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Temporal Efficacy of Selected Nematicides on *Meloidogyne* Species on Tobacco

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Abstract: Aldicarb, ethoprop, and fenamiphos were evaluated for their efficacy in controlling various species of root-knot nematodes on flue-cured tobacco and for their residual activity, as determined through periodic sampling and bioassays of soil taken from field plots. Field experiments were conducted at five locations over 2 years with flue-cured tobacco. Soil in plots treated with nematicides were formed into high, wide beds before transplanting with 'Coker 371-Gold' or 'K 326' tobacco. Residual control of *Meloidogyne* spp. was greatest ($P \leq 0.05$) with fenamiphos (in some cases up to 10 weeks, as measured in tomato bioassays of infested soil and root fragments). Suppression of nematode reproduction by ethoprop was short-lived, and numbers of second-stage juveniles + eggs and numbers of galls in bioassays sometimes surpassed those of untreated plots within 4 weeks after treatment. Aldicarb gave intermediate control over time as compared to the other compounds. Although nematicidal efficacy of all compounds varied with site and season, fenamiphos and aldicarb generally produced the highest yields.

Key words: chemical control, *Meloidogyne arenaria, M. incognita, M. javanica,* nematode management, population dynamics, root-knot nematode, nematicide, nematode, tobacco.

Estimated yield losses of flue-cured tobacco caused by *Meloidogyne spp.* are 14.7% worldwide, amounting to $2.7 billion (24). Tobacco producers in the United States rely on nematicides for profitable production (14), spending $15–20 million annually in North Carolina alone. The most damaging species of root-knot nematode that affect North Carolina flue-cured tobacco are *Meloidogyne arenaria* (Neal) Chitwood, *M. incognita* (Kofoid & White) Chitwood, and *M. javanica* (Treub) Chitwood. The northern root-knot nematode *M. hapla* Chitwood is commonly found in tobacco fields but causes limited yield losses. In addition, root-knot nematodes predispose tobacco to bacterial wilt (*Pseudomonas solanacearum*) and black shank (*Phytophthora parasitica*) (19), which are two of the most destructive diseases of tobacco (15).

Nematicides have been evaluated extensively on tobacco for efficacy against various *Meloidogyne* species (5,9,16,20,22). Data were usually collected on tobacco yield, juvenile counts at two or three dates, and root galling. More in-depth studies have been conducted on the relationships of root-knot nematode population levels and flue-cured tobacco yields, but this work did not address the effects of nematicides on these relations (3). Another study considered the impact of a nonfumigant versus a fumigant nematicide on *M. javanica* population dynamics (22). Nonfumigant nematicides were generally not effective against this species in Florida.

Nematicide efficacy is dependent on inherent toxicity, mode of action, initial kill rate, environmental conditions, and residual activity (4). The primary objective of this research was to evaluate the residual activity of ethoprop, fenamiphos, and aldicarb on the population dynamics of *Meloidogyne* spp. on flue-cured tobacco, as determined by periodic sampling of juvenile populations and soil bioassays. Secondary objectives included evaluation of these materials concerning their ability to enhance tobacco yield and quality in the presence of root-knot nematodes.

Materials and Methods

Two field experiments were conducted in 1988 and three in 1989. In 1988, one test was established in a field (92% sand,

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6% silt, 2% clay) infested with *M. javanica, M. arenaria,* and *M. incognita* in Columbus County, North Carolina. Plots were four rows wide, with 1.12-m row spacing and 14.93 m long. Treatments were arranged in a randomized complete block with 10 replicates. Each plot was split, with two rows being planted with cv. K 326 (resistant to *M. incognita* races 1 and 3) and two rows planted with cv. Coker 371-G (susceptible). A second test was established in 1988 in a field (90% sand, 9% silt, 1% clay) infested with *M. javanica* and *M. incognita* in Sampson County, North Carolina. Unless indicated otherwise, the same cultivars and field design were used in all tests. At both sites emulsifiable formulations of the nematicides ethoprop and fenamiphos were applied as broadcast treatments at 8.75 and 6.72 kg a.i./ha, respectively. The nematicides were incorporated into the upper 7–10 cm of soil with a disc. Aldicarb was applied as a band treatment at 3.36 kg a.i./ha and incorporated with a power rototiller. The soil was then formed into ridged rows ca. 45 cm high.

In 1989, a test was established in Lenoir County on a loamy sand (84% sand, 13% silt, 3% clay) infested with *M. incognita* race 4 and *M. javanica.* Another site in Caldwell County was on a sand (texture not available) infested with *M. arenaria.* The third site was the same Sampson County site as in 1988, although yield and value data were not recorded in 1989. The same nematicide treatments were used as in 1988 at all sites, plus a treatment of ethoprop concentrated into a 35-cm band and a treatment of a tank mix of ethoprop and fenamiphos (each at 4.38 kg a.i./ha). Plots were arranged as in the 1988 tests, except for Caldwell County, which had only one cultivar (K 326) and 6-row plots. Treatments in 1989 were replicated eight times.

Soil samples were collected and cores composited for each plot at approximately 2- or 4-week intervals, post plant, in 1988 and 1989, respectively. Twelve to fourteen 2.5-cm soil cores were taken 20 cm deep near the base of the tobacco plants. Second-stage juveniles (J2) were extracted by elutriation and centrifugation (7,13). Egg numbers were determined after root elutriation and NaOCl extraction (6). Bioassays were conducted by placing a soil subsample (250 cm^3) from each plot and a tomato seedling (cv. Rutgers) in a 10-cm clay pot in the greenhouse. Root-gall indices (0–100%) and numbers of galls per plant were determined after 4 weeks. Gall indices and root necrosis indices from the field plots were evaluated for an average index based on 12 plants/plot after the final harvest. Tobacco leaves were cured and then weighed and graded by U.S. government graders.

All data were subjected to analysis of variance. Preliminary analysis indicated that sites differed significantly; thus, further analyses were conducted separately on a site basis. Egg and J2 numbers were transformed by $\log_{10}(x + 1)$ before statistical analysis (nontransformed data are used in figures). Tobacco yield, value, necrosis and gall indices, and nematode numbers were subject to analysis as a randomized complete block design with cultivars as observations, because cultivar differences were not significant ($P \leq 0.05$). The Waller-Duncan k-ratio t-test (k-ratio = 100) was used to separate treatment means. Nematode data were also analyzed using the repeated measures analysis of the SAS GLM procedure (23), with replication × treatment as an error term. The Wilks lambda statistic was used to evaluate the significant time × treatment interaction with time × replication × treatment as an error term. Orthogonal contrasts were used to compare treatments at each sampling date within a location, using replication × treatment as an error term.

Results

Tobacco response to nematicide treatment: Fenamiphos- and (or) aldicarb-treated plots had the greatest yields and dollar values in all tests except Caldwell County (Tables 1,2), where no significant differences occurred. Prices ($/kg) were usually high-

TABLE 1. Yield and value of flue-cured tobacco and root-knot gall and necrosis indices in 1988 at Sampson and Columbus county sites.

Treatment and method of application	Rate kg a.i./ha	Yield (kg/ha)	Value ($/ha)	Gall index at harvest (0–100)	Necrosis index at harvest (0–100)
		SAMPSON			
Control	—	1,567 c	4,992 c	71 a	44 a
Ethoprop 6E broadcast	8.75	1,879 b	6,180 b	51 b	25 b
Fenamiphos 3E broadcast	6.72	1,943 b	6,407 b	39 c	15 c
Aldicarb 15G band	3.36	2,133 a	7,084 a	54 b	15 c
		COLUMBUS			
Control	—	2,240 b	7,642 b	72 a	29 a
Ethoprop 6E broadcast	8.75	2,187 b	7,393 b	75 a	29 a
Fenamiphos 3E broadcast	6.72	2,662 a	9,218 a	25 c	7 b
Aldicarb 15G band	3.36	2,639 a	9,008 a	34 b	9 b

All values are means of 10 replications with two observations per plot for resistant and susceptible cultivars. Cultivar × treatment interaction was not significant.

Means followed by the same letter are not significantly different (k-ratio = 100) Waller-Duncan *k*-ratio *t*-test.

est for fenamiphos-treated plots, whereas yield and value were highest for the fenamiphos- and aldicarb-treated plots. Although tobacco gall indices varied among tests, fenamiphos was most effective in restricting gall development, except for Sampson County in 1989. Root necrosis indices followed the same trends as gall

TABLE 2. Effects of nematicides and method of application on yield and value of tobacco and gall and necrosis indices at three locations in 1989.

Treatment and method of application	Rate kg a.i./ha	Yield (kg/ha)	Value ($/ha)	Gall index (0–100)	Necrosis index (0–100)
		LENOIR[a]			
Control	—	1,482 b	5,370 b	68 ab	82 b
Ethoprop 6E broadcast	8.75	1,507 b	5,436 b	69 b	72 b
Ethoprop 6E band	8.75	1,591 b	5,696 b	86 a	84 a
Fenamiphos 3E broadcast	6.72	1,973 a	7,220 a	32 d	42 d
Fenamiphos 3E + Ethoprop 6E broadcast	3.36 + 4.27	2,038 a	7,506 a	47 cd	48 c
Aldicarb 15G band	3.36	2,159 a	7,906 a	48 c	53 c
		SAMPSON[b]			
Control	—	—	—	33 a	18 a
Ethoprop 6E broadcast	8.75	—	—	28 ab	13 ab
Ethoprop 6E band	8.75	—	—	27 ab	11 bc
Fenamiphos 3E broadcast	6.72	—	—	24 bc	11 bc
Fenamiphos 3E + Ethoprop 6E broadcast	3.36 + 4.27	—	—	16 c	8 cd
Aldicarb 15G band	3.36	—	—	17 c	6 d
		CALDWELL			
Control	—	1,827 a	6,812 a	83 a	65 a
Ethoprop 6E broadcast	8.75	2,130 a	7,981 a	48 c	33 c
Ethoprop 6E band	8.75	2,221 a	8,282 a	71 ab	62 a
Fenamiphos 3E broadcast	6.72	2,430 a	9,067 a	43 c	27 c
Fenamiphos 3E + Ethoprop 6E broadcast	3.36 + 4.27	2,034 a	7,585 a	55 bc	38 b
Aldicarb 15G band	3.36	1,939 a	7,203 a	68 ab	52 ab

Means followed by the same letter are not significantly different (k-ratio = 100) Waller-Duncan *k*-ratio *t*-test. Means are based on six replications in Caldwell and eight replications in Lenoir and Sampson.

[a] Plots in Lenoir and Sampson counties were split with resistant and susceptible cultivars. Cultivars were combined with two observations per plot since the cultivar × treatment interaction was NS.

[b] Yield data were not collected at Sampson County in 1989.

indices. Differences between the resistant and susceptible cultivars were significant ($P \leq 0.001$) only in Columbus County, where the resistant cv. K 326 increased value by more than $1,000/ha and yield by 281 kg/ha compared with the susceptible Coker 371-Gold (Table 3). Root-gall and necrosis indices were usually greater for the susceptible cultivar, though not always significantly so ($P \leq 0.05$).

Effects of nematicide on nematode population dynamics: The population densities of *M. javanica* and *M. incognita* increased throughout the growing season at the Sampson County site in 1988 for all treatments (Fig. 1A). Orthogonal contrasts of eggs and juveniles were significant at Julian date (JD) 172 for control vs. nematicides ($P \leq 0.01$) and each nematicide vs. control ($P \leq 0.01$); at JD 186 for control vs. nematicides ($P \leq 0.01$); at JD 200 for control vs. nematicides ($P \leq 0.01$), control vs. ethoprop ($P \leq 0.05$), and control vs. aldicarb and fenamiphos ($P \leq 0.01$); at JD 218 for fenamiphos vs. control, aldicarb, and ethoprop ($P \leq 0.05$).

Nematicide treatment resulted in lower nematode numbers up to the end of growing season. At harvest only fenamiphos had lower ($P \leq 0.01$) numbers of eggs +

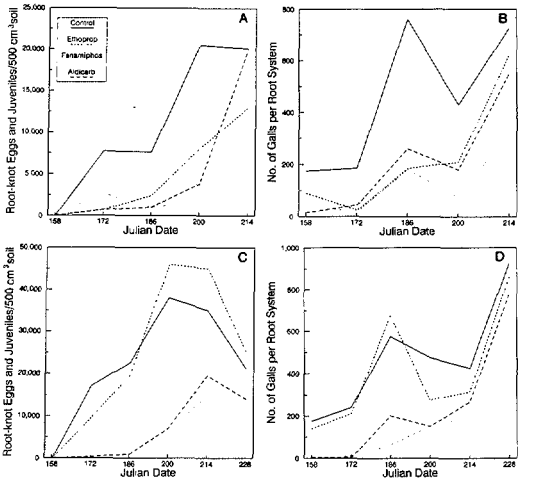

FIG. 1. Influence of nematicides ethoprop, fenamiphos, and aldicarb on *Meloidogyne* species on flue-cured tobacco at two sites in 1988. Data are means of 10 replicates with two observations per plot (cv. K 326 and Coker 371-Gold). A) Numbers of eggs and juveniles of *M. javanica* and *M. incognita* in Sampson County, North Carolina. Transplanted at Julian date (JD) 120 and harvested between JD 208–222. B) Numbers of root galls on tomato bioassays for Sampson County, North Carolina. C) Numbers of eggs and juveniles of *M. javanica*, *M. arenaria*, and *M. incognita* in Columbus County, North Carolina. Transplanted at JD 116 and harvested between JD 206–254. D) Numbers of root galls on tomato bioassays for Columbus County, North Carolina.

TABLE 3. Cultivar influence on yield, value, and gall and necrosis indices.

Location cultivar	Yield (kg/ha)	Value ($/ha)	Gall index (0–100)	Necrosis index (0–100)
		1988		
		SAMPSON COUNTY		
R K326	1,854	6,066	46**	23
S Coker 371-G	1,909	6,264	61	27
		COLUMBUS COUNTY		
R K326	2,572	8,823**	51	20
S Coker 371-G	2,293	7,810	52	17
		1989		
		SAMPSON COUNTY		
R K326	—	—	20**	10
S K394	—	—	29	12
		LENOIR COUNTY		
R K326	1,847	6,694	62	63**
S K394	1,937	6,353	64	53
		CALDWELL COUNTY		
R K326	2,097	7,822	62	47

Data are means of 40 observations in 1988 and 48 observations in 1989, except Caldwell County, which is a mean of 36 observations.

** Denote significant ($P \leq 0.001$) difference in cultivars. All other differences are NS ($P \leq 0.05$).

J2 than the control. Bioassays tended to verify these data (Fig. 1B), but there was reduction in the number of galls on tomato roots from bioassays from samples taken at JD 200. Orthogonal contrasts of root galls in the tomato bioassays were significant at JD 158 for control vs. nematicide ($P \leq 0.01$), aldicarb vs. fenamiphos ($P \leq 0.01$), and aldicarb vs. ethoprop ($P \leq 0.01$); at JD 172 and 186 for control vs. aldicarb vs. ethoprop and fenamiphos ($P \leq 0.10$); at JD 200 for nematicide vs. control ($P \leq 0.05$), and control vs. ethoprop and aldicarb vs. fenamiphos ($P \leq 0.01$); at JD 218 for nematicides vs. control ($P \leq 0.01$) and fenamiphos vs. aldicarb and ethoprop ($P \leq 0.01$). Plants in aldicarb-treated soil had lower ($P \leq 0.01$) numbers of galls at the first sampling than those for either the control, ethoprop, or fenamiphos. Aldicarb had less residual activity (persistence) than either ethoprop or fenamiphos for JD 172 and 186, as indicated by the high gall readings for this treatment. Fenamiphos treatments also resulted in lower ($P \geq 0.01$) numbers of galls in tomato bioassays than ethoprop or aldicarb treatments at JD 200 and 214.

Population densities of *Meloidogyne* at the Columbus County site in 1988 decreased after reaching maximum levels at JD 200 for the control and ethoprop treatments and after JD 214 for aldicarb and fenamiphos treatments (Fig. 1C). The rate of change (slope) of numbers of eggs and juveniles of *M. javanica, M. arenaria,* and *M. incognita* were different ($P \leq 0.01$) at time intervals JD 158–172 and JD 186–200 but not at other dates. Orthogonal contrasts at JD 174–214 showed populations treated with aldicarb or fenamiphos increasing at a lower rate vs. ethoprop and control ($P \leq 0.01$). Aldicarb and fenamiphos-treated plots had lower ($P \leq 0.01$) population densities of eggs + J2 than control or ethoprop treatments at every sampling from JD 172–214. Similarly, the numbers of galls on tomato bioassays were lowest ($P \leq 0.01$) in aldicarb- or fenamiphos-treated soil through JD 200 (Fig. 1D). The rates of change of numbers of root galls on tomato bioassays were different at intervals JD 158–172 ($P \leq 0.0547$), JD 186–200 ($P \leq 0.0003$), and JD 200–214 ($P \leq 0.0931$). According to orthogonal contrasts at JD 158–200, the population levels were lower when treated with aldicarb or fenamiphos vs. ethoprop or nothing ($P \leq 0.01$); at JD 214, populations were lower when treated with nematicides vs. no treatment ($P \leq 0.05$); at JD 227, fenamiphos-treated populations were lower than the nontreated population ($P \leq 0.05$). All nematicide treatments resulted in lower gall numbers in follow-up bioassays at JD 214, but only fenamiphos was significantly lower than the control at the end of the season (JD 228).

Numbers of *M. javanica* and *M. incognita* increased for the Sampson County location until the final sample date in 1989 (Fig. 2A). The Wilks lambda statistic for eggs and juveniles for time × treatment interaction using time × rep × treatment

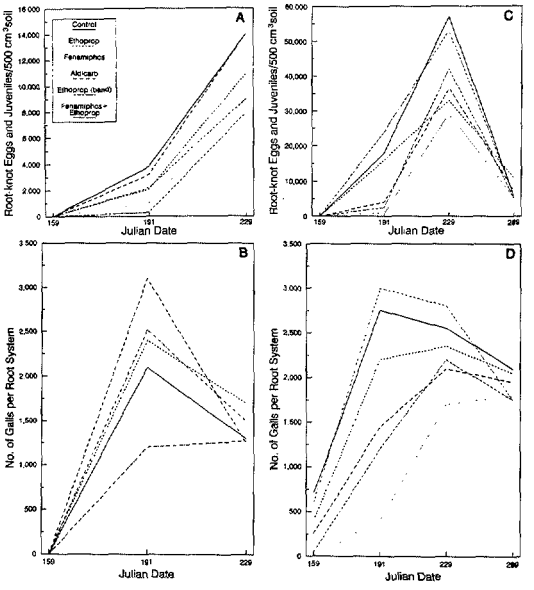

FIG. 2. Effects of five nematicide treatments on *Meloidogyne* species at two sites in 1989. A) Numbers of eggs and juveniles for Sampson County, North Carolina. Transplanted at Julian date (JD) 129. B) Numbers of root galls in tomato bioassays for Sampson County, North Carolina. C) Numbers of eggs and juveniles of *M. incognita* race 4 and *M. javanica* in Lenoir County, North Carolina. Transplanted at JD 129 and harvested between JD 205–241. D) Numbers of root galls in tomato bioassay for Lenoir County, North Carolina.

error was marginally significant ($P \leq 0.0935$). The population slopes were significantly different at time intervals JD 159–191 ($P \leq 0.0534$) and 191–227 ($P \leq 0.0307$). Significant orthogonal contrasts were at JD 191 for nematicides vs. control ($P \leq 0.01$) and fenamiphos vs. fenamiphos + ethoprop ($P \leq 0.01$). Nematode population densities were lower for all nematicide treatments than for the control at the first sampling, and the fenamiphos + ethoprop treatment was superior to fenamiphos alone. Nematode reproduction as measured by eggs and J2 was greater ($P \leq 0.01$) in the control and the aldicarb-treated plots than for the other nematicide treatments. This difference was reflected by the significantly different slopes according to the Wilks lambda statistics for the treatment × time interaction (Table 4). Gall numbers in bioassays for the fenamiphos + ethoprop-treated soil sampled at midseason were lower ($P \leq 0.05$) than the untreated control (Fig. 2B), but other nematicide treatments were not generally different from the control ($P \leq 0.10$).

Two species of root-knot nematodes, *M. javanica* and *M. incognita* race 4, were present at the Lenoir County site in 1989. Egg + J2 densities of these two species peaked at JD 227 and declined to low levels by the end of the experiment, JD 288 (Fig. 2C). Wilks lambda statistics for time × treatment interaction was significant ($P \leq 0.01$). Slopes were significantly different over JD 159–229 ($P \leq 0.0001$) but not over the last sample interval. The soil treatments with fenamiphos, fenamiphos + ethoprop, and aldicarb had lower (orthogonal contrasts, $P \leq 0.05$) numbers of *Meloidogyne* spp. eggs + J2 than the ethoprop band, ethoprop broadcast, or the control at JD 191 but not at other dates (Fig. 2C). Similar results were obtained with the bioassays, but the separation between treatments was more apparent in this case (Fig. 2D). The Wilks lambda statistic was again significant ($P \leq 0.0005$). Slopes were significantly different at JD 191–227 ($P \leq 0.0001$) but not at other intervals. Orthogonal contrasts were significant at JD 157 for ethoprop band, ethoprop broadcast, and control vs. ethoprop + fenamiphos, fenamiphos alone, and aldicarb ($P \leq 0.01$), and for aldicarb vs. fenamiphos ($P \leq 0.01$); at JD 191 for fenamiphos and fenamiphos + ethoprop vs. others ($P \leq 0.01$); and at JD 227 for fenamiphos vs. all others ($P \leq 0.01$). Fenamiphos alone was clearly superior to other treatments, with aldicarb and fenamiphos + ethoprop being intermediate, and ethoprop alone being least effective.

Population densities of *M. arenaria* increased to high levels in all treatments by midseason and then declined at season's end in 1989 at Caldwell County (Fig. 3A,B). Time × treatment interactions were not significant. All nematicide treatments had lower (orthogonal contrasts, $P \leq 0.01$) nematode numbers than the untreated control at JD 200 but not at any other sampling. Orthogonal contrasts for numbers of tomato root galls were not significant except at JD 200 for fenamiphos vs. control ($P \leq 0.01$) (Fig. 3B).

Although residual nematicide activity varied with site and season, fenamiphos control of *Meloidogyne* species was the most persistent, often lasting up to 10 weeks (Figs. 1,2). This compound reduced nematode populations well below those in untreated plots throughout the study. Aldicarb initially suppressed nematode numbers to levels equal to those exposed to fenamiphos (Figs. 1A–C; 2C,D; 3A,B) except in Sampson Co. (Fig. 2A), but later gave only intermediate control (Figs. 1A,B; 2C,D). At other sites, residual aldicarb efficacy was similar to fenamiphos (Figs. 1C,D; 3). These two compounds effectively controlled *M. arenaria* and *M. javanica* on both susceptible and resistant cultivars. The suppression of root-knot population densities by ethoprop was usually short-lived (Figs. 1B–D; 2A). Nematode and gall numbers were greater in bioassays from some sites where ethoprop was applied than in the nematicide controls (Figs. 1D; 2B). The main effects (treat-

TABLE 4. Wilks Lambda statistic for time × treatment interactions and F-test for slopes at selected sampling intervals for five locations and 2 years for the numbers of root-knot nematode galls per tomato plant in bioassays and numbers of *Meloidogyne* spp. eggs and juveniles per 500 cm^3 soil for tobacco plots.

			F-test significant at > at five sample intervals									
	Wilks lambda		Interval 1		Interval 2		Interval 3		Interval 4		Interval 5	
County	Gall[a]	Nematode[a]	Gall	Nematode	Gall	Nematode	Gall	Nematode	Gall	Nematode	Gall	Nematode
						1988						
Columbus	0.0001	0.0002	0.0547	0.0001	0.1649	0.2099	0.0003	0.2061	0.0931	0.0008	0.8763	0.1531
Sampson	0.0479	0.0011	0.0035	0.0002	0.6616	0.0993	0.3167	0.8640	0.6226	0.1076	—	—
						1989						
Lenoir	0.0005	0.0057	0.8732	0.0001	0.0001	0.7734	0.4416	0.4687	—	—	—	—
Sampson	0.1465	0.0935	0.1923	0.0534	0.0718	0.0307	—	—	—	—	—	—
Caldwell	0.3035	0.6685	0.3824	0.9208	0.1833	0.7092	0.1827	0.0226	0.4634	0.9030		

[a] For number of root galls per bioassay plant and nematode numbers, respectively.

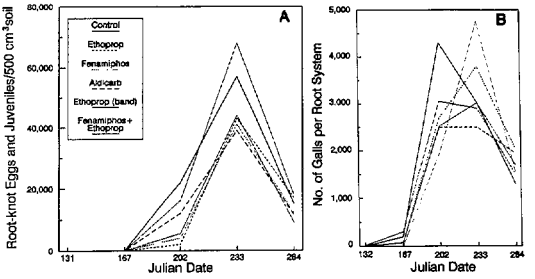

FIG. 3. Influence of selected nematicide treatments on *Meloidogyne arenaria* in Caldwell County, North Carolina in 1989. Transplanted at Julian date (JD) 139 and harvested between JD 206–254. A) Numbers of eggs and juveniles. B) Numbers of root galls in tomato bioassays.

ment and sample time) and the interactions of treatment and sample time were significant ($P \leq 0.05$) for most experiments.

DISCUSSION

Similar trends in plant response and nematode populations due to nematicide application were evident in most tests during both years. Considerable variation in *Meloidogyne* spp. composition, nematode population densities, and host plant response occurred among sites and between years. Other sources of variation may be due to environmental conditions, soil type, and other microflora (1,3). Data from the tomato bioassays were similar to the nematode assays in 1988 in that nematicides limited gall numbers at JD 200 but not at other dates.

This study confirms previous reports (5, 10,15,21) that fenamiphos reduces root-gall development and increases yield as compared to untreated controls and other nematicides. This material is usually equal or superior to other nonfumigants tested for nematode control and is used on 63% of the North Carolina tobacco acreage treated with a nonfumigant nematicide. The data herein also support the finding of Barker et al. (3) that mid-season egg + J2 estimates and tobacco root-gall indices are accurate measures of nematicide efficacy. Aldicarb was also effective in reducing *Meloidogyne* population densities early in our study, but even more effective in increasing yield as previously reported (2, 5,16). Although aldicarb was less effective on *M. arenaria* than on *M. incognita* or *M. javanica* in one study (12), no consistent control differences were observed in these tests. Ethoprop was not generally as effective as aldicarb or fenamiphos at the rates evaluated. The fact that ethoprop increased yield significantly at only one site (Caldwell County, *M. arenaria*) supports other research showing ethoprop to be less efficacious than most nematicides for *Meloidogyne* species other than *M. incognita* (10,16,22). Brodie and Good (5) found ethoprop effective in restricting root galls of *M. incognita*. Ethoprop at higher rates was somewhat effective against *M. incognita* (13.4 kg/ha) (9) and *M. javanica* (22) (27 kg/ha) in other research.

Root-knot nematode populations peaked and then declined before the last sampling at most locations. This decline, which was most prominent where population densities were highest (Figs. 1C; 2C; 3B), may have been due to a decline in food supply or quality. Tobacco began to ripen (lower leaves yellow) in July, and growers harvested two to four times during the following JD: Sampson 1988, 208–222; Columbus, 200–228; Lenoir, 205–241; Caldwell, 206–254. Roots begin to senesce during this process, and their quality as a food supply for *Meloidogyne* is probably reduced gradually. The rapid decline in nematode numbers after midseason at locations with high nematode densities may also be in response to damage incurred by the tobacco as a result of the pathogenic activity of these organisms. Another reason for decline may be variability among sampling dates, time intervals between sample dates, and years measured. The decline was especially steep at the sites in Caldwell and Lenoir counties in 1989, where harvests were most prolonged because of heavy July precipitation of 25 and 22 cm, respectively. *Meloidogyne* populations also reached the highest levels in these two tests. The population dynamics in these two tests are similar (Figs. 2C; 3A).

Eggs + J2 population densities showed a general upward trend, usually with a peak before the end of the season. Population levels in Lenoir (*M. incognita* and *M. javanica*) and Caldwell (*M. arenaria*) counties increased soon after transplanting and generally decreased more dramatically following their peak than in a previous experiment with only *M. javanica* (22). However, the Sampson County population (*M. javanica* and *M. incognita*) did not increase or decrease as dramatically either year. These differences are probably due to many environmental and edaphic factors, but the apparent higher juvenile and egg populations at the Caldwell and Lenoir sites may have caused populations to reach their carrying capacity sooner, thus accounting for most of these differences. Changes in species ratios within the *Meloidogyne* populations were not monitored and may also account for differences.

Lack of differences in cultivar response for gall indices is not surprising because none of these populations were characterized as *M. incognita* race 1 or 3. We have observed increased *Meloidogyne* problems with *M. incognita*-resistant tobacco cultivars. This trend may be the result of an increase in the frequency of occurrence of other *Meloidogyne* species as a result of selective pressure caused by the deployment of *M. incognita* resistant cultivars. Some differences in yield response was expected between cultivars because of tolerance or because the resistant K 326 cultivar has a higher yield potential than the susceptible cultivar tested.

The high initial reduction of populations by fenamiphos and aldicarb, as compared to ethoprop, may be partially explained by their activity on nematode acetylcholinesterase (AcCh). Sulfur-containing organophosphates (including ethoprop) are generally poor inhibitors of AcCh (17). Fenamiphos, however, is an exception to this rule and is superior to carbamates as an inhibitor of AcCh. Another study (18) showed that *Caenorhabditis elegans* regained nearly full activity after being washed following a 24-hour exposure to aldicarb. Fenamiphos-treated *C. elegans* regained only 10% activity after the same exposure and washing, which may account for the slightly longer fenamiphos activity in these studies.

Differential sensitivity of *Meloidogyne* species to the nematicides employed may account for some of the observed variation. *Meloidogyne incognita* is more sensitive to these materials than are *M. arenaria* and *M. javanica* (8). Other research conducted in North Carolina showed higher activity of fenamiphos than aldicarb in inhibiting nematode penetration of soybean under high moisture conditions (11).

We conclude from these data that, of the nematicides tested, fenamiphos has the greatest residual control of the mixed species populations of *Meloidogyne* in North Carolina. Furthermore, aldicarb is as efficacious as fenamiphos early in the season, and aldicarb-treated plants yield as well as fenamiphos-treated ones despite aldicarb's lower residual activity.

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