Influence of Water and Soil Temperature on the Concentration and Efficacy of Phenamiphos or Control of Root-Knot Nematodes[1]

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Abstract: Field plots of Tifton loamy sand were treated with phenamiphos for control of root-knot nematodes in a multiple-crop system of turnips, field corn, and southern peas. Preplant applications of phenamiphos protected roots of turnips and corn from damage by root-knot nematodes. Concentrations of phenamiphos at application in the 0–15-cm soil layer were near 6 μg/g on turnips and near 4 μg/g on corn and southern peas. After 30 d, concentrations were approximately 1 μg phenamiphos/g of soil for all crops. Concentrations of 2.0–3.8 μg phenamiphos/g of soil for 9-d duration appeared to be adequate for control of root-knot nematodes on field corn and southern peas in this multiple-crop system. Stepwise regression analyses indicated that 31%, 62%, and 22% of the variations in concentration of phenamiphos in the soil planted to turnips, corn, and southern peas, respectively, were attributable to the amount of water that the plots received. Soil temperature had no effect on concentrations of phenamiphos. *Key words:* nematode control, dissipation of phenamiphos, multiple-crop, *Meloidogyne incognita.*

Turnip (*Brassica rapa* L.), field corn (*Zea mays* L. subsp. *mays*), and southern peas (protopea, cowpea) (*Vigna unguiculata* [L.] Walp.) are grown widely as food and grain crops in the Southeastern United States. They are generally grown in mono-crop or double-crop systems in spring, summer, or fall, but the long growing season and mild winters in the Southeast allow these crops to be grown in sequence on the same land. Most nematode control data, developed from annual mono-crop systems (2, 6,7,8), may not be applicable to multiple cropping where nematode problems are severe (11).

Intensive multiple-crop agricultural systems can be expected to increase nematode control problems (15). This study was conducted in order to determine the influence of water and soil temperature on the concentration and efficacy of phenamiphos for control of root-knot nematodes in a cropping sequence of turnips, field corn, and southern peas.

MATERIALS AND METHODS

Plots were established on Tifton sandy loam (75% sand, 10% silt, 15% clay, pH 6.0–6.7) naturally infested with *Meloidogyne incognita* (Kofoid & White) Chitwood. Each plot contained three 1.8- × 6.7-m beds. Immediately before each crop was planted, phenamiphos (ethyl 4 (methylthio)*m*-tolyl isopropylphosphoramidate) was applied to designated plots. The experimental design was a randomized complete block with two treatments and six replications. Phenamiphos granules were broadcast on the soil surface of treated plots at the rate of 9 kg a.i./ha and incorporated 15

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cm deep with a tractor powered rototiller on the planting date of each crop. Untreated plots were controls. 'Shogoin' turnips, 'Funk's 4507' corn, and 'Worthmore' southern peas were planted on 15 Feb., 11 April, and 8 Aug., respectively.

Soil samples were collected on the first day of each month (±2 d) from January through December 1979 and nematode populations determined. Soil samples consisted of a composite of 20 cores (2 × 20 cm) randomly collected from the root zone of plants. The composite samples were thoroughly mixed and a 150-cm³ aliquant for each treatment was processed by the centrifugal-flotation method (3). Extracted nematodes were then identified and counted.

In addition, soil samples (1,000 cm³) for nematode assays and phenamiphos analyses were collected at depths of 0–7 cm and 7–15 cm immediately after nematicide application (0) and 1, 2, 4, 5, 11, 15, and 30 d after application on turnip; 0, 1, 2, 5, 9, 15, 30, and 62 d after application on field corn; and 0, 1, 2, 6, 9, 15, and 30 d after application on southern peas. Soil samples from 10 sites in each plot were composited and thoroughly mixed, and a 150-cm³ aliquant for each treatment was processed to separate nematodes from the soil as described above. *M. incognita* larvae were stained with nile blue (12) to distinguish dead from living specimens. Soil samples were taken from the composite and stored at –20 C until analyzed for phenamiphos. Fortified check samples were prepared and stored with the field samples for use as calibration and recovery standards. For phenamiphos analysis, soil samples were removed from the freezer, air dried to 0.5% moisture, and sieved through a 2-mm screen. For extraction of phenamiphos, 50 g of soil were transferred along with 200 ml of chloroform: methanol (1:1) to a 500-ml Erlenmeyer flask fitted with a screw cap lined with Teflon and shaken for 2 h on a wrist action shaker. The solvent was decanted from the soil, filtered through Whatman No. 1 filter paper, and 100 ml reduced to dryness *en vacuo* at 40 C. The dry residue was dissolved in 2 ml acetone and oxidized for 15 min with 5 ml 20% solution of $MgSO_4$ and 20 ml 0.1 M $KMnO_4$. The oxidized sample was transferred to a 125-ml separatory funnel and extracted three times with 20 ml dichloromethane. The pooled organic fraction was passed through anhydrous Na_2SO_4 and reduced to dryness *en vacuo*. The residue was dissolved in 4 ml of acetone and analyzed for phenamiphos by gas chromatography.

Separation and quantitation of phenamiphos were done on an HP 5840 gas chromatograph fitted with automatic liquid sampler and N/P thermionic detector. A glass column (6-mm × 2-mm i.d. × 180 cm) packed with 1.5% OV-17 and 1.95% OV-210 on 80–100 mesh Gaschrom Q was used with helium carrier gas at 30 ml/minute. The injection port, oven, and detector temperatures were 250, 240, and 300 C, respectively. Calibrations were done in the external standard mode by using extractions of fortified check samples at the 1.0-ppm level. The instrument was programmed for two 2-μl injections per vial with automatic recalibration after five samples. Recoveries ranged from 92.8% to 95.5%, and the detector was linear from 0.1 μg to 50 μg of oxidized phenamiphos.

Maximum and minimum soil temperatures 10 cm deep and the amount of moisture (rainfall and supplemental irrigation) that the plots received were recorded.

RESULTS

The concentrations of phenamiphos at soil depths of 0–7 and 7–15 cm are presented in Table 1. The concentrations in the 0–7-cm soil depth were near 7 μg/g on 0 and 1 d after application to turnip and decreased to < 1 μg/g 11 d after application. The concentrations were greater in the 0–7-cm depth than in the 7–15-cm depth up to day 5; after that time, concentrations were greater at the lower depth in plots of turnips.

The quantity and distribution of water received by all crops are presented in Table 1. A stepwise regression analysis indicated that 31% of the variation in phenamiphos concentrations in the soil (0–15-cm depth) was attributable to the amount of water that the plots received. The numbers of live root-knot nematode larvae in plots of turnip were greatest 2 d after application and subsequently decreased until 30 d after application. The percentage of the total number

Table 1. The effect of soil temperatures, amount of water, and phenamiphos concentrations on *Meloidogyne incognita* larvae as influenced by time on three crops in a multiple-crop system.

Crop	Days after application	Soil temp. (C) 10 cm deep		Water (cm) plots received*	Phenamiphos (μg/g) cm deep			Number nematodes/150 cm³ soil	
		Max.	Min.		0-7	7-15	0-15†	Live	Dead
Turnip	0	17	8	0	6.76	5.23	6.00	27	1
	1	20	9	0	7.23	5.17	6.20	33	11
	2	17	9	0	5.63	3.60	4.62	50	8
	4	15	2	0	3.99	3.91	3.95	30	8
	5	17	1	0.84	2.68	1.94	2.31	25	8
	11	20	7	7.62	0.83	1.47	1.15	24	7
	15	22	10	0.03	0.74	1.12	0.93	23	8
	30	26	9	7.67	1.01	1.23	1.12	6	10
Corn	0	29	14	0	4.24	3.45	3.84	103	14
	1	33	18	0	4.36	4.15	4.25	76	16
	2	33	21	0	3.68	3.39	3.54	58	38
	5	30	16	2.69	2.46	2.72	2.59	55	15
	9	32	18	1.27	2.16	1.93	2.04	34	24
	15	24	19	4.88	0.95	1.30	1.13	24	6
	30	26	22	4.80	0.38	0.84	0.61	3	1
	62	33	23	11.89	0.22	0.33	0.28	1	0
Pea	0	41	27	1.91	4.37	3.22	3.80	6	3
	1	37	26	0	2.38	2.75	2.56	2	2
	2	39	26	0	2.61	2.64	2.63	1	0
	6	34	22	3.18	1.95	2.28	2.12	0	0
	9	40	24	0.13	3.07	3.10	3.09	1	2
	15	41	26	2.03	2.12	2.99	2.55	0	0
	30	38	26	4.09	0.91	1.12	1.02	0	1

*Cumulative from preceding data.
†Mean of 0-7 and 7-15 cm deep.

of larvae that were dead ranged from 4 to 63; the largest percentage occurred 30 d after chemical application. Roots of turnip in plots treated with phenamiphos were free of galls at harvest (Table 2).

Concentrations of phenamiphos in the 0–7-cm soil depth were near 4 μg/g on 0 and 1 d after application of the nematicide to field corn and < 1 μg/g 15 d after application (Table 1). Phenamiphos concentration was greater in the 0–7-cm depth than in the 7–15-cm depth up to day 9; after that time, concentrations were greater at the lower depth in plots of corn. A stepwise regression analysis indicated that 62% of the variation in phenamiphos concentrations in the soil (0–15-cm depth) was attributable to the amount of water that the plots received. Numbers of live root-knot nematode larvae were greatest at the time of application and subsequently decreased until 62 d after application. The percentage of the total number of larvae that were dead ranged from 0 to 41; the largest percentages occurred 2 and 9 d after application. Roots of field corn in plots treated with phenamiphos were free of galls on 22 May and 23 July (Table 2).

The concentration of phenamiphos in the 0–7-cm soil depth was near 4 μg/g on day of application to southern peas and decreased to 1 μg/g 30 d after application (Table 1). The concentration was greater in the 0–7-cm depth than in the 7–15-cm depth at time of application; after that time, concentrations were greater at the lower depth in plots of southern peas. A stepwise regression analysis indicated that 22% of the variation in phenamiphos concentrations in the soil (0–15-cm depth) was attributable to the amount of water that the plots received. Numbers of live and dead root-knot nematode larvae were low in plots of southern peas. Roots of southern peas in all plots were free of galls on 28 August and 29 October (Table 2).

Application of phenamiphos suppressed numbers of nematodes to very low levels from June through December (Table 3).

The maximum and minimum soil temperature at the 10-cm depth are presented in Table 1. A stepwise regression analysis indicated that soil temperatures did not influence the variation in concentrations of phenamiphos in the soil.

DISCUSSION

The greater concentrations of phenamiphos soon after application in the 0–7-cm soil layer compared with the 7–15-cm depth in plots of turnip and corn were expected because a previous study showed that concentrations of ethoprop were greater in the 0–7-cm depth than in lower depths when this granular nematicide was incorporated into the soil with a tractor-powered rototiller (13). Plots of turnip and corn did not receive water until day 5, whereas, plots of southern peas received 1.9 cm water on day of application. The cumulative amounts of water moved the phenamiphos from the 0–7-cm depth to the lower depth on all plots. Brodie (1) reported that phenamiphos incorporated into the top 5 cm of Tifton sandy loam at 11.2 kg/ha in the field prevented galling of tomato roots by *Meloidogyne* sp. down to 20 cm. Earlier work stressed the importance of soil water (14) and irrigation or rainfall (13) in the dispersion of nonvolatile nematicides. The low water solubility of phenamiphos (0.04–0.07%) prevents rapid leaching from Tifton sandy loam in the absence of excess amounts of water (< 9.0 cm up to 15 d after applica-

Table 2. Effect of phenamiphos on root-gall indices in a multiple-crop system.

Treatment	Rate/ha (kg a.i.)	Root-gall index* Turnip 9 Apr.	Corn 22 May	Corn 23 July	Southern pea 28 Aug.	Southern pea 29 Oct.
Phenamiphos	9	1.0 b†	1.0 b	1.0	1.0	1.0
Control		2.0 a	1.7 a	1.1	1.0	1.0

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

†Numbers followed by different letters within columns are significantly ($P = 0.05$) different according to Student's t-test. No letters indicates nonsignificance.

Table 3. Effect of phenamiphos on *Meloidogyne incognita* in a multiple-crop system.

Treatment	Rate/ha (kg a.i.)	Number nematodes/150 cm³ soil											
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Phenamiphos	9	115 a*	141	25	33 a	33 a	0	1 b	1 b	3 b	0 b	0 b	1 b
Control		73 b	144	55	13 b	7 b	7	181 a	1092 a	144 a	81 a	119 a	37 a

*Numbers followed by different letters within columns are significantly ($P = 0.05$) different according to Student's t-test. No letters indicates nonsignificance.

tion) and allows sufficient time for adsorption by the plant of nematicidal concentrations.

Based on root-gall indices, phenamiphos concentrations of 2.0–6.0 μg/g of soil in plots of turnips and 2.0–3.8 μg/g of soil in plots of corn for 9 d appear to be adequate for control of root-knot nematodes in multiple-cropping systems. Numbers of nematode larvae in plots of turnip were not suppressed by phenamiphos, but roots of turnips in treated plots were not galled. This indicates that the nematodes failed to enter roots of turnips in treated plots and survived in the soil through May. *M. incognita* larvae can survive a few weeks in moist soil at summer temperatures in the absence of a host (16). If phenamiphos is nematistatic, numbers of larvae in treated soil would decrease with time and roots of plants would be free of galls. Our data support this hypothesis. The low numbers of nematode larvae in plots of southern pea were expected because 'Worthmore' cultivar is resistant to *M. incognita.* The numbers of nematode larvae in untreated plots of southern peas apparently were residual from the previous crop of field corn.

It has been reported that phenamiphos suppresses nematode populations and increases yields on many crops (4,5,9,10) in mono-crop systems. Our studies indicated that phenamiphos (9 kg a.i./ha) will give adequate control of *M. incognita* in intensive multi-crop systems including susceptible crops such as field corn. Environmental data indicate that the dissipation and degradation of phenamiphos are influenced by water but not by soil temperatures.

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