Supplement to Journal of Nematology 26(4S):690–696. 1994.
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Efficacy and Compatibility for Fenamiphos and EPTC Applied in Irrigation Water for Nematode and Weed Control in Snapbean Production[1]

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Abstract: A nematicide (fenamiphos) and a herbicide (EPTC) were injected into a sprinkler irrigation system separately and as tank mixtures and applied in 25.4 kl water/ha for nematode and weed control on snapbean. There were no differences ($P = 0.05$) between methods of injection of fenamiphos + EPTC on efficacy or crop response. The root-gall indices of cultivars Eagle and GV 50 were lower in fenamiphos-treated plots than those treated with EPTC alone and untreated plots. The yield and crop value were greater ($P = 0.05$) for cultivars Eagle and Nemasnap than GV 50. Fenamiphos 4.48 kg a. i./ha + EPTC 3.36 kg a. i./ha controlled root-knot nematodes, *Meloidogyne incognita,* ring nematodes, *Criconemella ornata,* and weeds, and resulted in greater plant growth, yield, and crop value than those from untreated plots. No benefits ($P = 0.05$) resulted from treatment with fenamiphos at 6.72 kg a. i./ha + EPTC treatment compared with fenamiphos at 4.48 kg a. i. + EPTC.

Key words: Criconemella ornata, EPTC, fenamiphos, *Meloidogyne incognita,* nemagation, nematode, *Phaseolus vulgaris,* root-knot nematode, snapbean, weeds.

The southern root-knot nematode, *Meloidogyne incognita,* is a serious pathogen on snapbean (*Phaseolus vulgaris*) in temperate and tropical regions (3,7). In addition to reduced plant vigor due to root-knot nematode damage (15,23), snapbean plants attacked by nematodes are predisposed to root-rotting fungi (18,19). These soilborne pathogens must be controlled to increase production efficiency and produce profitable yields.

Fenamiphos (Nemacur 3, Miles, Kansas City, MO), a nonvolatile nematicide, has been effective in nematode control through inhibition of motility (12), attraction to bean roots (13), and root penetration (14). Application of the nematicide in a 30–38 cm band over the row at 1.7–2.2 kg a. i./ha or broadcast over the entire soil surface area at 5.0–6.7 kg a. i./ha and incorporated into the top 15-cm soil layer has been recommended for many vegetable crops (2). Fenamiphos has also been applied with irrigation water for management of *M. incognita* on cucumber, southern pea, and squash (8,9,11). The objective of this study was to determine the compatibility and efficacy of fenamiphos for nematode control when injected into a sprinkler irrigation system singly and as a tank mix with a herbicide, EPTC (Eptam 6, Zeneca, Wilmington, DE) for weed control in snapbean production.

Materials and Methods

The study was conducted near Tifton, Georgia, on a Bonifay sand (loamy, siliceous, thermic, grossarenic plinthic paleudult; 93% sand, 3% silt, and 4% clay; 0.5% organic matter; pH 6.2–6.5) naturally infested with nematodes, *Meloidogyne incognita* and *Criconemella ornata,* and weeds, primarily yellow nutsedge (*Cyperus esculentus*), Florida pusley (*Richardia scabra*), and carpetweed (*Mollugo verticillata*). The experimental design was a split-split plot with nematicide and herbicide treatments as whole-plots, methods of injection as sub-plots, and snapbean cultivars as sub-sub plots. Whole-plots contained six beds,

Received for publication 9 August 1993.

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We thank D. E. Bertrand, W. L. Dickens, M. J. Hayes, T. L. Hilton, and W. C. Wright for technical assistance.

1.8 × 12.2 m each; sub-plots contained three beds, 1.8 × 12.2 m for each injection method; and sub-sub-plots contained one bed, 1.8 × 12.2 m for each snapbean cultivar. All treatments were replicated four times.

A crop residue of corn stalks, chopped into small pieces with a flail mower, and 3,360 kg/ha dolomitic limestone broadcast over the experimental plots on 22 January, were incorporated into the soil 10–15 cm deep with a disk harrow. A moldboard plow set 25–30 cm deep was used for complete inversion of the corn residue. Seed beds were established immediately after the soil was turned. All plots received 112 kg/ha 5–10–15 ($N–P_2O_5–K_2O$) fertilizer incorporated into the top 15-cm soil layer with a tractor-powered rototiller. Cultivars of snapbean included Eagle and GV 50, which are susceptible to *M. incognita* (6,15, 22) and Nemasnap, a bush-type, with resistance to *M. incognita* (23,24). Seeds of all snapbean cultivars were planted (250,000/ha) in rows 91 cm apart on 23 January.

All treatments were applied through an irrigation simulator with 25.4 kl water/ha (0.1 acre-inch) as previously described (11). Treatments were as follows: i) untreated control; ii) EPTC 3.36 kg a. i./ha; iii) fenamiphos 6.72 kg a. i./ha; iv) fenamiphos 2.24 kg a. i./ha + EPTC 3.36 kg a. i./ha; v) fenamiphos 4.48 kg a. i./ha + EPTC 3.36 kg a. i./ha; and vi) fenamiphos 6.72 kg a. i./ha + EPTC 3.36 kg a. i./ha. All plots received 37 kg/ha nitrogen as ammonium nitrate in a sidedress 27 days after planting (DAP).

Percentage weed control was determined by comparison of numbers of weeds in treated plots with those in untreated plots and recorded 21 DAP. Weeds present in plots were identified and recorded. All plots were cultivated after the weed control ratings were recorded. Supplemental irrigation was used as needed to maintain vigorous plant growth and development. Plant growth indices were recorded 48 DAP on a 1–5 scale: 1 = plants severely stunted, leaves yellow; 2 = plants moderately stunted, leaves pale green; 3 = plants slightly stunted, leaves light green; 4 = plants not stunted, leaves green; and 5 = plants not stunted, leaves dark green.

Soil was assayed for plant-parasitic nematodes on 7 April, 21 April, and 26 May. Twenty soil cores, 2.5-cm-d × 25 cm deep, were collected from each plot and mixed thoroughly. A 150-cm^3 subsample was processed by the centrifugal-flotation method (4). After harvest, 10 plants were selected at random from each plot and indexed for root galls on a 1–5 scale: 1 = no galling, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% roots galled (1).

Pods from a single row 3.05 m long from the center of the plots were harvested 48 DAP when 15–30% attained a diameter of at least 9.5 mm. Plants were removed from plots and counted. Pods were removed from plants, weighed, and a 500-g sample was graded by pod diameter. Crop value was calculated from a prevailing price of \$329/mt for pods with a diameter <9.5 mm and \$157/mt for pods with a diameter ≥9.5 mm (16).

Data were subjected to analysis of variance (17), and the Waller-Duncan k-ratio *t* test (21) was used to separate treatment means. Correlation and regression analyses were used to relate nematode numbers to root-gall indices and snapbean yield. Percentage weed control data were transformed $\sqrt{N + 1}$ for statistical analysis, and original data are presented. Only significant ($P = 0.05$) data are discussed.

Results and Discussion

There were no differences between methods of injection; therefore, the data were pooled and analyzed for differences among treatments. In untreated plots, population densities of *Criconemella ornata* increased from 126 to 219/cm^3 soil on Eagle, from 174 to 257/cm^3 soil on GV 50, and declined from 208 to 134/cm^3 soil on Nemasnap. The effects of the treatments on *C. ornata* population densities were similar for all sampling dates; thus only data from soil samples at harvest are presented (Table 1). The numbers of *C. ornata* were lower in plots treated with EPTC alone than untreated plots of cultivars Eagle and GV 50, but not Nemasnap. Population densities of *C. ornata* were lower in plots treated with fenamiphos alone and fenamiphos + EPTC than untreated plots of all cultivars. There were no differences in numbers of *C. ornata* among fenamiphos + EPTC treatments on all cultivars. Multiple-stepwise regression analyses indicated 24–28% of the variation in yield of all cultivars was due to changes in population densities of *C. ornata*. These analyses do not prove pathogenicity, but provide evidence that *C. ornata* may be a parasite of snapbean. *Criconemella ornata* population densities increased from 4 to 60/150 cm^3 soil on snapbean in a turnip–corn–snapbean cropping system, but did not affect yield (6). Therefore, the damage threshold level of *C. ornata* on snapbean appears to be between 60 and 200/150 cm^3 soil.

Numbers of *M. incognita* second-stage juveniles (J2) ranged from 0 to 20/150 cm^3 soil before treatment and were not different among plots. Their numbers were higher in untreated plots of cultivars Eagle and GV 50 than in plots treated with fenamiphos alone and fenamiphos + EPTC (Table 1). Numbers of *M. incognita* J2 were lower in plots of Nemasnap cultivar treated with fenamiphos 4.48 kg a. i./ha + EPTC and fenamiphos 6.72 kg a. i./ha + EPTC than in untreated plots. There were positive correlations between numbers of *M. incognita* J2 in the soil and root-gall indices at harvest for the cultivars Eagle ($r = 0.46$) and GV 50 ($r = 0.37$), but not for Nemasnap. Eagle and GV 50 cultivars are susceptible (6,15,22), and Nemasnap is resistant to *M. incognita* (23,24). The value of *M. incognita* resistance in cultivar Nemasnap is demonstrated in the lower root-gall indices, greater numbers of plants per plot, and greater yield and crop value than the other cultivars (Table 2). The reduction in yield and crop value of *M. incognita*-susceptible cultivars, Eagle and GV 50, when nematodes and weeds were not managed, resulted from a combination of stunted plants and damaged root systems. These results agree with those reported by Smittle and Johnson (15).

The root-gall indices of cultivars Eagle and GV 50 were lower in fenamiphos-treated plots than in those treated with EPTC alone or untreated (Table 1). Root-gall indices of cultivar Nemasnap were low and not affected by treatments. In untreated plots, more galls occurred on roots of cultivars Eagle and GV 50 than on Nemasnap. More galling occurred on roots of cultivars Eagle and GV 50 in EPTC-treated plots than in untreated plots, but did not affect yield. This is the first report of increased root galling caused by *M. incognita* on snapbean treated with a herbicide. The cause of the effect of EPTC on root galling is not known. The differences may be due to a direct effect of EPTC on *M. incognita* in the soil or in the roots of crop hosts, an indirect effect through reduction of weed hosts in EPTC-treated plots, or the influence of EPTC on the soil microfauna and microflora. Herbicides frequently increased population densities of *C. ornata* on peanut and corn and decreased population densities of *M. incognita* on corn, *Paratrichodorus minor* on peanut, and *Helicotylenchus dihystera* on corn, soybean, and peanut (6).

Plant growth of all cultivars, recorded 48 DAP, was greater in plots treated with EPTC alone than in untreated plots and increased as the rate of fenamiphos increased (Table 2). Plant growth was inversely correlated with numbers of *M. incognita* J2 in the soil at harvest ($r = -0.53$), root-gall indices ($r = -0.66$), numbers of *C. ornata* in the soil on 7 April ($r = -0.61$), 21 April ($r = -0.52$), and at harvest ($r = -0.51$); plant growth was also positively correlated with crop value ($r = 0.54$).

Plant stands of Eagle and Nemasnap cultivars at harvest were not different among treatments (Table 2). Numbers of GV 50 plants in plots treated with fenamiphos 2.24 kg a. i./ha + EPTC and fenamiphos

TABLE 1. Nematode population densities and root-gall indices of snapbean cultivars 48 days after planting as influenced by fenamiphos and EPTC applied through a sprinkler irrigation system.

		Cultivar								
		Eagle			Nemasnap			GV 50		
Treatment	Kg a. i./ ha	*Criconemella ornata*	*Meloidogyne incognita*	Root-gall index†	*Criconemella ornata*	*Meloidogyne incognita*	Root-gall index	*Criconemella ornata*	*Meloidogyne incognita*	Root-gall index
Untreated	—	219 a	31 a	2.38 b	134 a	6 a	1.00 a	257 a	13 a	1.95 b
EPTC	3.36	39 b	6 b	2.71 a	104 a	3 ab	1.03 a	45 b	13 a	2.79 a
Fenamiphos	6.72	15 b	3 b	1.04 d	4 b	1 ab	1.00 a	19 b	0 b	1.10 d
Fenamiphos + EPTC	2.24 3.36	11 b	6 b	1.43 c	6 b	4 ab	1.01 a	18 b	1 b	1.55 c
Fenamiphos + EPTC	4.48 3.36	11 b	1 b	1.04 d	5 b	0 b	1.00 a	6 b	0 b	1.15 cd
Fenamiphos + EPTC	6.72 3.36	4 b	0 b	1.06 d	2 b	0 b	1.00 a	8 b	0 b	1.16 cd

Data are means of four replicates. Means followed by the same letter are not different ($P = 0.05$) according to Waller-Duncan k-ratio t test. Nematode population densities are numbers per 150 cm^3 soil.

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

TABLE 2. Plant response, yield, and crop value of snapbean cultivars 48 days after planting as influenced by fenamiphos and EPTC applied through a sprinkler irrigation system.

		Cultivar											
		Eagle				Nemasnap				GV 50			
Treatment	kg a. i./ ha	Plant growth index†	Number plants/ ha (×1,000)	Yield (mt/ha)	Crop value ($/ha)	Plant growth index	Number plants/ ha (×1,000)	Yield (mt/ha)	Crop value ($/ha)	Plant growth index	Number plants/ ha (×1,000)	Yield (mt/ha)	Crop value ($/ha)
Untreated	—	2.75 d	188.0 a	3.85 c	1,154 c	2.75 d	239.1 a	5.29 b	1,483 b	2.75 d	191.3 c	3.26 c	947 c
EPTC	3.36	3.50 c	193.6 a	5.43 bc	1,555 bc	3.50 c	243.3 a	6.25 ab	1,755 ab	3.50 c	203.9 abc	3.83 bc	1,077 bc
Fenamiphos	6.72	4.00 b	189.1 a	6.68 ab	1,926 ab	4.00 b	229.9 a	5.31 b	1,524 ab	4.00 b	203.0 abc	4.99 ab	1,409 ab
Fenamiphos + EPTC	2.24 3.36	4.13 b	173.2 a	6.19 ab	1,717 b	4.13 b	231.0 a	6.91 a	1,934 a	4.13 b	204.6 ab	4.49 ac	1,284 abc
Fenamiphos + EPTC	4.48 3.36	4.50 b	195.6 a	6.37 ab	1,894 ab	4.50 b	231.0 a	6.32 a	1,810 a	4.50 b	195.2 bc	5.42 ab	1,523 a
Fenamiphos + EPTC	6.72 3.36	5.00 a	191.3 a	8.28 a	2,370 a	5.00 a	220.0 a	6.80 a	1,926 a	5.00 a	210.6 a	5.73 a	1,614 a

Data are means of four replicates. Means followed by the same letter are not different ($P = 0.05$) according to Waller-Duncan k-ratio t test.

† 1–5 scale: 1 = severely stunted, leaves yellow; 2 = moderately stunted, leaves pale green; 3 = slightly stunted, leaves light green; 4 = not stunted, leaves green; and 5 = not stunted, leaves dark green 48 days after planting.

6.72 kg a. i./ha + EPTC were higher than those in untreated plots. Plant stands were higher in cultivar Nemasnap followed by cultivars GV 50 and Eagle.

Yield and crop value of all cultivars were higher from plots treated with fenamiphos 4.48 kg a. i./ha + EPTC and fenamiphos 6.72 kg a. i./ha + EPTC than from untreated plots (Table 2). Yield and crop value of cultivars Eagle and Nemasnap from plots treated with fenamiphos alone and fenamiphos + EPTC were higher than those from untreated plots. The application of EPTC alone did not increase yield or crop value of any cultivar over the untreated control. Yield and crop value were higher for cultivars Eagle and Nemasnap than GV 50. Crop value was negatively correlated with numbers of *C. ornata* in soil on 7 April ($r = -0.52$), 21 April ($r = -0.55$), and at harvest ($r = -0.51$); numbers of *M. incognita* J2 in soil at harvest ($r = -0.49$); and root-gall indices ($r = -0.54$).

The percentage weed control was greater in plots treated with EPTC alone and fenamiphos + EPTC than in plots treated with fenamiphos alone or untreated plots (Table 3). The composition of the weed population that was not controlled in plots treated with EPTC ranged from 84 to 99% yellow nutsedge and 1 to 16% Florida pusley and carpetweed.

Based on numbers of *C. ornata* and *M. incognita* J2 in the soil at harvest, root-gall indices, yield, and crop value, fenamiphos 4.48 kg a. i./ha + EPTC was the optimum dosage of fenamiphos to manage these nematode species because no benefits resulted from the fenamiphos 6.72 kg a. i./ha + EPTC treatment. This means that the dosage of fenamiphos could be reduced from 6.72 kg a. i./ha to 4.48 kg a. i./ha or more without affecting damage caused by nematodes on yield of a resistant cultivar such as Nemasnap. However, a dosage of 4.48 kg a. i./ha or more may be required for susceptible cultivars such as Eagle and GV 50 in soil heavily infested with *M. incognita.*

The advantages of applying nematicides and herbicides with irrigation water are the ability to control the depth of soil penetration with the volume of water, lower cost compared with conventional application, reduction in hazards to the applicator, and effective management of nematodes and weeds (10,20). Our data demonstrated that fenamiphos and EPTC can be applied as a tank mix via sprinkler irrigation system with 25.4 kl water/ha for management of nematodes and weeds in snapbean production. Similar results with fenamiphos in tank mixtures with other herbicides applied with irrigation water have been reported for control of nematodes and weeds in other crops (5,11).

Control of most weeds by EPTC in a

TABLE 3. Effect of EPTC applied through a sprinkler irrigation system singly and in combination with fenamiphos on weed control in snapbean.

Treatment	Kg a. i./ha	Weed control (%)	Composition of uncontrolled weeds: Yellow nutsedge (%)	Composition of uncontrolled weeds: Other† (%)
Untreated	—	0 b	88 b	12 a
EPTC	3.36	94 a	99 a	1 b
Fenamiphos	6.72	0 b	84 b	16 a
Fenamiphos + EPTC	2.24 3.36	95 a	99 a	1 b
Fenamiphos + EPTC	4.48 3.36	94 a	96 a	4 b
Fenamiphos + EPTC	6.72 3.36	93 a	98 a	2 b

Data are means of four replicates. Means followed by the same letter are not different ($P = 0.05$) according to the Waller-Duncan k-ratio t test.

† Florida pusley and carpetweed.

tank mixture with fenamiphos was effective. However, the large percentage of yellow nutsedge in the uncontrolled weed population could become a serious problem in an all-vegetable crop rotation or in cropping systems where EPTC is used frequently.

Data from this study also demonstrate the importance of managing nematodes and weeds to produce high-quality yields of snapbean. More research is needed on the application of specific tank mixtures of nematicide + fungicide + herbicide through sprinkler irrigation systems to determine compatibility, efficacy, environmental effects, and economic feasibility for multiple-pest management in crop production systems.

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