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Effects and Carry-Over Benefits of Nematicides in Soil Planted to a Sweet Corn-Squash-Vetch Cropping System[1]

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Abstract: The effects of irrigation on the efficacy of nematicides on *Meloidogyne incognita* race 1 population densities, yield of sweet corn, and the carry-over of nematicidal effect in the squash crop were determined in a sweet corn-squash-vetch cropping system for 3 years. Fenamiphos 15G and aldicarb 15G were applied at 6.7 kg a.i./ha and incorporated 15 cm deep with a tractor-mounted rototiller. Ethylene dibromide (EDB) was injected at 18 kg a.i./ha on each side of the sweet corn rows (total 36 kg a.i./ha) at planting for nematode control. Supplemental sprinkler irrigation (1.52–4.45 cm), applied in addition to natural rainfall (4.60–10.80 cm) within 10 days after application of nematicides, did not affect nematicide efficacy against *M. incognita* or yield of sweet corn. Soil treatment with fenamiphos, EDB, and aldicarb increased the number and total weight of sweet corn ears and the weight per ear each year over untreated controls ($P \leq 0.05$). All nematicides provided some control of *M. incognita* on squash planted after sweet corn, but yields were consistently greater and root-gall indices lower on squash following sweet corn treated with fenamiphos than other nematicides.

Key words: aldicarb, chemical control, *Cucurbita pepo,* ethylene dibromide, fenamiphos, irrigation, *Meloidogyne incognita,* nematicide, nematode, root-knot nematode, squash, sweet corn, *Zea mays.*

Production of sweet corn (*Zea mays* var. *saccharata*) and summer squash (*Cucurbita pepo* var. *melopepo*) in Georgia from 1987 to 1994 increased from 4,332 to 6,369 hectares and 4,158 to 4,914 hectares, respectively (19). In 1994, the estimated farm value of sweet corn in Georgia was $34 million and $20.1 million for summer squash (19). Both crops can be grown on the same land unit in one year in the southeastern United States. Sweet corn can be planted in March and harvested 70–80 days later. Squash can be planted in June and July and harvested 2 months later.

Sweet corn (8,20) and squash (9,16) are hosts of many nematode species, including *Meloidogyne incognita.* Plant-parasitic nematodes are widespread in southern Georgia, and many require stringent management systems including crop rotation and use of nematicides (6,7,21).

With reports of widespread contamination of groundwater (3,22,24), concerns have mounted for the protection of this resource. Pesticides can contribute significantly to groundwater contamination (1,2, 27).

In the southeastern United States, most nematicides are injected into the soil or spread on the surface (broadcast or banded over the row) and incorporated into the soil for nematode control on crops. In Georgia, 80% of the sweet corn and 91% of the summer squash are grown using supplemental irrigation (19). Management of nematodes and nematicide usage to prevent groundwater pollution should be enhanced by information on nematode population changes and movement of nematicides in soil as influenced by a sweet corn-squash-vetch cropping system and irrigation.

This study was part of a large field experiment designed to determine the effects of irrigation on the 1) efficacy of nematicides on nematode population densities and yield of sweet corn and the carry-over effect of nematicides on squash, and 2) movement of pesticides in the soil profile and shallow groundwater. The data for the second objective have been published elsewhere (18).

MATERIALS AND METHODS

Plots for this 3-year (1983–1985) study were established in March 1983 on Boni-

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fay sand (siliceous thermic, grossarenic, plinthic paleudult; 93% sand, 3% silt, and 4% clay; <1% organic matter; and pH 6.0–6.7 in the 0–15-cm horizon). The soil was naturally infested with root-knot nematodes, *Meloidogyne incognita* race 1, and ring nematodes, *Mesocriconema ornatum*. The experimental design was a split-plot randomized complete block replicated four times with irrigation regimes (natural rainfall vs. natural rainfall + sprinkler irrigation) as whole plots and nematicide treatments as subplots. The soil was disc-harrowed 10 cm deep, turned 20–25 cm deep with a moldboard plow, and beds were established. Fertilizer (1,729 kg/ha 5% nitrogen, 10% P_2O_5, and 15% K_2O) was broadcast over all plots. Each plot contained three 1.8 × 12.2-m beds. Each year selected plots received supplemental irrigation in excess of the crop requirement within 10 days after nematicide application to enhance seedling emergence and the potential for nematicide transport (Table 1). In 1983, ethylene dibromide (EDB) was injected at 18 kg a.i./ha 15 cm from seed furrow on each side of the corn rows at planting (36 kg a.i./ha total) for nematode control. Fenamiphos 15G was applied at 2.24 kg a.i./ha in a 30-cm band (6.7 kg a.i./ha broadcast equivalent) and incorporated 15 cm deep with a tractor-mounted rototiller. The use of EDB as a soil fumigant in the United States was canceled in 1983 (10). In 1984 and 1985, aldicarb 15G was substituted for EDB, and both aldicarb and fenamiphos were applied as broadcast treatments at 6.7 kg a.i./ha. Atrazine (1.65 kg a.i./ha) and butylate (4.4 kg a.i./ha) were tank-mixed in 187 liters water/ha and applied as broadcast treatments for weed control. The granular nematicides and herbicide sprays were incorporated into the top 15 cm soil layer with a rototiller immediately in front of the planters. Seeds were planted in two rows 1.8 m apart on each bed. Untreated plots served as controls for nematicide treatments.

TABLE 1. Monthly precipitation (cm) during study and long-term precipitation at Tifton, Georgia.

Monthly average	Year 1983	1984	1985	Long-term[a] 1925–1977
January	13.2	17.5	13.7	10.3
February	18.0	11.4	8.6	10.3
March	19.3	18.8	6.9	11.8
April	13.7	15.5	6.4	10.7
May	3.0	14.0	7.4	9.2
June	15.5	8.1	6.9	11.5
July	4.6	24.4	11.4	15.0
August	11.4	3.3	16.3	13.2
September	13.7	10.9	3.0	8.9
October	2.3	7.1	10.4	5.2
November	16.0	4.8	18.8	5.3
December	15.7	2.5	11.7	8.9
Total	146.5	138.3	121.5	120.3

[a] Data provided by U.S. Weather Bureau for the Coastal Plain Experiment Station, Tifton, Georgia.

'Merit' sweet corn was planted in March each year. Plants in all plots were side-dressed with 830 kg/ha ammonium nitrate (33% N) in May. All plants were sprayed three to five times with methomyl (0.26 kg a.i./ha) in June for control of the corn earworm, *Helicoverta zea*. Ears of corn were harvested from plants in all plots in June, counted, and weighed.

Twenty soil cores (2.5-cm-d × 15 cm) were collected from the two rows in the center bed of each plot each year in March, April, and May as well as in June 1985; mixed thoroughly; and a 150-cm^3 subsample was processed for extraction of plant-parasitic nematodes by centrifugal-flotation (4). Ten plants from each plot were dug after harvest, and roots were examined for galls caused by *M. incognita* and scored using a 1–5 scale as follows: 1 = no galls; 2 = 1–25; 3 = 26–50; 4 = 51–75; and 5 = 76–100% roots galled.

After harvest, corn stalks and crop residue were shredded with a flail mower. The soil was disc-harrowed, plowed 25–30 cm deep with a moldboard plow, and beds were re-established in the original plots to determine the carry-over effect of nematicides on nematode population densities. All plots were planted to 'Dixie Hybrid' squash in July each year. Plants were side-dressed with 560 kg/ha 5% N, 10% P_2O_5, and 15% K_2O 3 weeks after planting. Carbaryl 50 WP (2.24 kg/ha) and benomyl 50 WP (0.56 kg/ha) were applied to squash as needed with a tractor-powered sprayer to control pickleworms and powdery mildew, respectively.

Twenty soil cores (2.5-cm-d × 15 cm deep) were collected from the two rows in the center bed of each plot at planting and after the final harvest. The cores were composited and mixed thoroughly. A 150-cm^3 subsample was processed for extraction of plant-parasitic nematodes as described for sweet corn.

Squash was harvested eight to 11 times from 8 August to 20 September each year, and the fruit were counted and weighed. Ten plants from the center bed of each plot were dug after the final harvest and examined for galls caused by *M. incognita* as described for sweet corn. Hairy vetch (*Vicia villosa*) was seeded (45 kg/ha) using a grain drill in rows 15 cm apart in October each year.

All data were subjected to least-squares analysis of variance (23), and means were separated by Waller-Duncan's k-ratio *t* test (k = 100) (26). Correlation analysis was used to determine the relationship of yield of crops with the nematode population densities in the soil and root-gall indices. Only significant ($P \leq 0.05$) differences will be discussed unless stated otherwise.

Results

During the period 1983 through 1985, annual rainfall at the study site ranged from above average in 1983 and 1984 to near average in 1985 (Table 1); however, monthly rainfall departed substantially from long-term means. Rainfall during February through May in 1983 and 1984 was approximately twice that in spring of 1985. Furthermore, fall 1983 was also wetter than usual and, when combined with the wet spring of 1984, produced a prolonged wet period of about 7 months. Rainfall and irrigation 10 days following nematicide applications are presented in Table 2. There were no irrigation × nematicide treatment interactions ($P \leq 0.05$); therefore, all data from whole-plots (irrigation regimes) were pooled and analyzed for differences among nematicide treatments.

Meloidogyne incognita race 1 was the most prevalent plant-parasitic nematode in the soil. Numbers of *M. incognita* second-stage juveniles (J2) in the soil were low and variable on sweet corn (Table 3). When differences in numbers of J2 occurred, numbers in plots treated with EDB, fenamiphos, and aldicarb were lower than those in untreated plots. In 1983 there was no evidence of fewer numbers of *M. incognita* J2 in plots of squash as a result of carry-over effects by nematicides applied at planting to the previous crop of sweet corn. In July 1984, numbers of *M. incognita* J2 were lower in plots containing squash following sweet corn treated with aldicarb or fenamiphos when compared with untreated plots. In July and August 1985, numbers of *M. incognita* J2 were lower in plots of squash following sweet corn treated with fenamiphos than those in aldicarb-treated or untreated plots.

Numbers of *M. ornatum* were low (usually <50/150 cm^3 soil) in all plots on all sampling dates except sweet corn in June (data not presented). The greatest number

Table 2. Amount (cm) of rainfall and irrigation water applied to plots 10 days after application of nematicides.

Year	Water source	Days after nematicide application										Total
		1	2	3	4	5	6	7	8	9	10	
1983	Rainfall	0.66	0.89	0	2.08	0.08	0	0	0.86	0	0.03	
	Irrigation	0	0	0	0	0	0	0	0	1.52	0	6.12
1984	Rainfall	2.69	0	0	0	0.33	0	1.50	1.75	0.08	0	
	Irrigation	0	0	0	0	0	4.45	0	0	0	0	10.80
1985	Rainfall	0	0	0.15	1.65	0	0	0	0.89	0.58	0	
	Irrigation	0	0	0	0	3.81	0	0	0	0	0	7.08

TABLE 3. Numbers of *Meloidogyne incognita* race 1 second-stage juveniles (J2) in soil in a sweet corn-squash-vetch cropping system.

		J2/150 cm³ soil						
		Sweet corn				Squash		
Treatment[a]	Rate (kg a.i./ha)	March	April	May	June	July	August	September
					1983			
Fenamiphos 15G	6.7	11 x[b]	0 x	0 y	—[c]	3 y	99 y	—
Ethylene dibromide	36.0	1 x	0 x	0 y	—	23 x	206 x	—
Control	—	3 x	1 x	4 x	—	7 y	91 y	—
					1984			
Fenamiphos 15G	6.7	48 x	11 x	0 y	—	0 y	1 x	4 x
Aldicarb 15G	6.7	56 x	1 x	1 y	—	0 y	3 x	5 x
Control	—	46 x	3 x	19 x	—	10 x	8 x	3 x
					1985			
Fenamiphos 15G	6.7	18 x	0 x	0 y	0 z	10 y	0 y	91 x
Aldicarb 15G	6.7	35 x	0 x	0 y	126 y	71 x	26 x	120 x
Control	—	8 x	1 x	11 x	289 x	71 x	39 x	93 x

Data are means of eight replications.

[a] Treatments were applied before planting sweet corn. In 1983, fenamiphos was applied at 2.24 kg a.i./ha in a 30-cm band in the row (6.7 kg a.i./ha broadcast equivalent) and incorporated 15 cm deep with a tractor-mounted rototiller. Ethylene dibromide was injected at 18 kg a.i./ha 15 cm from seed furrow on each side of the sweet corn rows (36 kg a.i./ha total). In 1984 and 1985, aldicarb was substituted for ethylene dibromide. Both aldicarb and fenamiphos were applied as broadcast treatments at 6.7 kg a.i./ha and incorporated 15 cm deep with a tractor-mounted rototiller.

[b] Numbers in columns followed by the same letter are not different according to the Waller-Duncan k-ratio *t* test (k = 100).

[c] Data not collected.

of *M. ornatum* (95/150 cm³ soil) occurred on sweet corn in June 1985 in the untreated plots and fewer (9/150 cm³ soil) in fenamiphos-treated plots. In July and September 1985, fewer *M. ornatum* occurred in plots of squash following sweet corn treated with fenamiphos than in plots treated with aldicarb or untreated (data not included).

The yield of sweet corn, reported as number and weight of ears per hectare, was greater from nematicide-treated plots than untreated plots each year (Table 4). In 1983, the number of sweet corn ears was inversely ($r = -0.40$) related to numbers of *M. incognita* J2 in the soil on 27 May. In 1984, the number ($r = -0.56$) and weight ($r = -0.56$) of ears of sweet corn were inversely related to the number of *M. incognita* J2 in the soil on 24 May. In 1985, the weight of ears ($r = -0.42$) of sweet corn was inversely related to number of *M. incognita* J2 in the soil on 17 June. Yield of sweet corn was not affected by numbers of *M. ornatum* in the soil. The size of sweet corn ears, based on weight, was greater from plants in nematicide-treated than in untreated plots. The average weight of ears from EDB-, aldicarb-, and fenamiphos-treated plots was 45%, 26%, and 27% larger, respectively, than those from untreated plots.

Root-gall indices of sweet corn ranged from 1.00 to 1.30 and were not affected by nematicide treatments (data not included). The root-gall indices of squash following fenamiphos- and EDB-treated sweet corn were not different than those from untreated plots in 1983 (Table 5). In 1984 and 1985, however, the root-gall indices of squash following fenamiphos-treated sweet corn were lower than those following aldicarb-treated or untreated sweet corn.

The number and weight of squash per hectare were positively correlated each year ($r = 0.94$–0.99) and will be referred to hereafter as yield (Table 5). The yield was greater in squash following fenamiphos-treated sweet corn than EDB-treated sweet corn in 1983. Yield of squash was inversely related to numbers of *M. incognita* J2 in the soil 6 September ($r = -0.51$) and root-gall indices ($r = -0.55$). There was no difference in squash yield in 1984

TABLE 4. Yield of sweet corn as influenced by nematicides in a sweet corn-squash-vetch cropping system.

	Number ears/ha (×1,000)			Kg/ha (×1,000)			Weight per ear (g)		
Year	Fenamiphos[a]	EDB/Aldicarb[a]	Control	Fenamiphos	EDB/Aldicarb	Control	Fenamiphos	EDB/Aldicarb	Control
1983	63.1 x[b]	58.1 x	39.1 y	14.7 x	13.9 x	6.7 y	233 x	240 x	166 y
1984	61.1 x	58.3 x	39.2 y	15.8 x	15.1 x	7.8 y	262 x	260 x	200 y
1985	78.3 x	71.1 x	61.0 y	17.9 x	17.7 x	12.3 y	227 y	250 x	204 z

Data are means of eight replications.

[a] Treatments were applied before planting sweet corn. In 1983, fenamiphos was applied at 2.24 kg a.i./ha in a 30-cm band in the row (6.7 kg a.i./ha broadcast equivalent) and incorporated 15 cm deep with a tractor-mounted rototiller. Ethylene dibromide (EDB) was injected at 18 kg a.i./ha 15 cm from seed furrow on each side of the sweet corn rows (36 kg a.i./ha total). In 1984 and 1985, aldicarb was substituted for EDB, both aldicarb and fenamiphos were applied broadcast at 6.7 kg a.i./ha and incorporated 15 cm deep with a tractor-mounted rototiller.

[b] Means in rows followed by the same letter are not different according to the Waller-Duncan k-ratio *t* test (k = 100).

TABLE 5. Root-gall indices caused by *Meloidogyne incognita* race 1 and marketable yield of squash following sweet corn treated with nematicides in a sweet corn-squash-vetch cropping system.

	Root-gall index			Number fruit/ha (×1,000)			Kg/ha (×1,000)		
Year	Fenamiphos[a]	EDB/Aldicarb[a]	Control	Fenamiphos	EDB/Aldicarb	Control	Fenamiphos	EDB/Aldicarb	Control
1983	4.70 y[b]	5.00 x	4.84 xy	76.0 x	59.2 y	63.9 xy	6.9 x	4.7 y	5.5 y
1984	3.24 y	4.46 x	4.81 x	22.9 x	16.8 x	17.5 x	1.9 x	1.5 x	1.6 x
1985	4.05 y	4.99 x	5.00 x	76.7 x	40.0 y	18.6 z	7.1 x	3.6 y	1.6 z

Data are means of eight replications.

[a] Treatments were applied before planting sweet corn. In 1983, fenamiphos was applied at 2.24 kg a.i./ha in a 30-cm band in the row (6.7 kg a.i./ha broadcast equivalent) and incorporated 15 cm deep with a tractor-mounted rototiller. Ethylene dibromide (EDB) was injected at 18 kg a.i./ha 15 cm from seed furrow on each side of the sweet corn rows (36 kg a.i./ha total). In 1984 and 1985, aldicarb was substituted for EDB, both aldicarb and fenamiphos were applied broadcast at 6.7 kg a.i./ha and incorporated 15 cm deep with a tractor-mounted rototiller.

[b] Means in rows followed by the same letter are not different according to the Waller-Duncan k-ratio *t* test (k = 100).

among nematicide treatments on the previous crop of sweet corn. Yield of squash was inversely related to root-gall indices ($r = -0.52$). In 1985, yield of squash was higher from plots previously treated with aldicarb and fenamiphos than untreated plots. Yield of squash was inversely related to numbers of *M. incognita* J2 in the soil 15 July ($r = -0.64$) and 13 August ($r = -0.66$); numbers of *M. ornatum* in the soil 15 July ($r = -0.47$), 13 August ($r = -0.49$), and 6 September ($r = -0.62$); and root-gall indices ($r = -0.85$).

Discussion

Our data indicate that supplemental sprinkler irrigation (1.52–4.45 cm) applied in addition to natural rainfall (4.60–10.80 cm) within 10 days after application of nematicides did not affect efficacy against *M. incognita* or yield of sweet corn in a sweet corn-squash-vetch cropping system. Johnson et al. (15) reported that simulated rainfall treatments (2.5 cm and 5.0 cm) applied 1 or 3 days after fenamiphos application at 6.7 kg a.i./ha did not affect the efficacy of the nematicide.

Soil treatment with fenamiphos, EDB, and aldicarb increased the number, weight, and size of sweet corn ears each year compared with untreated controls. These nematicides may also have provided some insect protection for sweet corn. The increase in yield and larger ears in nematicide-treated plots, however, correspond to reductions in *M. incognita* J2 population densities in the soil in May or June each year. *Meloidogyne incognita* J2 enter roots of sweet corn, cause little or not galling, and produce eggs (5,12,14). The eggs hatch and J2 infect roots of susceptible sequential crops.

Generally, based on root-gall indices and yield of squash, fenamiphos provided more carry-over effects than EDB and aldicarb. Yields of squash following nematicide treatments on sweet corn in 1983 and 1985 were comparable to those of squash treated with fenamiphos at 6.7 kg a.i./ha at planting in other studies (11,16,17). Our data indicate that the use of nematicides may be reduced by utilizing carry-over effects from a previously treated crop. The lower yield in 1984 than those in 1983 and 1985 most likely resulted from rainfall in 1984 that produced a prolonged wet period of about 7 months.

With parent fenamiphos having only a 2-day half-life and the fenamiphos sulfone a 16-day half-life, the fenamiphos sulfoxide was reported to be the dominant form of the pesticide (18). Fenamiphos sulfoxide and fenamiphos sulfone have pesticide activity and toxicity similar to that of fenamiphos (25). Waggoner and Khasawinah (25) reported that half-lives for the total fenamiphos residue (parent fenamiphos, fenamiphos sulfoxide, and fenamiphos sulfone) in soil ranged from 10 to 20 days. Johnson et al. (13) reported similar half-lives of fenamiphos in southeastern coastal plain soils.

Aldicarb dissipated rapidly from the soil at the depth sampled (18). The rapid decline in soil concentrations was due to both leaching and transformation. We found only traces or very low levels of aldicarb sulfoxide in both soil and shallow groundwater (18). Except for the first few days following application, the aldicarb sulfone was the dominant form in groundwater, whereas parent aldicarb, although persisting only a short time, was the dominant form extracted from the soil. Probably owing to their extreme mobility, the aldicarb sulfoxide/sulfone products were rapidly leached below the soil sampling depth.

Data from this study demonstrate the benefits of utilizing carry-over nematicidal effects in root-knot susceptible crops from a previously treated crop. This system of managing root-knot nematodes will reduce the use of nematicides.

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