Influence of Climate and Cropping Patterns on the Efficacy of Ethoprop, Methyl Bromide, and DD-MENCS for Control of Root-knot Nematodes[1]

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Abstract: Field plots of Tifton loamy sand were treated with methyl bromide, DD-MENCS, or ethoprop for control of root-knot nematodes, *Meloidogyne incognita,* in a multiple cropping system of turnips, field corn, and southern peas. Annual applications of methyl bromide and DD-MENCS in November or December suppressed nematode numbers to very low levels through September, but numbers increased in the following October, November, and/or December. No benefit was found from ethoprop applied to DD-MENCS-treated plots before the planting of each crop. Nematode numbers were not significantly suppressed by ethoprop alone. Concentrations of ethoprop in the 0–15-cm soil layer were near 6 μg/g at application but were <1 μg/g of soil 5 days later on corn and southern peas and 30 days later on turnips. Ethoprop concentrations of 4.6 to 5.6 μg/g of soil are too low for adequate control of root-knot nematodes on field corn and southern peas in multiple cropping systems. Stepwise regression analyses indicated that 81% and 36% of the variations in concentration of ethoprop in the soil were attributable to the amount of water that the plots received when the maximum soil temperature ranged from 10 C to 19 C and from 31 C to 41 C, respectively, and that 11% was attributable to the maximum soil temperature within the temperature range of 17 C to 33 C. *Key Words:* Nematode control, dissipation of ethoprop, multiple-cropping, *Meloidogyne incognita.*

Turnips (*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 USA. They are generally grown in a mono- or a double-cropping system in spring, summer, or fall, but the long growing season and mild winters in the southeast allow these crops to be grown consecutively on the same land. Most nematode-control data, having been developed from annual monocrop systems (4, 10, 11, 12), may not be applicable to multiple cropping where nematodes are severe (15).

Intensive agricultural systems such as multiple-cropping can be expected to intensify nematode control problems (19). This study was done to determine the influence of methyl bromide, DD-MENCS, and ethoprop on root-knot nematodes in a cropping sequence of turnips, field corn, and southern peas.

MATERIALS AND METHODS

Plots were established in September 1974 on Tifton sandy loam (75% sand, 10% silt, 15% clay) naturally infested with *Meloidogyne incognita* (Kofoid & White) Chitwood. Soil pH was maintained between 6.0 and 6.7 as measured in a saturated paste. Each plot contained three beds of 1.8 × 7.6 m. The experimental design was a split-plot in strips with treatments replicated six times. Treatments with broadcast rates given in kg/ha of active ingredient, were: 1) 98% methyl bromide + 2% chloropicrin (trichloronitromethane), 392 (MBR-CP); 2) 20% methyl isothiocyanate + 80% chlorinated C_3 hydrocarbons, 376.3 (DD-MENCS) plus *O*-ethyl *S,S*-dipropyl phosphorodithioate, 8.96 (ethoprop); 3) ethoprop, 8.96; and 4) control (no chemical). Fumigants were injected 25 cm deep into the soil by a machine with chisels 20 cm apart, and the soil surface was shaped and sealed with a bed-shaper attachment. Plots treated with MBR-CP were covered with black polyethylene (152 μm thick) immediately after application, and the cover was removed 48 h later. Granules of ethoprop were spread on the soil surface and incorporated into the top 15-cm soil layer with a tractor-driven rototiller. MBR-CP and DD-MENCS were applied annually in November or December (Table 1). Before each crop was planted, ethoprop was applied to DD-MENCS-treated plots if the numbers of root-knot nematode larvae/150 cm^3 soil exceeded 25 anytime during the year until 15 April 1977.

Received for publication 23 July 1979.

[1]Cooperative investigations of U. S. Department of Agriculture, Science and Education Administration, Agricultural Research; and the University of Georgia College of Agriculture Experiment Station, Coastal Plain Station, Tifton.

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TABLE 1. Dates of chemical application and planting in a multiple cropping system.

Year	Chemical			Crop		
	Methyl bromide	DD-MENCS + Ethoprop	Ethoprop	Turnip	Field Corn	Southern Pea
1974	Dec. 18	Dec. 17				
1975			Feb. 21	Feb. 21	Feb. 26	
			Apr. 22			Apr. 23
			Aug. 20	Aug. 20		Aug. 21
	Nov. 20	Nov. 20				
1976			Feb. 12	Feb. 12	Feb. 13	
			Apr. 2	Apr. 2		Apr. 2
			Aug. 10	Aug. 10		Aug. 10
		Dec. 6				
1977	Feb. 8				Feb. 23	
			Apr. 15	Apr. 15		Apr. 15
				Aug. 9		Aug. 10
	Nov. 14	Nov. 14				
1978				Feb. 15	Feb. 15	
				Apr. 12		Apr. 12
				Aug. 8		Aug. 9

Thereafter, ethoprop was not applied to DD-MENCS-treated plots. In other plots that received only ethoprop, it was applied before each crop was planted if the numbers of root-knot nematode larvae/150 cm^3 soil exceeded 25.

Soil samples (1,000 cm^3) for nematode assays were collected on the first day of each month ($\pm$2 days) from January 1974 through December 1978 to provide information on fluctuations within a season. Soil samples consisted of a composite of 20 cores (2 $\times$ 20 cm) collected randomly from the root zone of plants. The composite samples were mixed thoroughly, and a 150-cm^3 aliquant for each treatment was processed by the centrifugal-flotation method (7) to separate nematodes from the soil. Extracted nematodes were then placed in calibrated dishes for identifying and counting.

In 1978, soil samples (1,000 cm^3) for nematode assays and ethoprop analyses were collected 0–7 cm and 7–15 cm deep with a trowel immediately after application (0) and 1, 2, 5, 10, 15, 30, 50 days after application on turnip; 0, 1, 2, 5, 10, 15, 30, and 60 days after application on field corn; and 0, 1, 2, 5, 10, 15, 30, 45 and 65 days after application on southern peas. Soil samples from 10 sites in each plot were composited and mixed thoroughly, and a 150-cm^3 aliquant for each treatment was processed to separate nematodes from the soil as described above. Root-knot nematode larvae were stained with nile blue (17) to distinguish dead from living specimens. Representative soil samples were then taken from the composite and stored at –20 C for ethoprop analysis. Fortified check samples were prepared and stored with the field samples. Samples were usually processed within 2 weeks of collection. Soil samples were removed from the freezer and air-dried to 0.5% moisture; 100-g samples were extracted with benzene (2 $\times$ 100 ml) for 5 minutes in a Waring blender. The benzene extract was filtered through a Buchner funnel, and the filter cake was washed with an additional 50 ml of the solvent. The filtrate was transferred to a separatory funnel and washed 3 times with 25 ml of saturated NaCl solution and dried by filtration through Na_2SO_4. The residue was taken up in hexane and diluted to 10 ml for analysis.

Ethoprop was analyzed on an HP 5710 gas chromatograph fitted with an N/P thermionic detector. A glass column (6 mm $\times$ 180 cm) packed with 3% Poly S-179 on 100/120-mesh Gas-Chrom Q was used; carrier gas was helium at a flow rate of 30 ml/min. The inlet, oven, and detector temperatures were respectively 220, 220, and 300 C. Triplicate 2-μl on-column injections were made from each sample vial. Results were recorded with an HP 3380 reporting integrator calibrated in the external standard mode. The average of the three

determinations is reported; the standard deviations varied from 0.001 for a 5 ng/g concentration to 0.009 at 100 ng/g. Response over this range of ethoprop concentration was linear for this detector and column.

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

Data were subjected to analysis of variance, and significant differences were identified. Various combinations of data were also subjected to a stepwise regression analysis.

RESULTS

Data collected in 1974 before soil chemical application indicated that all the field plots were infested with *M. incognita* (Table 2). Annual applications of MBR-CP and DD-MENCS suppressed numbers of nematodes to very low levels through September, but numbers of nematodes increased in October, November, and December. The trend was similar in plots treated with DD-MENCS plus ethoprop before each crop was planted. The application of ethoprop preceding each crop in plots treated with DD-MENCS was discontinued after 15 April 1977 since no benefits were apparent. Results were unexpected from plots treated with ethoprop alone before each crop was planted if the numbers of root-knot nematode larvae/150 cm^3 soil exceeded 25. At most samplings, nematode numbers were not significantly ($P = 0.05$) suppressed by ethoprop below the numbers in untreated control plots. The two exceptions were in April and May 1975.

The concentrations of ethoprop at soil depths of 0–7 and 7–15 cm were monitored in 1978 on all crops. Since the results were similar for both depths, the data were composited and Table 3 presents means for 0–15 cm. The concentration of ethoprop in the soil was near 6 μg/g 2 days after application to turnip and decreased to <1 μg/g 30 days after application. A stepwise regression analysis indicated that 81% of the variation in ethoprop concentrations was attributable to the amount of water the plots received. During this time the number of live root-knot nematode larvae decreased slightly 2 days after application, increased 5 days after application, and subsequently decreased until 50 days after application. The concentration of ethoprop was near 6 μg/g at the time of application on plots planted with field corn but was <1 μg/g 5 days later. Eleven percent of the variation in ethoprop concentration was attributable to differences in the maximum soil temperature. The number of live nematodes in treated plots of corn was 42/150 cm^3 soil at day 0 and declined until 60 days after chemical application. Fifty-three percent of the variation in numbers of nematode larvae was attributable to the concentration of ethoprop in the soil. At time of application on plots of southern peas the concentration of ethoprop was near 6 μg/g. Five days later the concentration was <1 μg/g and remained <1 μg/g. Thirty-six percent of the variation in ethoprop concentrations was attributable to the amount of water the plots received. Numbers of live nematode larvae increased to 1,238/150 cm^3 soil 1 day after chemical application, generally declined to 8/150 cm^3 soil after 45 days, and increased to 300/150 cm^3 soil at 65 days. Sixty-nine percent of the variation in numbers of nematode larvae was attributable to the concentration of ethoprop in the soil. The percentage of the total number of nematodes that were dead was greater on turnip and field corn than on southern peas.

DISCUSSION

Previously, MBR-CP and DD-MENCS were found to control *M. incognita* on three sequential crops of cucumber (16). Therefore the long-term control of *M. incognita* with MBR-CP and DD-MENCS on turnip and field corn in the current studies was expected, but the rapid increase in numbers of nematodes on southern pea following field corn in plots treated with MBR-CP and DD-MENCS was unexpected. The application of ethoprop to DD-MENCS-treated plots before the planting of southern peas in 1975 and 1976 did not reduce nematode numbers in the soil. These results indicated that the residual effects of MBR-CP and DD-MENCS plus ethoprop will not prevent a rapid increase of *M. incognita* on southern pea following another susceptible crop such as field corn. The poor nematode control in plots treated with ethoprop be-

TABLE 2. Effect of soil chemical treatments on *Meloidogyne incognita* in a multiple cropping system.

Treatment	Rate/ha	Number nematodes/150 cm³ soil													
		1974			1975										
		Sept.	Oct.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Methyl bromide	392 kg	3	27	97	28	2	0	0	0	0	0	2	0	28	2	257
DD-MENCS + Ethoprop	327 liters + 8.9 kg a.i.	142	185	37	92	0	0	0	0	0	0	8	3	33	647	255
Ethoprop	8.9 kg a.i.	32	58	187	107	8	5	0	0	10	57	628	25	17	820	590
Control	——	85	72	30	82	0	10	0	0	23	48	342	157	3	867	492
LSD @ $P = 0.05$		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	267	ns	ns	195	ns
		1976													
Methyl bromide	392 kg				20	0	0	0	0	0	2	17	0	623	548	80
DD-MENCS + Ethoprop	327 liters + 8.9 kg a.i.				92	0	0	0	0	0	0	5	13	1,062	705	233
Ethoprop	8.9 kg a.i.				402	277	52	11	2	5	865	1,357	107	2,005	960	390
Control	——				108	157	48	42	8	30	1,118	1,667	220	1,725	747	475
LSD @ $P = 0.05$					217	144	ns	17	4	ns	381	387	119	ns	ns	ns
		1977													
Methyl bromide	392 kg				45	8	153	0	0	0	2	22	5	442	1,380	308
DD-MENCS + Ethoprop	327 liters + 8.9 kg a.i.				97	11	10	0	0	0	0	0	2	85	265	462
Ethoprop	8.9 kg a.i.				308	117	33	20	20	33	272	728	283	530	247	778
Control	——				408	92	78	28	8	28	313	788	75	735	330	793
LSD @ $P = 0.05$					106	ns	76	ns	9	12	118	490	ns	221	283	ns
		1978													
Methyl bromide	392 kg				49	28	9	0	0	0	0	88	12	1,347	1,837	351
DD-MENCS + Ethoprop	327 liters + 8.9 kg a.i.				28	5	6	0	0	0	0	11	4	484	1,632	105
Ethoprop	8.9 kg a.i.				174	134	79	3	13	3	173	769	189	1,171	1,977	381
Control	——				169	91	57	17	25	9	75	714	295	1,948	1,492	419
LSD @ $P = 0.05$					37	39	ns	ns	11	7	99	314	150	775	ns	ns

TABLE 3. Soil temperatures, amount of water, concentrations of ethoprop, and number of live and dead *Meloidogyne incognita* larvae as influenced by time on three crops in a multiple cropping system.

	Days after application																								
	Turnip								Field corn								Southern peas								
	0	1	2	5	10	15	30	50	0	1	2	5	10	15	30	60	0	1	2	5	10	15	30	45	65
Maximum soil temperature (C) 10 cm deep	16	17	11	10	16	15	19	19	26	23	23	32	28	27	33	33	37	35	34	33	41	32	35	32	31
Minimum soil temperature (C) 10 cm deep	5	5	9	6	4	8	8	18	19	19	15	17	14	12	17	23	25	25	26	24	28	25	25	24	20
Amount of water (cm) plots received[a]	0	0.38	0.25	1.14	0.91	1.83	11.86	10.16	0.41	5.59	1.98	0	2.41	0.64	11.10	19.02	0.10	1.55	0	3.43	1.27	3.00	4.47	4.06	1.98
Ethoprop concentration (ppm)	4.23	4.81	5.58	3.47	3.81	2.65	0.07	0.02	5.50	—[b]	2.08	0.08	0.01	0.02	0.01	0.01	5.59	4.32	4.56	0.17	0.08	0.04	0.02	0.01	0.01
Number live nematode larvae/ 150 cm^3 soil	164	95	58	149	140	29	10	4	42	—	23	29	24	10	2	7	744	1238	949	196	600	55	20	8	300
Number dead nematode larvae/ 150 cm^3 soil	0	26	26	43	109	17	9	4	11	—	19	21	20	8	2	0	25	154	161	47	167	11	16	50	146

[a]Cumulative from preceding date.
[b]Soil samples were not collected following 5.5-cm rainfall.

fore the planting of each crop in 1975, 1976, and 1977 was unexpected.

Previous studies (5, 6) indicated that ethoprop is not a persistent chemical in the soil, and that its persistence varies with application rate, formulation (liquid or granular), organic content of soil, soil type, soil temperature, soil moisture, and microflora. The half-life of ethoprop in field tests varied from 3 to 30 days. A laboratory percolation study (6) on a sandy loam indicated that ethoprop moved downward 30 cm after 12.5 cm of water was applied. Brodie (2, 3) studied the vertical movement of ethoprop in Tifton sandy loam by measuring the control of root-knot nematodes at various depths. He reported 90% control 20 cm deep after incorporation of ethoprop in the top 5 cm of soil. More recently, Rohde *et al.* (18) found little downward movement of ethoprop in soil beyond an incorporation depth of 15 cm, and dissipation was 90% within 3 weeks in the soil layer at 0–10 cm. Our research corroborated that ethoprop is not persistent in the soil and that the half-life ranges from 3 to 30 days (6).

Concentrations of ethoprop were higher over a longer period on turnips than on field corn and southern peas. Turnips were planted in February, when maximum soil temperatures 10 cm deep ranged from 10 to 19 C. During that time of year, microbial activity in the soil is low (1). Our data indicated that when maximum soil temperatures were 19 C the variation in residual concentration of ethoprop was influenced more by the amount of water applied to plots than by soil temperatures. As the maximum soil temperature increased between 23 and 33 C on field corn, the variation in ethoprop concentration in the soil was influenced more by the maximum temperature than by the amount of water the plots received. At high maximum soil temperatures between 31 and 41 C on southern peas, the variation in residual concentration of ethoprop was influenced more by the amount of water applied to plots than by soil temperature.

It has been reported that ethoprop suppresses nematode populations and increases yields on many crops (8, 9, 12, 13, 14) in monocrop (one crop per year) systems, but our studies indicated that ethoprop (8.9 kg a.i./ha) will not give adequate control of *M. incognita* in intensive multicrop systems including highly susceptible crops such as field corn and southern peas. The poor control of root-knot nematodes indicated that the effectiveness of ethoprop is reduced under the high nematode population pressures associated with multiple cropping. Moisture and temperature data indicate that the degradation of ethoprop is activated by certain environmental conditions.

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