Increase in Cabbage Yield by Fenamiphos Treatment of Uninfested and *Heterodera schachtii*-Infested Field Soils

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ABSTRACT

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In field microplot tests, fenamiphos was broadcast onto cabbage field soils and incorporated into the top 8–12 cm at a rate of 6.7 kg a.i./ha. All insect and disease control measures were made according to recommendations for commercial use. In 1977, marketable heads of cabbage grown in soils infested with 0.7 and 12 eggs of *Heterodera schachtii* per gram of soil (damaging level = six to nine eggs) averaged 4.3 and 3 kg, respectively. Addition of fenamiphos to the same soils resulted in 23% (5.3 kg/head) and 73% (5.2 kg/head) increases in marketable head weight, respectively. Applications of fenamiphos did not significantly affect the final population of *H. schachtii*. The influence of fenamiphos on cabbage yield was minimal when field soils were pretreated with Telone C-17 at 374 L/ha or by autoclaving. Increase of cabbage yield by fenamiphos, however, occurred in field soils previously pasteurized for 30 min at 50 C. Intermediate increases with fenamiphos were also obtained in soils previously pasteurized at 60, 70, or 80 C. A similar effect on cabbage yield was obtained with aldicarb at 6.7 kg a.i./ha. Control of foliar insects by fenamiphos and aldicarb did not explain the observed increase in cabbage yield. Soil treatment with the miticide propargite, the nitrification inhibitor nitrapyrin, and the fungicide metalaxyl (selectively active against pythiaceous fungi) did not increase cabbage yield. These data indicate that higher yields of cabbage obtained by treating soil with fenamiphos or aldicarb are due to control of soilborne biological agent(s) other than plant-parasitic nematodes.

Cabbage (*Brassica oleracea* var. *capitata* L.) is a major vegetable crop grown in New York for both fresh market and processing. The value of the crop was estimated to exceed $33 million in 1978 (18). The sugar beet cyst nematode (*Heterodera schachtii* Schmidt) (SBCN) has been shown to cause significant yield losses to cabbage in several areas (2,11,15,16). This nematode was first discovered in New York in 1961 and is now widely distributed throughout the cabbage-growing area of western New York (2,12). Cabbage infected by a high population of SBCN has a reduced root system that results in a smaller and less compact head (2). The damaging level of SBCN to cabbage in field microplots was shown to be six to nine eggs per gram of soil (2).

The nonvolatile nematicide fenamiphos was included in a test in which effects of several initial population (P_i) densities of SBCN on cabbage yield were determined. Application of fenamiphos resulted in significant increases in marketable yields of cabbage at all levels of P_i tested, including those below the damaging level. The objectives of this study were 1) to determine the influence of fenamiphos and other nonvolatile nematicides on cabbage yield at different P_i densities of SBCN and 2) to determine the nature of yield increases associated with fenamiphos treatments. Preliminary results of this work were reported previously (1,3).

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MATERIALS AND METHODS

All tests were conducted in field microplots as described previously (2). Each microplot consisted of an unglazed clay tile (25 cm in diameter and 30 cm long) placed vertically in the soil to about 25 cm. Uninfested and SBCN-infested soils (Ontario loam or Lima silt loam, pH 7.1) were obtained from cabbage fields on a vegetable farm near Geneva, NY. Different P_i densities of SBCN were obtained by mixing appropriate amounts of each soil together. Fenamiphos, aldicarb, and ethroprop were broadcast at planting and incorporated in the top 8–12 cm of soil at 6.7 kg/ha. Nitropyrin (N-Serve) was applied similarly at 2,337 ml of 24E formulation per hectare.

In some treatments, soil was autoclaved for 1 hr at 121 C and 8.1 kg/cm^2 pressure or treated with aerated steam for 30 min (pasteurized) at 50, 60, 70, or 80 C. Fumigation with Telone C-17 was done at 374 L/ha under a tarpaulin. After aerating and mixing, 15,000 cm^3 of each soil was added to the appropriate tiles.

The center of each microplot was planted with three seeds of the cabbage cultivar Roundup and later thinned to one seedling. When needed, extra seeds were also planted at the edges of tiles for early destructive sampling. Cultural practices including herbicide application, planting, fertilizers, and insect and disease control were according to the Cornell Recommendations for Commercial Vegetable Production (Publication Office, Cornell University, Ithaca, NY 14853). In all tests, each treatment was replicated 10 times using a completely randomized block design. The data reported in this paper were obtained from experiments conducted over four growing seasons (1977 through 1980).

Marketable yield and the P_i and final population (P_f) of SBCN were recorded as described previously (2). At 4–5 wk after planting, 10 seedlings per treatment were dug, washed, and weighed. Roots were rated for discoloration and segments were placed directly on water agar or were first surface-sterilized for 5 min in 10% Clorox and placed on acidified potato-dextrose agar. Plants were compared and rated for size on a scale of 1 (smallest plant in the trial) to 5 (largest plant in the trial). Flea beetle (*Phyllotreata* sp.) damage on seedlings was recorded on a scale of 0–3, where 0 =

Table 1. Effect of soil treatment with fenamiphos on population dynamics of *Heterodera schachtii* and yield of direct-seeded cabbage at five initial nematode population densities in 1977

P_i[a] (eggs/cm^3 soil)	Avg. marketable yield[b] (kg/cabbage head)		Yield increase (%)	P_f:P_i[b]	
	Without fenamiphos	With fenamiphos[c]		Without fenamiphos	With fenamiphos
0.7	4.3 ± 0.90	5.3 ± 0.69*	23	370	165 ns
1.5	4.1 ± 0.96	5.1 ± 0.95*	22	25	28 ns
3.0	3.8 ± 0.96	5.1 ± 0.71*	34	19	20 ns
6.0	3.7 ± 1.00	5.4 ± 0.58*	46	24	11 ns
12.0	3.0 ± 0.99	5.2 ± 1.10*	73	4	3 ns

[a] P_i = initial and P_f = final population densities (eggs/cm^3 soil) of *H. schachtii*.

[b] The marketable yield and the P_f:P_i ratio data of the untreated and fenamiphos-treated soil were analyzed by the Tukey *t* test; * = significant and ns = not significant differences at $P = 0.05$.

[c] Fenamiphos was applied as a broadcast treatment at planting at 6.73 kg/ha.

no visible holes, 1 = 1–3, 2 = 4–10, and 3 = more than 10 feeding holes per seedling. In addition, feeding damage by larvae of the diamondback (*Plutella maculipennis* Curtis), imported cabbage moth (*Ascia rapae* Linne), and/or cabbage looper (*Autographa brassicae* Riley) was recorded on a scale of 0 (no apparent damage) to 5 (most severe damage). At harvest, total and marketable yields were recorded. Roots were dug, washed, weighed, and rated for size and discoloration. Degree of discoloration was rated as 1 = clean, 2 = lightly, 3 = moderately, and 4 = severely discolored roots. Root size was rated on a scale of 1 (smallest root system) to 5 (largest root system).

Table 2. Effect of fenamiphos on cabbage yield in uninfested and *Heterodera schachtii*-infested soils that were untreated or treated with steam or chloropicrin in 1978

Soil[a]	Preplant soil treatment	Avg. marketable yield (kg/cabbage head) Without fenamiphos	With fenamiphos	Yield increase (%)	P_f/cm^3[b] Without fenamiphos	With fenamiphos
H. schachtii-infested (0.7 eggs/cm^3)	None	2.77	3.31*[c]	20	159	101
H. schachtii-infested (7 eggs/cm^3)	None	2.45	3.09*	26	220	191
H. schachtii-infested (7 eggs/cm^3)	Telone	3.54	3.81	8	0	0
Nematode-free soil	None	3.13	3.99*	28	0	0
Nematode-free soil	Steam	3.59	3.72	4	0	0

[a] The two soils were obtained from a vegetable farm near Geneva, NY. The lower population (0.7 eggs/cm^3) was obtained by mixing the two soils in a ratio of 1:9.
[b] P_f = final population density (eggs/cm^3 soil) of *H. schachtii*.
[c] * = Significantly different from the corresponding check treatment (without fenamiphos) by the Tukey *t* test ($P = 0.05$).

Table 3. Comparative effect of fenamiphos and aldicarb on pest control and growth of cabbage grown in untreated and autoclaved cabbage field soil placed in microplots in 1979

Soil Treatment[a]	FBD[b]	Seedling wt. (g)[c]	Head SI[d]	Worm DI[e]	Markt. head wt. (kg)[f]	Root discol.[g]	Root SI[h]	Root wt. (g)
Natural								
None	1.8	3.0	2.9	1.8	3.5	2.0	3.6	130
Fenamiphos	0.4	6.4	3.8	1.2	4.4	1.9	3.8	138
Aldicarb	0.0	11.7	4.4	0.9	5.4	2.0	3.2	141
Autoclaved								
None	1.4	6.2	3.5	1.2	4.4	1.1	4.0	145
Fenamiphos	0.8	11.2	4.2	1.6	4.6	1.3	4.1	158
Aldicarb	0.2	15.6	4.2	1.2	5.1	1.0	4.1	148
Treatment contrast			**Data evaluation (mean square)**					
Nat. vs. auto. soil (A)	0.03	235.20**[i]	0.17	0.02	6.34	10.42**	4.27**	3,125
Plus vs. minus nematicides (B)	10.40**	584.80**	8.97**	1.10	55.60**	0	0	913
Aldicarb vs. fenam. (C)	1.25	234.70**	3.14*	1.41*	26.70	0.10	0.90	133
Interaction 1[i]	1.80	5.42	1.83	2.55**	18.02	0.03	0.13	14
Interaction 2	0.05	2.35	0.04	0.01	1.56	0.40*	0.90	442
Error	0.45	23.06	0.57	0.31	7.06	0.07	0.47	1,353

[a] The soil was autoclaved for 1 hr at 121 C and 15 psi. Fenamiphos and aldicarb were applied on a broadcast basis at planting at 6.7 kg/ha and incorporated to a depth of 8–12 cm.
[b] FDB = flea beetle damage recorded 5 wk after planting using a scale of 0–3. A rating of 0 refers to no visible holes, 1, 2, or 3; 1 = 1–2, 2 = 4–10, and 3 = > 10 feeding holes per seedling.
[c] Ten seedlings were collected from each treatment 5 wk after planting, washed, and their fresh weight recorded. Roots were also rated for discoloration and plated on agar media for isolation of plant parasitic fungi.
[d] SI = size index. About 12 wk after planting, cabbage plants in all treatments were rated for head size on a scale of 1 (smallest head in the trial) to 5 (largest head).
[e] DI = damage index. Insect damage caused by diamondback moth, imported cabbage worm, and/or the cabbage looper was recorded 12 wk after planting on a scale of 0 (no apparent damage) to 5 (very severe damage).
[f] The trial was harvested 16 wk after planting. Each plant was cut at soil line and total weight recorded. Heads then were trimmed according to accepted guidelines for commercial use and weighed again (marketable weight).
[g] At harvest, roots were dug, washed, and rated for discoloration on a scale of 1 to 4, where 1 = clean, 2 = lightly, 3 = moderately, and 4 = severely discolored root systems.
[h] Refers to size index of roots using scale of 1 (smallest root system) to 5 (largest root system).
[i] Significant differences of the appropriate orthogonal contrast: * = $P = 0.05$ with 1 degree of freedom and ** = $P = 0.01$ with 54 degrees of freedom for the critical *F* value. Interaction 1 = statistical interaction of A × B and interaction 2 = statistical interaction of A × C.

RESULTS

Application of fenamiphos to natural field soil resulted in a significant increase in cabbage yields regardless of the P_i density of SBCN (Table 1). In the initial experiment, cabbage yield was reduced significantly (30%) by SBCN only at the highest P_i density tested (12 eggs per cubic centimeter). Addition of fenamiphos at 6.7 kg/ha to soil with the same P_i level (12 eggs per cubic centimeter), however, resulted in a 73% increase in yield. Furthermore, applications of fenamiphos resulted in increases of cabbage yields at all other P_i densities included. The P_f of SBCN was not significantly different among the untreated and fenamiphos-treated plots (Table 1). The P_f densities of SBCN were negatively correlated with the P_i densities.

In a second experiment conducted during 1978, fenamiphos resulted in a significant increase in yield of cabbage grown in natural field soil uninfested or infested with 0.7 or 7 eggs per cubic centimeter of SBCN (Table 2). Fenamiphos applied to a portion of the SBCN-infested soil previously fumigated with Telone C-17 or to the autoclaved portion of uninfested soil resulted in a smaller and nonsignificant increase in cabbage yield (Table 2).

In a test conducted in 1979, both aldicarb and fenamiphos significantly increased cabbage yield in natural field soil (Table 3) that had no detectable population density of SBCN and a very low number of other plant-parasitic nematodes (one *Helicotylenchus* spp., four *Paratylenchus projectus*, and four *Pratylenchus penetrans* per 100 cm^3). Cabbage yield did not increase significantly, however, when either aldicarb or fenamiphos was added to an autoclaved portion of the soil. Increase of cabbage growth resulting from application of fenamiphos or aldicarb was observed early in the growing season as indicated by the size index of the plants recorded on 30 August (Table 3). In another test conducted in 1979, cabbage yield was also increased by application of fenamiphos to soil previously autoclaved or pasteurized for 30 min at 50, 60, 70, or 80 C (Table 4). Percent increase in yield was highest in untreated soil and soil pasteurized at 50 C, whereas the increase obtained with fenamiphos in the autoclaved soil treatment was the smallest.

Both aldicarb and fenamiphos significantly reduced feeding injury by flea beetles (Tables 3 and 4); however, plants from natural or autoclaved soil without nematicide application had similar flea beetle feeding injury but cabbage yields differed significantly (Table 3). There was no significant difference in the worm injury index among treatments (Table 3). Insect injury by larvae of chewing insects was kept to a minimum as a result of application of recommended insecticides to all plots as soon as feeding symptoms

were noticed on untreated plots. Aldicarb and fenamiphos had no effect on the root discoloration index; however, roots of plants growing in autoclaved soil were lighter in color regardless of nematicide treatment (Table 3). There was no significant difference among treatments in root weight or size (Table 3). Regardless of the treatment, no fungal pathogen was consistently isolated from root segments 5 wk after planting. Application of the miticide propargite (Omite) at 2.2 kg a.i./ha or the fungicide metalaxyl (Ridomil) at 2.2 kg a.i./ha had no effect on cabbage yield.

Because of favorable environmental conditions in 1980, cabbage growth was excellent in all treatments as suggested by the average marketable weight per head, which exceeded 4.5 kg (Table 5). The only exception was the ethroprop treatment, for which the average marketable head was 3.8 kg, indicating phytotoxicity of ethroprop to cabbage at the rate used. Nevertheless, the average total or marketable weight of cabbage was highest for treatments that included fenamiphos (Table 5). Flea beetle infestation was very low and data collected 5 wk after planting showed no difference among treatments in flea beetle damage, even when foliage insecticidal sprays were omitted.

Examination of roots 5 wk after planting and at harvest generally revealed no differences in weight or any symptoms indicating activity of parasitic microorganisms. Roots of seedlings grown in soil pasteurized at 60 and 80 C, however, were lighter in color, especially when examined 5 wk after planting. Addition of nitrapyrin (N-Serve) (nitrification inhibitor) did not result in an increase in yield; however, addition of nitrapyrin and fenamiphos together resulted in higher yield than that obtained with either material alone (Table 5). Soil pasteurization alone did not significantly increase cabbage yield in 1980. Addition of fenamiphos to soil previously pasteurized at 50, 60, or 80 C resulted in higher yields (Table 5).

DISCUSSION

The efficacy of fenamiphos and aldicarb against plant-parasitic nematodes including SBCN is well documented (8–10). SBCN is the major nematode infecting cabbage in New York, with a damaging level of six to nine eggs per gram of soil. Fenamiphos has been registered for use on cabbage against this nematode. Although fenamiphos reduces the P_i density of SBCN, the P_f density in treated soil is often similar to that in untreated soil, as our data showed.

Data presented in this paper indicate that both fenamiphos and aldicarb increase cabbage yield, even in soils with SBCN P_i densities below the damaging level and in uninfested soils. Stimulation of crop yield by a nonvolatile nematicide, regardless of nematode control, has been reported previously (5). Also, considerable information has been published concerning yield responses resulting from application of fumigant-type nematicides that were not caused by nematode control (13,14).

Our data indicate that the increase in cabbage yield beyond that caused by nematode control may be associated with control of a soilborne biotic agent(s) by fenamiphos and aldicarb. This agent(s) is apparently controlled by autoclaving soil or by soil fumigation with Telone C-17. In this investigation, Telone C-17 was applied at a high rate (374 L/ha) in a gasproof container. Telone C-17 applied at a high rate has a broad spectrum of biocidal activity (19). It may be less effective if applied at a lower rate and without a tarpaulin cover.

The miticide propargite also did not affect cabbage yield when tested in 1979, which indicates that soil mites are not playing a major role. Soil mites can function as carriers of plant pathogens and may be associated with increased disease severity (6). Likewise, nitrapyrin alone did not influence cabbage yield in this investigation. Nitrapyrin is a nitrification inhibitor that aids in maintaining high levels of ammonium nitrogen in soil (4,13). Based on our data, the effect of fenamiphos or aldicarb is not apparently associated with inhibition of nitrification in soil.

It is not understood, however, why fenamiphos and nitrapyrin applied together resulted in higher yields than those obtained when either was applied alone. Although fenamiphos and aldicarb have insecticidal activity, this property apparently did not contribute to the increase in cabbage yield reported in this paper. A complete insect control program was applied to all plots. During this investigation, there were no differences in insect injury except that caused by flea beetles in 1979. Plants growing in fenamiphos- or aldicarb-treated soil had less flea beetle damage than those grown in untreated soil; however, flea beetle damage was not correlated with yield. Metalaxyl, a fungicide specific for pythiaceous fungi, was not effective in increasing cabbage yield, which indicates that these fungi are not involved. Fungal isolations made from root segments obtained from nematicide-treated and untreated plots were similar (mostly *Trichoderma* spp., *Penicillium* spp., *Fusarium* spp., and *Mucor* spp.) and did not reveal

Table 4. Effect of steam sterilization and treatment of soil with aerated steam for 30 min at 50, 60, 70, and 80 C, with and without fenamiphos, on flea beetle control and growth of cabbage in natural soil placed in microplots in 1979

Soil treatment	Flea beetle damage		Avg. marketable yield (kg/cabbage head)		Yield increase (%)
	Without fenamiphos	With fenamiphos	Without fenamiphos	With fenamiphos	
Untreated	1.8 ± 1.10	0.4 ± 0.55*[a]	3.5 ± 0.98	4.4 ± 1.27	26
50 C	1.6 ± 0.89	0.4 ± 0.55*	3.7 ± 1.26	4.8 ± 1.23*	30
60 C	1.2 ± 1.10	0.8 ± 0.45	4.0 ± 1.31	4.7 ± 1.35	18
70 C	2.0 ± 1.00	0.2 ± 0.45*	4.3 ± 1.40	5.0 ± 1.40	16
80 C	2.0 ± 1.00	0.8 ± 0.45*	4.4 ± 1.22	5.2 ± 0.82*	18
Autoclaved	1.4 ± 0.55	0.8 ± 0.84	4.4 ± 1.17	4.6 ± 1.44	5

[a] * = Significantly different from the corresponding check treatment (without fenamiphos) by the Tukey t test ($P = 0.05$).

Table 5. Effect of several soil treatments with and without fenamiphos on cabbage yield obtained in field microplots in 1980

Soil treatment[a]	Average head weight (kg)			
	Total		Marketable[b]	
	Without fenamiphos	With fenamiphos	Without fenamiphos	With fenamiphos
None	7.4 ± 1.30	8.3 ± 1.81	4.9 ± 0.85	5.5 ± 1.22
None[c]	7.4 ± 1.30	8.1 ± 1.45	4.8 ± 0.85	5.5 ± 0.96
50 C	6.9 ± 1.04	8.8 ± 1.53*[d]	4.7 ± 0.66	5.8 ± 0.90*
60 C	7.6 ± 2.00	8.2 ± 1.48	5.0 ± 1.09	5.6 ± 1.01
80 C	7.6 ± 1.14	9.1 ± 0.95*	5.1 ± 0.82	6.1 ± 0.64*
N-Serve	7.3 ± 2.17	9.0 ± 1.19	4.8 ± 1.47	6.0 ± 1.15
Ethoprop	6.0 ± 2.09	...	3.8 ± 1.37	...
Aldicarb	8.0 ± 1.77	...	5.4 ± 0.96	...

[a] Soil used was a natural cabbage soil free of *Heterodera schachtii*.

[b] Factorial analysis of the soil temperature and the nematicide (with and without fenamiphos) treatments data showed that fenamiphos significantly ($P \leq 0.001$) affected yield. Soil temperature had no significant affect on yield and there was no significant interaction between soil temperature treatment and the fenamiphos treatment.

[c] This treatment did not receive insecticidal sprays for control of flea beetles, whereas all other treatments did.

[d] * = Significantly different from the corresponding check treatment (without fenamiphos) by the Tukey t test ($P = 0.05$).

pathogenic root parasites; thus, there is possible involvement of nonparasitic rhizosphere organisms. Soil microorganisms have been reported to produce substances that stimulate plant growth (7). We speculate that fenamiphos and aldicarb may favor the growth-promoting bacteria that have recently been shown to increase plant growth and yield (17).

All experiments reported in this paper were conducted in soils obtained from different fields on the same farm. The effects of fenamiphos and aldicarb treatments on cabbage yield should be tested in soils from different locations. Soil type, previous cropping history, and other cultural practices all may influence the biological agent that is depressing cabbage yields, thus modifying the effects of fenamiphos or aldicarb. Detailed field testing of fenamiphos on several farms involved in commercial production of cabbage is warranted.

In this investigation, all treatments were harvested when heads within the most advanced treatment began to crack. Because fenamiphos or aldicarb might be involved in altering crop maturity, an experiment with sequential harvests should be conducted. To investigate the possible hormonal-type effects of these compounds, experiments should be conducted in different media such as sand. In preliminary greenhouse tests, cabbage growth was not significantly increased by application of fenamiphos to autoclaved sand; however, addition of fenamiphos to cabbage field soil resulted in a significant increase of plant size, top weight, and root weight after 8 wk.

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