Journal of Nematology 24(4):533–539. 1992.

Nematode Numbers and Crop Yield in a Fenamiphos-Treated Sweet Corn–Sweet Potato–Vetch Cropping System[1]

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Abstract: Nematode population densities and yield of sweet corn and sweet potato as affected by the nematicide fenamiphos, in a sweet corn–sweet potato–vetch cropping system, were determined in a 5-year test (1981–85). Sweet potato was the best host of *Meloidogyne incognita* of these three crops. Fenamiphos 15G (6.7 kg a.i./ha) incorporated broadcast in the top 15 cm of the soil layer before planting of each crop increased ($P \leq 0.05$) yields of sweet corn in 1981 and 1982 and sweet potato number 1 grade in 1982 and 1983. Yield of sweet corn and numbers of *M. incognita* second-stage juveniles (J2) in the soil each month were negatively correlated from planting ($r = -0.47$) to harvest ($r = -0.61$) in 1982. Yield of number 1 sweet potato was inversely related to numbers of J2 in the soil in July–October 1982 and July–September 1983. Yield of cracked storage roots was positively related to the numbers of J2 in the soil on one or more sampling dates in all years except 1985. Some factor(s), such as microbial degradation, resistant *M. incognita* development, or environment, reduced the effect of fenamiphos.

Key words: fenamiphos, *Ipomoea batatas, Meloidogyne incognita,* nematicide, nematode, root-knot nematode, sweet corn, sweet potato, vetch, *Vicia sativa, Zea mays.*

Sweet corn (*Zea mays* var. *saccharata* (Sturtev.) Bailey) and sweet potato (*Ipomoea batatas* (L.) Lam.) are grown in several regions of the United States as cash crops for fresh market and processing. Both crops can be grown on the same land in 1 year in the southeastern United States. Sweet corn can be planted March 10–15 and harvested 70–80 days later. Sweet potato can then be planted in June and harvested 90–140 days later. Annual repetition of this sweet corn–sweet potato cycle is a poor production practice because of the possibility of increasing soil-borne and nematode diseases, which can suppress marketable yields (4,10,17,21).

Sweet corn (7–10) and sweet potato (5, 11,12) are hosts of numerous insects and nematodes. *Meloidogyne incognita* (Kofoid & White) Chitwood is a major plant-parasitic nematode of sweet potato in the southern United States (12,15), but the effect of this nematode on sweet corn needs further characterization. Other plant-parasitic nematodes are also widespread in southern Georgia, and many of them, along with *M. incognita,* may require stringent management systems—including resistant cultivars, crop rotation, and the use of nematicides for susceptible crops (8,9, 18). Management of important nematodes in a sweet corn–sweet potato cropping system should be enhanced by gaining more information on nematode population changes as influenced by these crops and the use of the nematicide fenamiphos (5, 8,9). Our objective was to determine the effects of fenamiphos and a sweet corn–sweet potato–vetch (*Vicia sativa* L.) cropping system on nematode population changes and crop yields.

MATERIALS AND METHODS

Field plots were established in March 1981 and maintained until December 1985 on a Tifton loamy sand (fine-loamy, siliceous, thermic Plinthic Paleudults) (85% sand, 10% silt, 5% clay; 0.5% organic matter; pH 6.0–6.7). The plots were naturally infested with *M. incognita* race 1, *Pratylenchus* spp. (ca. 65% *P. scribneri* Steiner, 25% *P. brachyurus* (Godfrey) Filipjev & Schuur-

Received for publication 2 March 1992.
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mans Stekhoven, and 10% *P. zeae* Graham), *Paratrichodorus minor* (Colbran) Siddiqi, and *Criconemella ornata* (Raski) Luc & Raski.

The experiment was part of a larger split-plot design with cropping sequences (whole-plots) in strips replicated twice, and nematicide treatments as subplots with three 1.8-m wide × 7.7-m long beds replicated 12 times. The soil was disc-harrowed, plowed 25–30 cm deep with a moldboard plow, and shaped into beds 10–15 cm high. Fenamiphos 15G was broadcast at 6.7 kg a.i./ha over one-half of each plot and incorporated into the top 15-cm soil layer with a tractor-mounted rototiller immediately before planting sweet corn, sweet potato, and vetch each year. The remaining half of each plot was left untreated. The location and treatments remained the same all 5 years. Weeds and insects were controlled with pesticides listed in Table 1.

The annual cropping sequence was sweet corn cultivar Merit, sweet potato cultivar Jewel, and vetch cultivar Cahaba White. Sweet corn seeds were planted 15 cm apart in rows spaced 91 cm apart in March and harvested in June each year. Corn was hand-harvested, separated into marketable and unmarketable ears (based on size), counted, shucked, weighed, and examined for insect damage. Immediately after harvest, 20 plants were dug from each plot and rated for root galling by *M. incognita:* 1 = no galling, 2 = 1–25, 3 = 26–50, 4 = 51–75, and 5 = 76–100% galling (1). The remaining stalks were chopped into small pieces for easy soil incorporation. Plots were moldboard plowed and bedded in preparation for sweet potato planting.

Vine cuttings (30 cm long) of sweet potato containing 3–4 nodes were transplanted 30 cm apart in single rows spaced 1.37 m apart. The crop was harvested 116–140 days after transplanting. Sweet potato storage roots were lifted mechanically from the soil and sorted by hand into four grades (5): number 1 = roots 5–9 cm d, 8–23 cm long, well-shaped and free of defects; canner = roots 2–5 cm d, 5–18 cm long; jumbo = roots exceeding the number 1 grade in size but still marketable; cull = roots 3 cm d or more but misshapen, or with unattractive skin and not marketable; and crack = cracked storage roots. Ten storage roots, at least two from each grade, were randomly selected from all plots, sliced into cross sections 2 mm thick, and

TABLE 1. Pesticides applied to crops to control weeds and insects in a sweet corn–sweet potato–vetch cropping system experiment from 1981 to 1985.

Nematicide treatment†	Pesticide applied	Rate (kg a.i./ha)	Number of applications per year‡	Crop
Fenamiphos	Alachlor +	2.24 +		
	Atrazine +	0.84 +		
	Cyanazine	0.67–0.84	1	Sweet corn
	Methomyl	0.50	4–11	Sweet corn
	Diphenamid	5.04	1	Sweet potato
	Chloramben	4.48	1	Sweet potato
	Fonofos	0.50–3.36	1–2	Sweet potato
	Chlorpyrifos	0.56–2.24	1	Sweet potato
None	Atrazine +	0.84 +		
	Cyanazine	0.84	1	Sweet corn
	Methomyl	0.50	4–6	Sweet corn
	Diphenamid	5.04	1	Sweet potato
	Fonofos	2.24	1	Sweet potato
	Chlorpyrifos	0.56–2.24	1	Sweet potato

† Fenamiphos 15G was broadcast at 6.7 kg a.i./ha and incorporated into the top 15 cm soil layer with a tractor-mounted rototiller.
‡ Number of pesticide applications was based on weed and insect populations each year.

examined for *M. incognita* females. The numbers of females were recorded on a 1–5 scale: 1 = no infection, 2 = 1, 3 = 2–3, 4 = 4–6, and 5 = 7 or more females in each storage root (5). Fibrous roots of sweet potato were rated for galls caused by *M. incognita* as described for sweet corn. Immediately after sweet potato storage roots were harvested, the field was disc-harrowed and moldboard plowed, and beds were prepared for planting vetch.

Vetch seeds were planted at 35.8 kg/ha with a grain drill in October 1981–83 and served as a winter cover crop. The plots were left fallow in winters of 1984–85. Roots of four vetch plants per plot were dug monthly from January–March 1982, stained with 0.05% acid fuchsin in lactophenol, and cleared in lactophenol (16,22). The stage of development and number of *M. incognita* per root system were recorded. Each nematode was classified as vermiform = second-stage juvenile (J2) showing no signs of development, swollen = some degree of swelling indicating that development had begun, or globose = spherical shape, late juvenile stages and adults. In March, the field was disc-harrowed and moldboard plowed 25–30 cm deep, beds were formed, and the cropping cycle was repeated.

Twenty cores of soil, 2.5 cm d × 25 cm deep, were collected from the rows of all crops at monthly intervals from January 1981 through December 1985. Soil cores were mixed, and nematodes were extracted from a 150-cm^3 subsample using a centrifugal-flotation method (6).

Supplemental irrigation was applied as needed to enhance seedling emergence and plant growth when rainfall was insufficient. All plots received 2,240 kg/ha dolomitic limestone in March 1982 and 1984. The limestone was spread on the soil surface, and the soil was disc-harrowed and plowed. Liquid formulations of fertilizer (10% nitrogen + 34% phosphorus, a 32% solution of NH_4NO_3-urea, and 60% KCl) were applied broadcast through an irrigation system in multiple applications after planting each crop based on soil test recommendations. The total kg per ha applied to each crop each year was 168–224 nitrogen (N), 76 phosphorus (P), and 190–224 potassium (K) for sweet corn and 56–90 N, 57–137 P, and 168–224 K for sweet potato. In addition, sweet corn received sulfur, zinc, and magnesium, and sweet potato received sulfur.

The data were subjected to analysis by least-squares analysis of variance (23). Correlation analysis was used to determine the relationship of yield of crops with the nematode population densities in the soil each month during 1981–85.

RESULTS

Meloidogyne incognita was the most prevalent plant-parasitic nematode in the soil. Numbers of J2 in untreated plots ranged from 0–10/150 cm^3 soil in sweet corn in 1981. They increased to 116/150 cm^3 soil by October 1981 in untreated plots of sweet potato (Table 2). Sweet potato was a good host and sweet corn maintained the surviving population. Numbers of J2 in the soil were low in 1981 and were not affected by fenamiphos. Numbers of J2 were generally higher in 1982 and 1983 than in 1981. Numbers were lower in fenamiphos-treated plots than untreated plots on most sampling dates in 1982–83. The numbers of J2 were not different ($P \leq 0.05$) in fenamiphos-treated than in untreated plots on most sampling dates in 1984 and 1985. The large numbers of J2 in untreated plots of vetch and sweet corn after 1983 appeared to be carryover inoculum from sweet potato. Numbers of J2 in untreated plots of vetch declined from November to February each year.

Root-gall indices ranged from 1.00 to 1.60 on sweet corn and 1.00 to 1.30 on sweet potato each year and were not affected by fenamiphos (data not included). *Meloidogyne incognita* females in sweet potato storage roots were not detected in 1981 and 1982. Their numbers were low in the storage roots from all plots: fenamiphos—1.17 vs. untreated—1.95 in 1983, fenamiphos—1.87 vs. untreated—1.97 in

TABLE 2. Population densities of *Meloidogyne incognita* second-stage juveniles in a sweet corn–sweet potato–vetch cropping system.

		Number/150 cm³ soil									
		1981		1982		1983		1984		1985	
Month	Crop†	F‡	Ck‡	F	Ck	F	Ck	F	Ck	F	Ck
January	Vetch	0§	4	2	64	27	430	126	303	1,185	1,250
February	Vetch	0	0	5	55	7	247	60	167	670	1,338
March	Sweet corn	0	10	3	15	57	213	72	99	496	490
April	Sweet corn	0	0	2	47	29	143	74	98	2,128	1,293
May	Sweet corn	0	1	0	17	39	27	1	0	273	173
June	Sweet corn	0	3	1	72	0	93	67	305	430	850
July	Sweet potato	1	0	0	64	7	450	228	542	1,389	1,070
August	Sweet potato	0	3	0	120	17	180	123	96	340	208
September	Sweet potato	5	22	21	1,185	29	469	4,258	4,043	2,178	2,071
October	Sweet potato	13	116	91	3,136	2,297	4,224	6,675	4,753	4,184	3,635
November	Vetch	8	294	118	1,095	702	4,150	3,961	4,204	2,771	1,953
December	Vetch	3	140	23	564	308	743	2,253	1,703	1,078	617

Data are means of 12 replications.

† Vetch cv. Cahaba White was planted as a winter cover crop following sweet potato from 1981–83; plots were fallowed 1984–85.

‡ F = Fenamiphos 15G applied broadcast before planting at 6.7 kg a.i./ha and incorporated into the top 15 cm soil layer with a tractor-mounted rototiller; Ck = untreated control.

§ Means with a contiguous underline are not different ($P \leq 0.05$) for a given month within a year according to least significant difference analysis.

1984, and fenamiphos—1.93 vs. untreated—1.73 in 1985.

Meloidogyne incognita in roots of vetch were swollen and averaged 20 per root system, but there was no evidence of galls in January 1982. One month later, females, eggs, or galls still were not observed in roots of vetch. By March, three small galls had formed. Only one root system was galled severely (index = 4.00) and contained J2, swollen, globose, and females with eggs.

Number of *Paratrichodorus minor* were low (usually less than 37/150 cm³ soil) in all plots on all sampling dates except sweet corn in June 1984 and 1985 and sweet potato in July 1984 and 1985. The greatest number of 134/150 cm³ soil occurred on sweet corn in June 1985 in the untreated plots. Numbers of *Pratylenchus* spp. and *C. ornata* also remained low (<33/150 cm³ soil) throughout this experiment (data not included).

The yield of sweet corn (number and weight of ears per hectare) was greater from fenamiphos-treated plots than untreated in 1981 and 1982, but not thereafter (Table 3). The weight per ear increased each year, but numbers of ears changed little. Ears from fenamiphos-treated plots were 0 to 51% larger each year than from untreated plots.

Yields of number 1 sweet potatoes were greater from plots treated with fenamiphos than from untreated plots in 1982 and 1983 (Table 4). The yields of canner,

TABLE 3. Yield of sweet corn as influenced by fenamiphos in a sweet corn–sweet potato–vetch cropping system.

	Yield			
	Number ears/ha		Weight (kg/ha)	
Year	F†	Ck†	F	Ck
1981	53,121‡	45,412	12,787	10,260
1982	46,008	40,122	12,184	8,065
1983	45,353	48,579	23,202	22,689
1984	41,828	49,296	22,025	23,997
1985	54,694	49,493	26,600	24,812

Data are means of 12 replications.

† F = Fenamiphos 15G applied broadcast before planting at 6.7 kg a.i./ha and incorporated into the top 15 cm soil layer with a tractor-mounted rototiller; Ck = untreated control.

‡ Means with contiguous lines are not different ($P \leq 0.05$) according to least significant difference analysis.

TABLE 4. Yield (kg/ha) and grade† of sweet potato as influenced by fenamiphos in a sweet corn–sweet potato–vetch cropping system.

	Number 1		Canner		Jumbo		Cull		Crack	
Year	F‡	Ck‡	F	Ck	F	Ck	F	Ck	F	Ck
1981	12,745§	12,128	7,206	7,157	328	314	2,117	2,704	496	851
1982	11,299	7,149	8,842	7,570	863	574	1,551	1,814	399	1,764
1983	8,900	4,042	6,915	6,108	385	212	1,248	1,676	3,982	7,080
1984	9,285	8,838	7,630	6,552	235	1,308	2,770	2,852	10,395	9,836
1985	9,814	10,452	7,365	7,168	948	1,529	3,209	2,571	6,990	7,834

Data are means of 12 replications.

† Grade: Number 1 = roots 5–9 cm d, 8–23 cm long, well-shaped and free of defects; canner = roots 2–5 cm d, 5–18 cm long; jumbo = roots exceeding the number 1 grade in size but still marketable; cull = roots 3 cm d or more, but misshapen, or with unattractive skin and not marketable; and crack = cracked storage roots.

‡ F = Fenamiphos 15G was applied broadcast before planting at 6.7 kg a.i./ha and incorporated into the top 15 cm soil layer with a tractor-mounted rototiller; Ck = untreated control.

§ Means with contiguous lines are not different ($P \leq 0.05$) according to least significant difference analysis.

jumbo, and cull sweet potatoes were not affected by the nematicide treatment. Fenamiphos-treatment reduced the quantity of cracked storage roots in 1982 and 1983.

Yield of sweet corn (number and weight of ears per hectare) were negatively correlated with numbers of *M. incognita* J2 in soil each month from planting ($r = -0.47$) to harvest ($r = -0.61$) in 1982. Yield of number 1 sweet potato was inversely related to numbers of *M. incognita* J2 in the soil July–October 1982 ($r = -0.41$ to -0.61) and July–September 1983 ($r = -0.44$ to -0.48). Yield of canners was also inversely related to numbers of J2 in the soil July–September 1982 ($r = -0.51$ to -0.61). Yield of cracked storage roots was positively related to numbers of J2 in the soil in July 1982 ($r = 0.72$), 1983 ($r = 0.66$); August 1981 ($r = 0.41$), 1982 ($r = 0.70$), 1983 ($r = 0.74$), 1984 ($r = 0.56$); and September 1981 ($r = 0.50$), 1982 ($r = 0.55$).

DISCUSSION

Soil treatment with fenamiphos increased the number and weight of sweet corn ears for the first 2 years, but not thereafter. The increase in yield in fenamiphos-treated plots was not related to reduction of nematode population densities, except *M. incognita* in 1982. *Meloidogyne incognita* J2 enter roots of sweet corn, cause little or no galling, and produce eggs (7,13). Fenamiphos may have provided some protection for sweet corn from insects. The large numbers of *M. incognita* J2 in plots of vetch and sweet corn appeared to be carryover inoculum from the previous crop of sweet potato.

Based on yield of all grades of sweet potato, the *M. incognita* J2 population density in the soil was below damaging levels in 1981. The rapid increase in numbers of *M. incognita* J2 in sweet potato and the increase in yield of number 1 storage roots following fenamiphos-soil treatment in 1982 and 1983 agree with other results (5,12). Based on yield and correlation coefficients, we conclude that ca. 100 *M. incognita* J2/150 cm^3 soil at planting is the damage threshold for Jewel sweet potato. Definitive damage function research is needed to document this conclusion, however.

As indicated by the numbers of *M. incognita* J2 in the soil and yield of sweet potato, the efficacy of fenamiphos diminished in 1984 and 1985. We previously had similar results with ethoprop (5). Enhanced degradation of a number of pesticides occurs in soils with a history of previous exposure to the chemical (3,19,20). The duration of enhanced degradation after single or multiple-field applications of a pesticide or the microorganisms responsible for the degradation needs further study. Ou (19) conducted laboratory and field studies on the microbial degradation of fenamiphos in soils. He concluded that (i) degradation of fenamiphos in soil was enhanced after one field application of the nematicide at 4.48 kg a.i./ha, and that such enhancement lasted more than 3 but less than 4 years; (ii) half-lives for total toxic residue in soil were shortened after just one application of fenamiphos; (iii) microorganisms (axenic cultures or mixed cultures) capable of degrading fenamiphos could not be isolated from the field-treated soil samples; however, a mixed bacterial culture obtained from a field-treated sample, when in the presence of a small amount of soil, mineralized the nematicide; and (iv) biodegradable chemicals such as glucose enhanced the biodegradation of fenamiphos. More recently, Ou et al. (20) reported that fenamiphos in soil collected from a golf course was rapidly degraded. The rapid degradation of fenamiphos was most likely due to the repeated applications of fenamiphos to the site for over 15 years. This may have resulted in an increase of fenamiphos-degrading microbes in the site. Judging from the short half-lives of fenamiphos in the soil, the efficacy of the nematicide will be much reduced. It is not known whether the loss of efficacy is caused by microbial degradation of fenamiphos, the evolution of a population of *M. incognita* that can tolerate high concentrations of fenamiphos, or other factors. The probability of such a population developing is less than the effects of microbial degradation or other factors on nematicide efficacy. More research is needed to identify the cause of degradation.

Cahaba White vetch, highly resistant but not immune to *M. incognita, M. incognita acrita* Chitwood, and *M. javanica* (Treub) Chitwood, and susceptible to *M. arenaria* (Neal) Chitwood and *M. hapla* Chitwood, was released in 1978 (2). *Meloidogyne incognita* J2 entered roots of Cahaba White, developed slowly, and females produced low numbers of eggs in March, effecting a population reduction. By that time, the vetch was disc-harrowed and soil was prepared for planting sweet corn. The vetch could act as a trap crop for *M. incognita.* The threshold soil temperature for development of *M. incognita* is ca. 10 C (24). The minimum soil temperature 20 cm deep is usually above 10 C during the winter months in southern Georgia (14). *Meloidogyne incognita* survives the winter as J2 and eggs in fallow plots in this area. Both the vetch cultivar and soil temperature could have contributed to the *M. incognita* population decline.

Based on our data, fenamiphos applied before planting sweet corn, sweet potato, and vetch for control of *M. incognita* should not exceed 3 years. Thereafter, the crop rotations and(or) the nematicides should be changed.

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