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Analysis of 1,3-Dichloropropene for Control of *Meloidogyne* spp. in a Tobacco Pest Management System[1]

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Abstract: 1,3-Dichloropropene (1,3-D) and nonfumigant nematicides were evaluated for control of *Meloidogyne* spp. and soil and foliar insects in a tobacco pest management system. In a field with a high *Meloidogyne* spp. population density (root gall index 4.0 to 4.5 on a 0 to 10 scale in untreated controls), tobacco yields and crop values increased (482 kg/ha and $1,784/ha for 1, 3-D; 326 kg/ha and $1,206/ha for fenamiphos; 252 kg/ha and $933/ha for ethoprop) with nematicide application over an untreated control. In fields with a low population density of *Meloidogyne arenaria* or *M. incognita* (root gall index 2.3 to 2.5 in untreated controls), yields ranged from 1,714 to 2,027 kg/ha and were not altered by fumigant or nonfumigant nematicide application. Carbofuran, a soil-applied nonfumigant nematicide/insecticide, reduced the number of foliar insecticide applications required to keep insect populations below treatment threshold (3.8 vs. 4.5, respectively, for treated vs. untreated). Carbofuran reduced the cost ($23/ha) of foliar insecticide treatments when compared to an untreated control. Although nonfumigant nematicides provided some soil and foliar insect control, the cost of using a fumigant plus a lower insecticidal rate of a soil insecticide/nematicide was comparable to the least expensive non-fumigant nematicide when the cost of foliar insecticide applications was included in the cost estimates. Savings in foliar insecticide cost by use of soil-applied nonfumigant nematicide/insecticides were small ($23/ha) in comparison to potential value reductions by root-knot nematodes when the nonfumigant nematicides fenamiphos or ethoprop ($578/ha and $851/ha, respectively) were used instead of 1,3-D.

Key words: 1,3-dichloropropene, *Meloidogyne arenaria, M. incognita, M. javanica,* nematicide, nematode management systems, *Nicotiana tabacum,* root-knot nematode, tobacco.

Root-knot nematodes (*Meloidogyne* spp.) are economically significant pathogens of many field crops in temperate regions of the world (Johnson, 1982; Sasser and Carter, 1982). Tobacco producers in the southeastern United States integrate nematicide applications into crop management systems where pest complexes include nematodes, bacteria, fungi, and soil insects. The efficacy of fumigant and nonfumigant nematicides for the control of *Meloidogyne* spp. on high-value crops such as tobacco is well documented (Brodie and Good, 1973; Fortnum et al., 1990; Johnson, 1989; Nordmeyer et al., 1982; Rich et al., 1984). Fumigant nematicides provide superior root-knot nematode control in comparison with nonfumigant nematicides, but nonfumigant nematicides remain popular with some producers. The primary reason for their popularity is their potential to control some insect species (Manley, 1995) as well as nematodes. Wireworms *Conoderus falli* Lane, *C. amplicollis* (Gyllenhal), and *C. vespertinus,* (F.); cutworms *Agrotis ipsilon* (Hafnagel), *Feltia subterranea* (F.), and *Peridroma saucia* (Hubner); flea Beetles *Epitrix hirtipennis* (Melsheimer); aphids *Myzus nicotianae* Blackman; budworms *Heliothis virescens* (F.); and hornworms *Manduca sexta* (L.) are endemic in tobacco fields in the southeastern United States. Farm management decisions are typically based on a systems approach, where agricultural pesticides may be targeted at several pests. In calculating the economic benefits of a pesticide, the complexity of the pest populations, alternative control options, and the multiple pest targets of a particular pesticide should be considered.

The use of 1,3-dichloropropene (1,3-D) as a standard in-row treatment presents several management problems for producers. In-row fumigation requires fumigant application a minimum of 21 days prior to transplanting. Soil insecticides, applied immediately prior to planting, are difficult to incorporate on a formed fumigated bed and may reduce insecticide efficacy. In addition, wet weather may restrict fumigant application and timely transplanting. However, in spite of the spectrum of pests controlled by nonfumigant nematicides and the difficulty in fumigant application, the use of fumigant nematicides is common in South Carolina. This is possibly due to the increasing frequency of difficult-to-control root-knot nematode species such as *M. arenaria* or *M. javanica* and the lack of labeling of some pesticides for control of these species (Fortnum, 1995).

The fumigant nematicide 1,3-D provides better control of *Meloidogyne* spp. and greater yield and value than nonfumigant nematicides (Fortnum et al., 1990; Rich and Zimet, 1996). However, unlike systemic nonfumigant nematicides, 1,3-D provides little or no insect control. In production systems where crop rotation is effective in reducing initial *Meloidogyne* spp. population densities (Pi), nonfumigant nematicides may provide effective control of both insects and nematodes.

There is currently no information available to allow cost-benefit analysis of using 1,3-D vs. nonfumigant nematicides in tobacco where both insect and nematode management is required. The objective of this study was to assess the benefits of 1,3-D and various nonfumigant nematicides for the control of *Meloidogyne* species in several integrated pest control systems.

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Materials and Methods

Crop rotation and nematicide applications in fields containing a high Pi of Meloidogyne spp.: The trial was located at the Pee Dee Research and Education Center, Florence County, South Carolina, on a Norfolk sandy loam soil (75% sand, 17% silt, 8% clay, 0.08% organic matter; pH 5.9). The site had been infested with a mixture of *M. incognita* race 3, *M. arenaria* race 2, and *M. javanica* (Fortnum et al., 1987). The test site was tilled with a moldboard plow and disc-harrowed twice in a perpendicular direction.

Selected rotation crops were planted into the infested plots and alternated with tobacco in a 2-year rotation. Treatments were arranged in a factorial design with previous rotation crop as main plots and nematicide treatments applied to tobacco as subplots. The rotation crops were selected to reduce nematode population densities so that nonfumigant nematicides could be used with an expectation of moderate to excellent tobacco yields. Rotation crops were classified as susceptible, moderately resistant, or resistant based on the levels of nematode reproduction they supported. Corn was susceptible to *M. incognita* with moderate resistance to *M. arenaria* and *M. javanica* (Windham and Williams, 1987); cotton was a nonhost to *M. arenaria* and *M. javanica* and was susceptible to *M. incognita* (Taylor and Sasser, 1978); and sorghum was resistant to *M. incognita, M. javanica,* and *M. arenaria* (Fortnum and Currin, 1988). A winter rye cover crop followed by a weed-free fallow served as a control (Johnson and Motsinger, 1989). The selected crops and planting dates were corn (*Zea mays* L. 'Pioneer 3320'), 28 April 1988 and 14 May 1990; sorghum (*Sorghum bicolor* (L.) Moench 'Coker 7723') and cotton (*Gossypium hirsutum* L. Deltapine 90, 18 May 1988 and 14 May 1990; rye (*Secale cereale* L. 'Abruzzi') -summer fallow, 10 November 1987 and 15 December 1989, respectively. Seeding rates for corn, cotton, and sorghum were 6, 13, and 20 seeds/m row, respectively. Rye seeds were broadcast (100 kg/ha). Rye plots were mowed at maturity and disc-harrowed as needed to suppress weeds. Each rotation crop was planted into main plots consisting of four subplots to which nematicides treatments were applied immediately preceding the tobacco crop. Corn, cotton, and sorghum subplots consisted of 4 rows (spaced 1 m wide × 10.6 m long) centered within each 4.8-m-wide subplot. All crops were nonirrigated and maintained by standard agronomic practices.

Tobacco seedlings, cultivar Coker 319 (*M. incognita*-susceptible), were transplanted on 5 May 1989 and 16 May 1991 into plots previously planted to the rotation crops in 1988 and 1990. Subplots consisted of four rows (were spaced 1.2 m apart × 10.6 m long) with plants spaced 60 cm apart within the row. Subplots were treated with nonfumigant nematicides, 1,3-D, or left untreated. All previous crop and nematicide treatments were replicated four times. The fumigant nematicide was applied on 29 March 1989 and 16 April 1991. A positive pressure pump was used to inject 6.7 ml 1,3-D/m row (56 liters/ha) 15 cm deep with a single chisel placed in the center of a 60-cm-wide bed. Bedding discs were used to seal the chisel opening and form a 36-cm-high bed with fumigant placement 40 cm from the top of the bed. The nonfumigant nematicides fenamiphos (6.7 kg a.i./ha) and ethoprop (13.4 kg a.i./ha) were applied on 3 May 1989 and 24 April 1991 as broadcast soil sprays in 280 liters water/ha and incorporated with a disc harrow. Nonfumigant nematicides were applied to plots rotated with corn, cotton, sorghum, or rye-fallow. Mature tobacco leaves were harvested three times from the center two rows in each plot. Yield was based on fresh leaf weight, assuming that cured leaf weight was 20% of fresh weight. After the last harvest, 10 plants from the center two rows in each plot were excavated at random and rated for root galling on a 0-to-10 scale, where 0 = no galls, 1 = 1–10%, 2 = 11–20%, 3 = 21–30%, 4 = 31–40%, 5 = 41–50%, 6 = 51–60%, 7 = 61–70%, 8 = 71–80%, 9 = 81–90%, and 10 = 91–100% of the root tissue galled (Barker et al., 1986).

Pest management programs in fields containing low Pi of Meloidogyne spp.: Two test sites were selected at the Pee Dee Research and Education Center, Florence, South Carolina. Site 1 was infested with a low Pi of *M. arenaria* race 2, and site 2, was infested with a low Pi of *M. incognita* race 3. Initial nematode populations (Pi) in soil (spring sample) were below detectable levels. Both test sites had previously been inoculated with *Meloidogyne* spp. and had a history of damage by *Conoderus* spp. on tobacco (Fortnum et al., 1987). Site 1 was a Norfolk sandy loam (75% sand, 17% silt, 8% clay, 0.8% organic matter; pH 5.9), and site 2 was Goldsboro sandy loam (78% sand, 18% silt, 4% clay, 0.8% organic matter; pH 5.9). Both were planted with an *M. incognita* susceptible tobacco cultivar the previous year, and the roots were lightly galled (root gall indices <3 on a 0-to-10 scale) (Barker et al., 1986). The fields were selected to evaluate the efficacy of nonfumigant vs. fumigant nematicides to control foliar insects. Insect feeding preferences vary between fumigated and nonfumigated tobacco due to color changes (severely stunted plants with chlorotic leaves) in root-knot nematode-damaged tobacco, altering the attractiveness of leaves to foliar insects (Johnson, pers. comm.). Insect date were collected only in fields with a low Pi of *Meloidogyne* spp. (Fortnum, 1995).

Test sites were prepared with a moldboard plow. Soil was leveled with a field cultivator on 20 April 1993 and 13 May 1994 for site 1 and on 28 April 1993 and 13 May 1994 for site 2. 1,3-Dichloropropene (94%) was applied at 56 liters a.i./ha (6.7 ml/m) with a positive pressure pump and injected 15 cm deep with a single chisel placed in the center of a 60-cm-side bed. Bedding discs were used to seal the chisel opening and form a 36-cm-high bed so that fumigant placement was 40 cm from the top of the bed. Fumigant was applied on 4 May 1993 and 13 May 1994 at sites 1 and 2, respectively. Fenamiphos (6.7 kg a.i./ha), ethoprop (13.4 kg a.i./ha), carbofuran (6.7 kg a.i./ha), and chlorpyrifos (2.24 or 5.6 kg a.i./ha) were applied on 25 May 1993 and 24 May 1993 for sites 1 and 2, respectively, and on 31 May 1994 at both sites. Treatments were applied as broadcast soil sprays in 280 liters water/ha. Aldicarb (3.4 kg a.i./ha) was applied on the same days in a 45-cm band with a Gandy applicator (Gandy, Model M904, Qwatonna, MN). Soil insecticides for wireworm control were applied at the same time as nonfumigant nematicides. Soil insecticide/nematicide, fumigant nematicides, and foliar insecticide treatments are listed in Table 1, as are insect pests controlled by nonfumigant insecticide/nematicides.

Plots were disk-harrowed immediately after application to a depth of 15 cm, and bedding disks were used to form a 60-cm-wide and 36-cm-high bed. Untreated control plots were disk-harrowed, bedded, and maintained in a similar fashion. The tobacco was fertilized with 756 kg/ha 6-6-18 (N, P, K analysis) fertilizer, with an additional 224 kg/ha 16-0-0 nitrogen fertilizer applied. Standard agronomic practices, such as the use of sucker control materials, were used (Gooden et al., 1993). Plots at both sites consisted of four rows (1.2-m spacing), 12.2 m long, bordered by untreated, unplanted rows. Treatments were arranged in a randomized complete block design, replicated five times, and the tests were repeated. The tobacco cultivar K 326 was planted at site 1 on 27 May 1993 and 6 June 1994, and the cultivar Coker 371 was planted on site 2 on 3 June 1993 and 1 June 1994. K 326 is resistant to *M. incognita* races 1 and 3 and susceptible to *M. arenaria,* whereas Coker 371 is susceptible to all races of *M. incognita* and *M. arenaria.*

Populations of wireworm (*Conoderus* spp.) were determined by destructive sampling from the center row 3 weeks after transplanting. Ten plants were selected at random and excavated, and root-tissue was rated for wireworm damage. Damage was recorded as the number of plants exhibiting signs of insect feeding. Severity of insect feeding was rated on a 0-to-7 linear scale where: 0 = no damage and 7 = very heavy damage. Foliar insects were scouted on a 7-day schedule from 3 weeks following transplanting to harvest. Field plots were scouted (10 plants/plot) for flea beetles, aphids, budworms, and hornworms. Foliar insect sprays were applied according to published threshold levels (Gooden et al., 1993). Foliar insecticides are listed in Table 1. Records of insecticide applications were made to estimate crop production costs for the respective production systems.

A soil composite of 20 cores (each 2-cm diam. × 20 cm deep) was removed from the root rhizosphere of the plot row (left center row) immediately following the last harvest. A 500-cm^3 soil aliquot was processed by semiautomatic elutriation and centrifugal-flotation (Byrd et al., 1976; Jenkins, 1964) at the Clemson University Agricultural Services Laboratory to assess population densities of *Meloidogyne* spp. Values are represented as J2/100 cm^3 soil.

Leaves were harvested at maturity from one center row and cured. Yield calculations and crop value were based on cured leaf weights. Each leaf harvest was cured using standard procedures and leaf-graded by U.S. government graders. Total value was determined by calculating the value of each harvest (weight × average price/kg/grade) and combined over all harvests. At the last harvest, 10 plants from each plot row were excavated at random and rated for galling as described earlier (Barker et al., 1986). Data were analyzed using analysis of variance (ANOVA), and means were compared with planned contrasts (Steel and Torrie, 1960). All calculations were performed with the Statistical Analysis System-JMP (SAS Institute, Cary, NC).

Insecticide and nematicide cost estimates ($/liter or

TABLE 1. Seven pest management programs for control of *Meloidogyne* spp. and insect pest complexes on flue-cured tobacco.

Pest management program	Preplant nematicide treatments	Preplant soil insecticides[a]		Foliar insecticides applied when insect populations reach damage threshold[a]			
		Wireworms	Cutworms	Flea beetles	Aphids	Budworms	Hornworms
1	1,3-D	chlorpyrifos	chlorpyrifos	acephate	acephate	acephate	Bt
2	1,3-D	ethoprop	acephate	acephate	acephate	acephate	Bt
3	Ethoprop	*[b]	acephate	acephate	acephate	acephate	Bt
4	Fenamiphos	chlorpyrifos	chlorpyrifos	acephate	*	acephate	Bt
5	Fenamiphos + Carbofuran	*	chlorpyrifos	*	*	*	*
6	Aldicarb	chlorpyrifos	chlorpyrifos	*	*	acephate	Bt
7	Carbofuran	*	*	acephate	acephate	acephate	Bt

[a] Treatment thresholds: Flea beatles, treat when there is an average of 3 flea beetles per plant; aphids, treat when 10% of the plants have 50 or more live aphids on at least one leaf; budworm, 0 to 4 weeks post transplanting, treat when 4% of plants are infested; 4 weeks until flowering, treat when 10% of plants are infested; Hornworms, treat when 10 or more worms are found per 100 plants.

[b] * = no additional treatment should be required, Bt = *Bacillus thuringiensis.*

kg) were determined by surveying three local vendors in Florence, South Carolina. Average application cost estimates of soil insecticides/nematicides, fumigant nematicides, and the foliar insecticides were calculated based on a 20-ha production size.

Results

Crop rotation and nematicide applications in fields containing a high Pi of Meloidogyne spp.: Tobacco yields recorded following nonfumigant and fumigant nematicide applications (Table 2) (Fortnum et al., 2001) have been used to calculate the effects of nematicide application on crop values. Because ANOVA indicated a crop × nematicide interaction was not observed, values were averaged across rotation crops ($P = 0.05$). In rotated tobacco, yields were increased 482 kg/ha and value increased $1,784/ha following 1,3-D application when compared to an untreated control ($P \leqslant 0.001$). The nonfumigant nematicides ethoprop and fenamiphos increased tobacco yields (289 kg/ha) and value ($1,495/ha) over an untreated control (Fortnum et al., 2001). Yield and crop value did not differ ($P = 0.05$) for tobacco grown in ethoprop or fenamiphos-treated soil. 1,3-Dichloropropene increased tobacco yield (193 kg/ha) and value ($289/ha) over ethoprop or fenamiphos-treated tobacco ($P \leqslant 0.01$).

Pest management programs in fields containing low Pi of Meloidogyne spp.: Seven pest management programs for control of *Meloidogyne* spp. and insect complexes on flue-cured tobacco are listed in Table 1. Yield and value of tobacco were not altered by fumigant or nonfumigant nematicide application in all fields with low Pi (Table 3). Second-stage juvenile population did not differ among nematicide treatments, and gall indices were ≤3.2 for all insecticide/nematicide combinations (Table 3). Final-season J2 population densities were low (166-424 J2/100 cm^3 soil).

Insect populations were high across all trials, and as many as five foliar applications of acephate or Bt were required to control foliar insects. Because a significant treatment × test interaction was not observed on all variables examined ($P = 0.05$), data were averaged across test sites and years. Aldicarb and fenamiphos-treated soil required greater ($P \leqslant 0.05$) use of foliar Bt insecticide than the untreated control (Table 3). Carbofuran as a soil-applied nematicide/insecticide reduced the number of total foliar insecticide treatments (3.8 vs. 4.5, respectively, for treated vs. untreated) and cost ($23/ha) when compared to an untreated control. Although nonfumigant nematicides provided some insect control, the cost of using a fumigant in concert with an insecticidal rate of a soil insecticide/nematicide (366-457 $/ha) was comparable to the least expensive nonfumigant nematicide when the cost of foliar insecticide applications was included in the cost estimates (288-514 $/ha) (Table 3).

Wireworm populations and damage ratings varied by insecticide and nematicide treatment, and a site × treatment interaction was observed ($P \leqslant 0.05$) (Table 4). 1,3-Dichloropropene alone did not provide sufficient wireworm control (damage or number of insect scars) at either site 1 or 2 when compared to an untreated control ($P = 0.05$). Application of chlorpyrifos or ethoprop, at lower application rates along with 1,3-D, reduced wireworm damage (number of damaged plants) when compared to 1,3-D alone ($P = 0.001$) at both sites 1 and 2 in 1993. No wireworm damage was observed at site 1 in 1994, and application of chlorpyrifos or ethoprop did not reduce the number of wireworm-damaged plants at site 2 in 1994 (Table 4). Ethroprop and chlorpyrifos applied at higher (nematicidal) application rates reduced the number of wireworm-damaged plants

Table 2. Yield and value of Coker 319 tobacco as affected by application of ethoprop, fenamiphos, or 1,3-D in a field containing mixed populations of *Meloidogyne incognita, M. arenaria,* and *M. javanica.*

Treatment and broadcast rate (a.i./ha)	Row rate (a.i./m row)	Cost ($/liters)	liters/ha	Nematicide cost ($/ha)	Control estimates[a]	Yield (kg/ha)[b]	Increase over untreated control (kg/ha)	Crop value ($/ha)	Increase over untreated control ($/ha)	Net return ($/ha)
Untreated	—	—	—	—	—	2,321	—	8,587	—	—
Ethoprop, 9.0 kg	1.0 g	16.92	12.4	210	Fair	2,573	+252	9,520	933	723
Fenamiphos, 3.4 kg	0.4 g	16.20	9.3	151	Good	2,647	+326	9,793	1,206	1,055
1,3-D 56 liters	6.7 ml	2.84	56.0	159	Excellent	2,803	+482	10,371	1,784	1,625
Contrasts										
Untreated control vs. 1,3-D						***[c]		***		
Ethoprop + fenamiphos vs. 1,3-D						**		**		
Ethoprop vs. fenamiphos						ns		ns		

[a] Root-knot nematode control estimates based on South Carolina production guide. Coker 319 tobacco is susceptible to *Meloidogyne incognita, M. arenaria,* and *M. javanica.*

[b] Yield averages were collected following rotation with corn, cotton, sorghum, or a rye-summer fallow. Yield summary is the average of 32 plots (4 replications, 4 rotation crops, and 2 cycles through the rotation). A significant crop × nematicide interaction was not observed, and data were averaged over rotation crops ($P = 0.05$). Value based on an average price of $3.70/ha.

[c] ***$P = 0.001$; **$P = 0.01$; ns = non significant.

TABLE 3. List prices and total application costs of soil-applied fumigant and nonfumigant nematicide/insecticides, foliar-applied insecticides, and yield and value of tobacco grown in several pest management programs averaged over four field trials in Florence, South Carolina.

Soil-applied treatments	Cost ($/liter or kg)[a]	Broadcast rate (liters or kg/ha)	Row rate (a.i./m row)	Nematicides and soil insecticides cost ($/ha)	Number of foliar sprays			Foliar sprays ($/ha)	Total insecticide/ nematicide cost ($/ha)[b]	Additional cost/ha over untreated	Yield (kg/ha)	Value ($/ha)[c]	Root-gall index
					Acephate	Bt	Total						
Nematicide rating													
High													
1,3-D	2.84	56.0 liters	6.7 ml	215.06	3.8	0.8	4.6	150	366	0.14	1,879	6,299	2.3
+chlorpyrifos	11.92	4.7 liters	0.3 g										
1,3-D	2.84	56.0 liters	6.7 ml	318.09	3.4	1.0	4.4	139	457	−11.46	2,000	6,862	1.7
+ethoprop	16.92	9.4 liters	0.8 g										
Moderate													
Ethoprop	16.92	18.7 liters	1.61 g	316.40	3.7	0.8	4.5	148	464	−2.4	2,027	6,992	2.2
Fenamiphos	16.20	18.7 liters	0.8 g	358.96	3.8	1.0	4.8	157	514	6.09	2,001	6,627	1.8
Aldicarb*	7.05	22.4 kg	0.4 g	213.94	4.0	1.0	5.0	163	376	12.02	1,739	5,845	1.8
+ chlorpyrifos	11.92	4.7 liters	0.27 g										
Fenamiphos	16.20	9.4 liters	0.40 g	360.96	3.5	0.8	4.2	140	501	−10.69	1,900	6,442	1.7
+ carbofuran	16.24	9.4 liters	0.54 g										
+ chlorpyrifos	11.92	4.7 liters	0.27 g										
Low													
Carbofuran	16.24	14 liters	0.81 g	283.38	3.2	0.6	3.8	126	410	−23.52	1,998	6,766	3.2
+ chlorpyrifos	11.92	4.7 liters	0.27 g										
Chlorpyrifos	11.92	11.7 liters	0.67 g	139.46	3.7	0.9	4.6	149	288	−1.57	1,714	5,849	3.1
Untreated	—	—	—	0	3.8	0.7	4.5	151	151	0.0	1,907	6,546	2.5
ANOVA (*P*)					ns	*	**	*		*	ns	ns	**
Contrasts													
1,3-D vs. untreated					ns	ns	ns	ns		ns	ns	ns	ns
Ethoprop vs. untreated					ns	ns	ns	ns		ns	ns	ns	ns
Fenamiphos vs. untreated					ns	*	ns	ns		ns	ns	ns	ns
Aldicarb vs. untreated					ns	*	ns	ns		ns	ns	ns	ns
Carbofuran vs. untreated					ns	ns	**	*		*	ns	ns	ns
Carbofuran vs. fenamiphos + carbofuran					ns	ns	ns	ns		ns	ns	ns	**

Nematicide ratings based on Tobacco Production Guide, South Carolina Extension Circular 569.

[a] Costs are based on average retail sale price recorded at three vendors in Florence, South Carolina. Price estimates are based on the purchase of sufficient product to treat 20 ha.

[b] Acephate application costs are based on (1.12-kg/ha application rate of acephate at $23.43/kg = $26.24/ha product) + application cost of $9.88/ha = $36.12 total expense for each hectare treated; Bt = *Bacillus thuringiensis;* application costs are based on 0.28-kg/ha application rate of Bt at $36.45/kg = $9.11/ha product + application cost of $9.88/ha = $18.99 total expense for each hectare treated.

[c] Value = total expenditure for foliar insect control − expenditure for foliar insecticides in controls receiving no soil insecticides or nematicides.

when compared to an untreated control at sites 1 and 2 in 1993 and at site 2 (*P* = 0.07) in 1994. When fenamiphos, aldicarb, or carbofuran was applied in combination with chlorpyrifos, the number of plants with wireworm damage and the damage rating were generally lower in all sites exhibiting wireworm damage (Table 4).

Discussion

Fumigant nematicides provide better root-knot nematode control than nonfumigants and can increase crop value as much as $1,784/ha in fields containing high populations of *Meloidogyne* spp. (Fortnum et al., 2001). Yield reductions can occur even where crop rotation is practiced if the environment is suitable for nematode development or if populations of the more aggressive *Meloidogyne* species such as *M. arenaria* and *M. javanica* are found within the field (Fortnum and Currin, 1993; Fortnum et al., 2001). Because most tobacco fields are rotated with poor hosts for these species such as cotton, high *Meloidogyne* spp. populations are not commonly observed. Proper rotations also may encourage the development of less aggressive root-knot nematode species, making control easier.

Nonfumigant nematicides have been popular with some producers who do not anticipate significant root-knot damage to their tobacco crop. The primary advantages of nonfumigant nematicides are their ease of application and control of specific secondary insect pests. This report suggests that the complexity of foliar insect populations on tobacco minimized the effectiveness of soil-applied nematicides/insecticides in reducing the number and cost of foliar insecticide sprays that were needed. Although nonfumigant nematicides may control specific insects such as aphids or budworms, populations of insects generally occur as complexes involving many insect species. No insecticide/nematicide combination adequately controlled all insect pests, and all nonfumigant treatments required additional foliar insecticide treatments to keep insect populations below damage threshold levels. As a consequence, there was little difference in total expenditures for insect control regardless of the nematicide/insecticide application.

TABLE 4. Effect of soil-applied nematicide/insecticides on wireworm (*Conoderus falli, C. amplicollis, C. vespertinus*) damage in tobacco field sites containing *Meloidogyne arenaria* (site 1) and *M. incognita* (site 2).

Treatments (rate a.i./ha)		Number of wireworm-damaged plants/20 plants[a]				Wireworm-damage rating[c]			
		Site 1		Site 2		Site 1		Site 2	
Nematicides/soil insecticides	Soil insecticides	1993	1994	1993	1994	1993	1994	1993	1994
1,3-D 56 liters/ha	chlorpyrifos 2.2 kg	2.0	0.2	0.4	4.2	0.5	0	0.1	0.6
1,3-D 56 liters/ha	ethoprop 6.7 kg	1.8	0	0.8	2.0	0.4	0	0.1	0.3
1,3-D 56 liters/ha	—	3.8	0	3.6	3.4	1.0	0	0.7	0.6
Ethoprop 13.4 kg	—	1.6	0	0.6	1.8	0.4	0	0.4	0.3
Fenamiphos 6.7 kg	chlorpyrifos 2.2 kg	2.6	0	2.0	0.4	0.7	0	0.9	0.1
Aldicarb 3.4 kg	chlorpyrifos 2.2 kg	2.0	0	1.4	1.2	0.5	0	0.5	0.2
Carbofuran 6.7 kg	chlorpyrifos 2.2 kg	2.2	0	1.4	1.8	0.5	0	0.7	0.2
Chlorpyrifos 5.6 kg	—	1.0	0	0.8	0.6	0.3	0	0.3	0.1
Fenamiphos 3.4 kg + carbofuran 4.5 kg	chlorpyrifos 2.2 kg	1.4	0	2.0	1.6	0.4	0	0.6	0.2
Untreated	—	4.6	0	4.0	3.0	1.7	0	1.0	0.5
ANOVA (*P*)[b]		***	ns	***	*	**	ns	***	*
Contrasts									
1,3-D vs. untreated		ns	ns	ns	ns	**	ns	ns	ns
1,3-D vs. 1,3-D + chlorpyrifos, 1,3-D + ethoprop		***	ns	***	ns	**	ns	**	ns
Ethoprop, chlorpyrifos vs. untreated		***	ns	***	ns (0.07)	***	ns	***	*

[a] Data are the means of five replications.
[b] ns = not significant at $P = 0.05$, *$P = 0.05$, ** $P = 0.01$, ***P 0.001.
[c] Wireworm damage rated on a linear scale where 0 = no damage and 7 = heavy damage. Wireworm damage was rated 3 weeks following transplanting.

Root-knot nematodes have the potential to severely limit tobacco yields (Fortnum et al., 2001), and forecasting root-knot nematode damage is uncertain. 1,3-Dichloropropene provides excellent nematode control at a low cost to producers. To control nematodes, nonfumigant nematicides must be applied at higher application rates than would be applied for insect control alone. The cost of nonfumigant nematicides, considered moderate in efficacy for root-knot nematode control, was similar to the cost of 1,3-D plus a soil insecticide applied at the lower insecticidal rate. There was no economic advantage in using the nonfumigant nematicides even when no root-knot nematode damage was observed.

1,3-Dichloropropene at 56 liters/ha alone did not provide sufficient wireworm control. The addition of either ethoprop or chlorpyrifos provided adequate control of wireworms in 1993 but not at site 2 in 1994. Thorough incorporation of insecticides into a preformed bed can be difficult and wireworm control may be erratic if proper incorporation is not achieved. If the preformed bed is too high, attempting to incorporate the soil insecticide with a power-driven rotary hoe may redistribute the insecticide from the middle of the bed (planting zone) to the side of the row (Martin and Gooden, 1992). The poor wireworm control at site 2 in 1994 may be due to a movement of the soil insecticide from the planting zone to the sides of the planting row. Although more difficult to apply, 1,3-D plus an insecticidal rate of chlorpyrifos provided the greatest increase in yield and value with the lowest cost.

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