.55 | 7.87 | 7.87 | 2.79 |
| 4. DD-MENCS + H | 0.24 | 8.80 | 6.68 | 6.68 | 2.08 |
| 5. Nematicide (N)† + H + PCNB + ethazole | 0.14 | 5.79 | 0.11 | 3.77 | 0.77 |
| Film mulch | | | | | |
| 6. Control | 0.38 | 5.46 | 2.63 | 5.35 | 0.31 |
| 7. Herbicide | 0.65 | 6.38 | 3.14 | 4.34 | 0.09 |
| 8. DD-MENCS | 1.69 | 16.83 | 2.50 | 8.18 | 1.94 |
| 9. N + H + PCNB + ethazole | 1.20 | 6.31 | 3.77 | 4.39 | 0.39 |
| Main effects | | | | | |
| Unmulched (vs) mulched | 0.34 0.98‡ | 3.35 8.75 | 3.61 3.01 | 4.52 5.57 | 0.92 0.68 |
| Control (vs) N + H + PCNB + ethazole | 0.44 0.67 | 2.95 6.05 | 2.72 1.94 | 4.08 4.08 | 0.16 0.58 |
| Control (vs) DD-MENCS | 0.44 1.21 | 2.95 11.19 | 2.72 5.19 | 4.08 8.03 | 0.16 2.37 |
| Control (vs) herbicide (H) | 0.44 0.33 | 2.95 4.00 | 2.72 3.39 | 4.08 3.99 | 0.16 0.11 |
| Interactions | | | | | |
| 3 + 8 (vs) 1 + 6 (with) 1 + 3 (vs) 6 + 8 | 1.09§ 0.56 | 8.64 5.51 | 2.66 5.25 | 5.50 6.61 | 0.97 1.55 |
| Unmulched: 1 (vs) 3 | 0.49 0.73 | 0.44 5.55 | 2.81 7.87 | 2.81 7.87 | 0.00 2.79 |
| Mulched: 6 (vs) 8 | 0.38 1.69 | 5.46 16.83 | 2.63 2.50 | 5.35 8.18 | 0.31 1.94 |

*Bensulide, 6.72 kg/ha active ingredient.

†Ethoprop, 8.96 kg/ha active ingredient.

‡The test for mean differences for comparisons below is based on the results from least squares analysis or transformed data (Log n + 1) or square root where appropriate. Means underlined by contiguous line are not significantly ($P = 0.05$) different.

§The mean 0.85 is the average of the treatment number 1 (0.49) + treatment number 9 (1.20), and the mean 0.26 is the average of treatment number 5 (0.14) + treatment number 6 (0.38).

affected by soil chemical treatments compared with the herbicide-treated plots under film mulch.

## DISCUSSION

Our research in the Coastal Plain soils corroborated the observations of others (2,8) that soil temperatures increase under film mulch, especially before foliage covers the mulch. Root growth and development are accelerated under film mulch, making potential feeding sites for nematodes more abundant. This phenomenon probably accounts for the greater numbers of *M. incognita* on cantaloup, cucumbers, and squash, and *M. ornata* and *M. incognita* on sweet corn in film-mulched plots than in unmulched plots.

Our data indicate the feasibility of using a single application of selected pesticide combinations to control multiple soilborne pests on vegetable crops. Granules containing a NHF consistently reduced populations of nematodes, grasses, and broadleaf weeds and increased yields of slicing cucumber and sweet corn. In most tests, there were no significant differences in percentage of grass and broadleaf weed control between plots treated with the NHF combination and plots treated with only the herbicide. This indicates that nematicide granules impregnated with herbicides were as effective as the herbicides applied separately for weed control. Similar results have been reported for other crops (12). There were no significant differences in percentage grass and weed control between film-mulched plots treated with herbicide and untreated plots. This indicates that herbicides may not be needed in film-mulched plots unless specific weed problems develop. The results indicated that herbicides did not affect nematode populations on cucurbits. Similar results have been reported for other crops (11). However, butylate suppressed numbers of *M. ornata* on sweet corn in 1973.

Our results confirm increases in yields of vegetables, except slicing cucumbers, with film mulch (2,3,8,15). Without film mulch, nematodes caused much greater losses, and soil fumigation with DD-MENCS more than doubled growth and yield of most crops. In cantaloup and slicing cucumber, however, the combined influence of soil fumigation and film mulch led to an additional doubling of yield over soil fumigation alone.

Nematodes decrease growth and yield more frequently when plants are under stress. When sweet corn had an adequate supply of water and nutrients, no reduction in yield was observed in the presence of large numbers of nematodes. This indicates that the potential damage caused by nematodes on certain crops may be partially masked and compensated for by additional water and nutrients. Even so, large numbers of nematodes could cause crop failure in the succeeding crop if multiple cropping was practiced under the film-mulch, trickle-irrigation system; consequently, nematodes must be controlled for maximum yields. The importance of low initial nematode populations on yields of the second and third crops in a multicrop system has been reported (13,16).

Negative correlations of nematodes with plant growth and yield alone are not proof that nematodes are the cause of yield reduction, although they support the hypothesis that nematodes cause significant damage to vegetable crops. Other factors must be considered in judging the importance of nematodes in vegetable production. The significant increase in plant growth and yield by controlling both nematodes and fungi indicates the synergistic effect of these pests on these and other vegetable crops, as reported from a similar test (18). Nematodes and soil-borne fungi can be destructive pathogens when acting alone, and their combined pathogenic potential could be much greater than the sum of their individual effects. Disease complexes present special control problems. A satisfactory control program could involve the use of effective nematicides or broad-spectrum soil fumigants in combination with film mulch and trickle irrigation. This production system should provide uniform plants, increase land use efficiency, and permit minimal use of pesticides and maximum yields.

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