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Spring or Fall Fumigation for Control of *Meloidogyne* spp. on Tobacco[1]

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Abstract: Tests were conducted in 1987–88 to compare the efficacy of spring or fall fumigant nematicide applications for control of *Meloidogyne arenaria* and *M. incognita* on tobacco. Chloropicrin, 1,3-D, methyl isothiocyanate, and a methyl isothiocyanate–1,3-D mixture were applied as row treatments. Fenamiphos, fenamiphos + fensulfothion, or ethoprop were applied in the spring as nonfumigant nematicide standards. Fumigant nematicides increased yields and reduced galling ($P = 0.01$) in all four tests. Spring or fall applications of fumigant nematicides were effective in controlling *M. arenaria* and *M. incognita* and were superior to the nonfumigant nematicides tested.

Key words: chemical control, fumigation, management, *Meloidogyne arenaria*, *Meloidogyne incognita*, nematicide, *Nicotiana tabacum*, root-knot nematode, tobacco.

An epidemic of root-knot occurred in 1982 on flue-cured tobacco (*Nicotiana tabacum* L.) in South Carolina. *Meloidogyne arenaria* (Neal) Chitwood and *M. incognita* (Kofoid and White) Chitwood, the principal species involved, were frequently found in the same fields (7). *Meloidogyne arenaria* is more virulent on tobacco than *M. incognita*; no commercial tobacco cultivars are resistant to this species (1).

The efficacy of fumigant and nonfumigant nematicides for control of *Meloidogyne* spp. on tobacco and other crops has been addressed by several workers with variable results (3,5,9,11,15). In Florida, tobacco plants grown in plots infested with *M. javanica* (Treub) Chitwood and fumigated with DD (1,2-dichloropropane-1,3-dichloropropene) had greater yields than tobacco in similar plots treated with ethoprop (15). Others showed that tobacco plants grown in soil infested with *M. incognita* and treated with nonfumigant nematicides, such as ethoprop, fenamiphos, or aldicarb, had similar or greater yields than plants grown in plots treated with DD (3). Efficacy of a given nematicide may vary with nematode species (13), and cool, wet weather can prevent or lessen the efficacy of spring applications of fumigant nematicides, thus complicating control programs. Our objective was to evaluate the fumigants chloropicrin, 1,3-D, and two formulations of methyl isothiocyanate, applied in the spring or fall, for control of *M. arenaria* or *M. incognita* and for yield enhancement of flue-cured tobacco. A preliminary report of a portion of this paper has been published (14).

Materials and Methods

Fumigant nematicides were applied in the spring before planting on four field sites, two infested with *M. arenaria* (sites 1 and 3) and two with *M. incognita* (sites 2 and 4). At sites 3 and 4, additional fumigant applications were made the preceding fall.

Sites 1 and 4 were at the Pee Dee Research and Education Center, Florence, South Carolina, on a Norfolk sandy loam (75% sand, 17% silt, 8% clay; pH 5.9, 0.8% organic matter) that was infested with root-knot nematodes by a method described previously (6) and planted in tobacco for 2 years. Site 2 was in Florence County, South Carolina, on a Goldsboro sandy loam (78% sand, 18% silt, 4% clay; pH 5.9, 0.8% organic matter). Soybeans had been planted at this site the previous year. Site 3 was in Horry County, South Carolina, on a Suffolk loamy fine sand (80% sand, 15% silt, 5% clay; pH 5.7, 0.8% organic matter). Tobacco had been planted at this site the pre-

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vious year. Sites 2 and 3 were naturally infested with *Meloidogyne* spp. Perineal patterns and second-stage juvenile (J2) morphometrics were used to identify the *Meloidogyne* spp. (17).

Disk harrowing and in-row subsoiling 35 cm deep preceded all treatments. The fumigant nematicides and rates of application evaluated were SN 556 (methyl isothiocyanate [MIT], 40%, Nor-am Chemical Company, Wilmington, DE), 75 liters/ha (9 ml/m); SN 530 (20% MIT, 40% 1,3-D, Nor-am Chemical Company), 75 liters/ha (9 ml/m); 1,3-D (94%), 56 liters/ha (6.7 ml/m); and chloropicrin (96%), 28 liters/ha (3.4 ml/m). All fumigants were applied with a gravity flow-meter and injected 15 cm deep with a single chisel placed in the center of a 60-cm-wide bed. Bedding disks 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. Fumigants were applied in the fall on 14 December 1987 (site 3) and 8 December 1987 (site 4). Fumigants were applied in the spring on 9 April 1987 (site 1), 22 March 1988 (site 2), 15 March 1988 (site 3), and 8 March 1988 (site 4). Nonfumigant nematicides fenamiphos (6.7 kg a.i./ha), fenamiphos + fensulfothion (3.4 + 6.7 kg a.i./ha), or ethoprop (13.4 kg a.i./ha) were applied 24–120 hours before transplanting as broadcast soil sprays in 280 liters water/ha. Plots were immediately disk harrowed 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. Soil temperatures at the time of fumigant and nonfumigant nematicide applications ranged from 10 to 16 C.

The fungicide metalaxyl and herbicide pendimethalin were applied at 0.56 kg a.i./ha (0.007 g a.i./m) in all test plots with directed sprays on top of formed beds and incorporated 10 cm deep with rolling cultivators. Plots at sites 1 and 4 consisted of a single row, 12.2 m long, bordered by untreated rows with a 1.2-m row spacing. Treatments were replicated four times. Tobacco cultivar Clemson PD4 was transplanted on 18 May 1987 (site 1) and 10 May 1988 (site 4). Mature leaves were harvested four times from plots at sites 1 and 4. Yield calculations were based on fresh leaf weight, assuming a 20% cured leaf weight. At sites 2 and 3, plots consisted of four treated rows, 51.8 m long with a 1.2-m row spacing. Tobacco cultivars Northrup King (NK) 394 (site 2) and NK 340 (site 3) were transplanted on 19 April and 15 April 1988, respectively. Treatments were replicated three times. Mature leaves were harvested four times (site 2) or three times (site 3), and cured leaf weights recorded from the four-row plots. All plots were maintained using standard agronomic practices (8); they did not receive supplemental irrigation.

A soil composite of 20 cores (each 2 cm d × 20 cm deep) was removed from the root rhizosphere of the plot row of sites 1 and 4 and another composite of 40 cores was removed from the root rhizosphere of the two inside plot rows of sites 2 and 3 at transplanting, 60 days after transplanting (midseason), and at the last harvest. A 500-cm^3 soil aliquot was processed by semiautomatic elutriation (4) and centrifugal-flotation (2,10) to assess J2 population densities of *Meloidogyne* spp. At the last harvest, 10 plant roots from the plot row (sites 1, 4) or 20 plant roots from the two inside plot rows (sites 2, 3) were excavated at random and rated for galling on a 0–10 scale where 0 = no galling and 10 = 100% of the root system galled (2). Root necrosis was rated on a 0–5 scale where 0 = no necrosis and 5 = 100% of the root system necrotic.

Each experiment had a randomized complete block design. Data were subjected to analysis of variance, and when treatment effects were detected ($P = 0.05$), means were compared with planned contrasts (16).

Results and Discussion

Spring fumigation: The spring application of chloropicrin, 1,3-D, SN 556 (site 1), or SN 530 increased tobacco yields ($P = 0.01$) relative to the untreated control

TABLE 1. Yield of Clemson PD 4 tobacco and mean numbers of *Meloidogyne arenaria* juveniles as affected by fumigant and nonfumigant nematicides applied in the spring preceding the tobacco crop (site 1).

Treatment and broadcast rate (a.i./ha)†	Row rate (a.i./m row)	Yield (kg/ha)	Root galling‡	J2/500 cm³ soil (Pf)§	Root necrosis‖
Chloropicrin, 28 liters	3.4 ml	3,483	1.0	250	1.5
1,3-D, 56 liters	6.7 ml	2,698	0.9	345	1.8
SN 530, 75 liters	9.0 ml	2,937	1.2	280	1.5
SN 556, 75 liters	9.0 ml	3,296	1.0	280	1.2
Fenamiphos, 6.7 kg	0.2 g	1,537	2.7	440	3.8
Untreated		666	2.7	690	4.5
Contrasts:					
Untreated vs. nonfumigants		**	ns		
Untreated vs. fumigants		**	**		
Nonfumigants vs. fumigants		**	**		
1,3-D vs. SN 530		ns	ns		
1,3-D vs. SN 556		*	ns		
Chloropicrin vs. 1,3-D + SN 530		**	ns		

Data are means of four replications. Means were compared using planned contrasts after ANOVA; * $P = 0.05$, ** $P = 0.01$; ns = not significant at $P = 0.05$.

† Fumigants applied with a single chisel per row and bedded with disk-hillers; fenamiphos applied broadcast as a liquid spray in 280 liters water/ha and disk harrowed. SN 530 = 20% methyl isothiocyanate (MIT) and 40% 1,3-D; SN 556 = 40% MIT.

‡ Root-gall index based on a 0–10 scale: 0 = no root galling and 10 = 100% of the root surface galled.

§ J2 = second-stage juveniles. Pf = final population densities of *Meloidogyne arenaria* extracted from 500 cm³ rhizosphere soil 130 days after planting. Populations of J2 at planting were below detectable levels.

‖ Root necrosis based on a 0–5 scale where 0 = no necrosis and 5 = 100% of the root system necrotic.

in two spring fumigation trials (sites 1, 2) (Tables 1, 2). Spring fumigation at sites 1 and 2 increased yields ($P = 0.01$) over the nonfumigant nematicides fenamiphos (site 1), fenamiphos + fensulfothion, or ethoprop (site 2). Chloropicrin (sites 1, 2, $P = 0.01$) and SN 556 (site 1, $P = 0.05$) increased yields over 1,3-D. Black shank

TABLE 2. Yield of Northrup King 394 tobacco and mean numbers of *Meloidogyne incognita* juveniles as affected by fumigant and nonfumigant nematicides applied in the spring preceding the tobacco crop (site 2).

Treatment and broadcast rate (a.i./ha)†	Row rate (a.i./m row)	Yield (kg/ha)	Root galling‡	J2/500 cm³ soil§		J2/g dry root
				Pm	Pf	
Chloropicrin, 28 liters	3.4 ml	3,310	1.8	85	1,790	330
1,3-D, 56 liters	6.7 ml	2,783	1.4	40	1,875	206
SN 530, 75 liters	9.0 ml	3,077	1.2	40	2,375	167
Ethoprop, 13.4 kg	0.2 g	2,783	3.3	290	290	621
Fenamiphos, 3.4 kg + fensulfothion, 6.7 kg	0.1 g 0.2 g	2,455	5.0	250	1,210	357
Untreated		1,995	6.0	415	1,210	502
Contrasts:						
Untreated vs. nonfumigants		**	**			
Untreated vs. fumigants		**	**			
Nonfumigants vs. fumigants		**	**			
Ethroprop vs. (fenamiphos + fensulfothion)		ns	*			
Chloropicrin vs. 1,3-D + SN 530		*	ns			

Data are means of three replications. Means were compared using planned contrasts after ANOVA; * $P = 0.05$, ** $P = 0.01$; ns = not significant at $P = 0.05$.

† Fumigants applied with a single chisel per row and bedded with disk-hillers; ethoprop and fenamiphos + fensulfothion applied broadcast as liquid sprays in 280 liters water/ha and disk harrowed. SN 530 = 20% methyl isothiocyanate and 40% 1,3-D.

‡ Root-gall index based on a 0–10 scale: 0 = no root galling and 10 = 100% of the root surface galled.

§ J2 = second-stage juveniles. Pm and Pf = midseason and final population densities of *Meloidogyne arenaria* extracted from 500 cm³ rhizosphere soil 60 and 160 days after planting. Populations of J2 at planting were below detectable levels.

TABLE 3. Yield of Northrup King 340 tobacco and mean numbers of *Meloidogyne arenaria* juveniles as affected by fumigant and nonfumigant nematicides applied in the fall or spring preceding the tobacco crop (site 3).

Treatment and broadcast rate (a.i./ha)†	Row rate (a.i./m row)	Yield (kg/ha)	Root galling‡	J2/500 cm³ soil§			J2/g dry root
				Pi	Pm	Pf	
Fall application							
Chloropicrin, 28 liters	3.4 ml	3,297	1.4	0	415	1,085	79
1,3-D, 56 liters	6.7 ml	3,200	1.6	85	0	1,665	24
SN 530, 75 liters	9.0 ml	2,914	1.3	40	165	875	27
Spring application							
Chloropicrin, 28 liters	3.4 ml	3,016	3.6	125	40	2,415	16
1,3-D, 56 liters	6.7 ml	2,997	1.0	40	125	375	0
SN 530, 75 liters	9.0 ml	3,142	2.3	0	85	750	61
Fenamiphos, 3.4 kg + fensulfothion, 6.7 kg	0.1 g 0.2 g	2,432	9.1	40	0	2,460	191
Untreated		2,461	9.5	40	0	1,375	153
Contrasts:							
Untreated vs. nonfumigants		ns	ns				
Untreated vs. fumigants		**	**				
Nonfumigants vs. fumigants		**	**				
Fall vs. spring		ns	*				
Chloropicrin vs. 1,3-D + SN 530		ns	*				
1,3-D vs. SN 530		ns	ns				
Chloropicrin vs. 1,3-D		ns	*				

Data are means of three replications. Means were compared using planned contrasts after ANOVA; * $P = 0.05$, ** $P = 0.01$; ns = not significant at $P = 0.05$.

† Fumigants applied with a single chisel per row and bedded with disk-hillers; fenamiphos + fensulfothion applied broadcast as a liquid spray in 280 liters water/ha and disk harrowed. SN 530 = 20% methyl isothiocyanate and 40% 1,3-D.

‡ Root-gall index based on a 0–10 scale: 0 = no root galling and 10 = 100% of the root surface galled.

§ J2 = second-stage juveniles. Pi, Pm, and Pf = initial, midseason, and final population densities of *Meloidogyne arenaria* extracted from 500 cm³ rhizosphere soil 0, 60, and 114 days after planting.

(*Phytophthora parasitica* var. *nicotianae* Breda de Haan) damage was observed at site 1 and root necrosis was lower ($P = 0.05$) in fumigated plots than in untreated or fenamiphos-treated plots. Chloropicrin is recommended for control of soil fungi and bacteria (8,12), and the control of the blackshank fungus may have contributed to the higher yields observed with chloropicrin at site 1. Our data suggest SN 556 may be superior to the standard formulation SN 530 or 1,3-D in fields containing the blackshank fungus.

Root galling by *M. arenaria* (site 1) and *M. incognita* (site 2) was reduced ($P = 0.01$) compared with the untreated control by all spring applied fumigants (Tables 1, 2). Spring fumigation at sites 1 and 2 reduced galling by *M. arenaria* and *M. incognita* relative to the nonfumigant nematicides fenamiphos (site 1), fenamiphos + fensulfothion, or ethoprop (site 2); however, there were no differences in root galling among the fumigants 1,3-D, SN 530, SN 556 (site 1), or chloropicrin.

Fall-spring fumigation: The application of chloropicrin, 1,3-D, SN 556 (site 4), or SN 530 increased tobacco yields ($P = 0.01$) compared with the untreated control in the fall-spring fumigation trials (sites 3, 4) (Tables 3, 4). Fumigation at sites 3 and 4 increased yields ($P = 0.01$) relative to the nonfumigant treatment, fenamiphos + fensulfothion (Tables 3, 4), and there were no differences in yields among the fumigants. The nonfumigant fenamiphos + fensulfothion did not increase yields relative to the untreated control at site 3; however, a similar application of the nonfumigant nematicide at site 4 increased yields ($P = 0.01$) relative to the untreated control. At site 3, yields from fall and spring fumigated plots did not differ. Spring fumigated plots outyielded ($P = 0.01$) fall fu-

TABLE 4. Yield of Clemson PD 4 tobacco and mean numbers of *Meloidogyne incognita* as affected by fumigant and nonfumigant nematicides applied in the fall or spring preceding the tobacco crop (site 4).

Treatment and broadcast rate (a.i./ha)†	Row rate (a.i./m row)	Yield (kg/ha)	Root galling‡	J2/500 cm³ soil§			J2/g dry root
				Pi	Pm	Pf	
Fall application							
Chloropicrin, 28 liters	3.4 ml	4,845	7.7	315	250	2,220	844
1,3-D, 56 liters	6.7 ml	4,820	5.8	290	220	845	521
SN 530, 75 liters	9.0 ml	5,186	5.8	190	530	565	533
SN 556, 75 liters	9.0 ml	5,114	7.2	280	220	1,560	1,229
Spring application							
Chloropicrin, 28 liters	3.4 ml	5,324	5.2	155	65	530	888
1,3-D, 56 liters	6.7 ml	5,731	5.0	250	440	375	496
SN 530, 75 liters	9.0 ml	5,354	5.4	280	0	1,375	796
SN 556, 75 liters	9.0 ml	5,567	5.5	250	500	845	768
Fenamiphos, 3.4 kg + fensulfothion, 6.7 kg	0.1 g 0.2 g	4,497	8.0	315	155	315	1,280
Untreated		2,724	9.2	685	565	905	885
Contrasts:							
Untreated vs. nonfumigants		**	ns				
Untreated vs. fumigants		**	**				
Nonfumigants vs. fumigants		**	**				
Fall vs. spring		**	**				
Chloropicrin vs. 1,3-D + SN 530 + SN 556		ns	ns				
1,3-D vs. SN 556 + SN 530		ns	ns				
1,3-D vs. SN 530		ns	ns				
SN 556 vs. SN 530		ns	ns				
Chloropicrin vs. 1,3-D		ns	ns				

Data are means of four replications. Means were compared using planned contrasts after ANOVA; * $P = 0.05$, ** $P = 0.01$; ns = not significant at $P = 0.05$.

† Fumigants applied with a single chisel per row and bedded with disk-hillers; fenamiphos + fensulfothion applied broadcast as a liquid spray in 280 liters water/ha and disk harrowed. SN 530 = 20% methyl isothiocyanate (MIT) and 40% 1,3-D; SN 556 = 40% MIT.

‡ Root-gall index based on a 0–10 scale: 0 = no root galling and 10 = 100% of the root surface galled.

§ J2 = second-stage juveniles. Pi, Pm, and Pf = initial, midseason, and final population densities of *Meloidogyne incognita* extracted from 500 cm³ rhizosphere soil 0, 60, and 158 days after planting.

migated plots at site 4. One problem encountered with the application of fumigant nematicides in the fall was the development of winter weeds. Cultivation for weed control at site 4 may have mixed treated and untreated soil, thus reducing nematode control. Although the yields were lower at site 4 following fall fumigation, compared with spring fumigation, fumigant nematicides increased yields over the nonfumigant nematicide fenamiphos + fensulfothion ($P = 0.01$).

Root galling was lower ($P = 0.05$) in fall fumigated plots compared with spring fumigated plots at site 3; however, spring fumigated plots had less galling ($P = 0.01$) than did fall fumigated plots at site 4. The erratic nature of spring vs. fall fumigation suggests that the environment at the time of fumigant application and weed control by cultivation may affect root-knot nematode control when fumigants are applied in the spring or fall. At all test sites, J2 population densities increased at midseason and at harvest in soil and roots but treatment effects were not observed (Tables 1–4).

Fall fumigation provides growers with greater flexibility in timing fumigant application to optimum soil temperature and moisture. The successful use of fall fumigation will depend on controlling winter weeds without contamination of treated beds with untreated soil.

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