Supplement to the Journal of Nematology 31(4S):694–699. 1999.
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Fosthiazate Controls *Meloidogyne arenaria* and *M. incognita* in Flue-Cured Tobacco[1]

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Abstract: The nematicide fosthiazate was evaluated over a 3-year period for management of *Meloidogyne incognita* race 3 (site 1) and *M. arenaria* race 2 (site 2) in flue-cured tobacco. Fosthiazate was applied broadcast and incorporated at rates ranging from 22 to 88 g a.i./100 m^2, and compared with the nematicides fenamiphos (67 g a.i./100 m^2), 1,3-D (56.1 L/ha, 670 ml/100-m row), and an untreated control. Root-gall indices and leaf yields were averaged over the 3-year period. Root galling was negatively correlated in a linear relationship with fosthiazate application rate at sites 1 and 2. Leaf yields were positively correlated with fosthiazate application rate at site 1 and could be described by a quadratic equation. Leaf yields were greater at 33 and 88 g a.i./100 m^2 application rates (site 2) than the untreated control. Leaf yields in fosthiazate (88 g a.i./100 m^2)-treated plots infested with *M. incognita* or *M. arenaria* were not different from plots fumigated with 1,3-D. Plants in plots with fosthiazate applied in a row band (1993) had a lower root-gall index than those in plots with the same rate of fosthiazate applied broadcast. Fosthiazate may provide an alternative to fumigation for control of *M. incognita* and *M. arenaria.*

Key words: 1,3-D, fenamiphos, fosthiazate, *Meloidogyne arenaria, Meloidogyne incognita,* nematicide, nematode, root-knot nematode, tobacco.

Root-knot nematodes (*Meloidogyne* spp.) are commonly associated with flue-cured tobacco (*Nicotiana tabacum* L.) in the southeastern United States (Lucas, 1975; Taylor and Sasser, 1978). Approximately 90 percent of the tobacco in South Carolina is treated with a nematicide, but crop losses caused by *Meloidogyne* spp. still range from 0.5 to 1.0% of the tobacco crop (Gooden et al., 1994). Fumigant nematicides containing 1,3-dichloropropene (1,3-D) and (or) chloropicrin are popular due to superior nematode control when compared to nonfumigant nematicides (Gooden et al., 1994). However, fumigant nematicides require a 21-day waiting period between application and transplanting to prevent crop injury. Cool, wet weather can reduce the efficacy of fumigant nematicides. During cool, wet springs growers can delay fumigation and planting or use a nonfumigant nematicide, although delayed planting or use of a nonfumigant nematicide on South Carolina tobacco likely would reduce leaf yields. Tobacco farmers need more effective nonfumigant nematicides with a short waiting period between application and transplanting.

Nonfumigant nematicides, such as fenamiphos, ethoprop, and carbofuran, are labeled for use in South Carolina but are applied to fewer and fewer fields due to the increasing prevalence of more aggressive species of root-knot nematodes. *Meloidogyne incognita* (Kofoid and White) Chitwood is the most common species of *Meloidogyne;* however, *M. arenaria* (Neal) Chitwood is increasing in importance in South Carolina tobacco fields (Fortnum et al., 1984). *Meloidogyne arenaria* race 2 is more virulent on tobacco than *M. incognita,* and no commercial tobacco cultivars are resistant to *M. arenaria* (Barker, 1989; Barker et al., 1981).

Fosthiazate, a nonfumigant nematicide, is effective in controlling several species of plant-parasitic nematodes including *Meloidogyne arenaria* race 1 (Minton et al., 1993), *Globodera tabacum solanacearum* (Johnson, 1995), *Belonolaimus longicaudatus* (Giblin-Davis et al., 1993), and *Pratylenchus penetrans* (Kimpinski et al., 1997; Sturz and Kimpinski, 1999). Control of *Meloidogyne arenaria* race 1 by fosthiazate was comparable to the control obtained with applications of fenamiphos (Minton et al., 1993). However, fenamiphos

Received for publication 3 May 1999.
[1] Technical contribution No. 4481 of the South Carolina Agriculture and Forestry Research System. Mention of a trade name does not constitute a guarantee or warranty of the product by the South Carolina Agriculture and Forestry Research System and does not imply approval to the exclusion of other products that may also be suitable.
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The authors thank J. Cottingham for technical assistance.
This paper was edited by T. L. Kirkpatrick.

outperformed fosthiazate in fields infested with *M. javanica* (Rich et al., 1994), suggesting nematode control may vary with *Meloidogyne* spp. Fosthiazate, although effective in controlling several nematode species, is not labeled for use on tobacco in South Carolina.

The goals of this study were to investigate the efficacy of fosthiazate for managing *M. incognita* race 3 and *M. arenaria* race 2 in South Carolina tobacco, and to determine the efficacy of band vs. broadcast application.

Materials and Methods

Fumigant and nonfumigant nematicides were applied in the spring before planting on two field sites: one infested with *M. incognita* race 3 and one infested with *M. arenaria* race 2. Both test sites were located at the Pee Dee Research and Education Center, Florence, South Carolina, on a Norfolk sandy loam (site 1, 75% sand, 17% silt, 8% clay, 0.8% organic matter, pH 5.9) and a Goldsboro sandy loam (site 2, 78% sand, 18% silt, 4% clay, 0.8% organic matter, pH 5.9). Both sites were infested with root-knot nematodes by a method described previously (Fortnum et al., 1987) and planted with tobacco the year preceding the trials.

Disk-harrowing and in-row subsoiling 35 cm deep preceded all treatments. The fumigant nematicide 1,3-dichloropropene (1,3-D) (94%), 56 L/ha (670 ml/100 m of row), was applied with a positive pressure pump system 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, forming a 36-cm-high bed with fumigant placement 40 cm from the top of the bed. Fumigants were applied on 15 April 1991, 20 April 1992, and 13 April 1993. The nonfumigant nematicides, fenamiphos (67 g a.i./100 m^2) and fosthiazate (22, 33, 44, and 88 g a.i./100 m^2), were applied 24 to 96 hours before transplanting as broadcast soil sprays in 280 liters water/ha using a CO_2-charged delivery system. 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. Applications were made on 14 May 1991, 10 May 1992, and 18 May 1993. In 1993, fosthiazate was also applied as a band treatment. Fosthiazate (17 and 33 g a.i./ha, 20 and 40 g a.i./100 m of row, respectively) was sprayed on the soil surface in 280 liters of water/ha (3.36 liters/100 m row) in a 30-cm band in the center of the row and immediately incorporated into the soil using a power-driven rotary hoe with a bed shaper. Untreated control plots were disk-harrowed, bedded, and maintained in a similar fashion. Soil temperatures at the time of nematicide application were 21–23 °C and 21–26 °C (15-cm depth) for the fumigant and nonfumigant nematicides, respectively. Tobacco seedlings were obtained from methyl bromide-treated plant beds. 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 consisted of a single row of plants, 12.2 m long, bordered by untreated rows with a 1.2-m row spacing. All treatments were replicated five times and arranged in a randomized complete block design (RCBD). Tobacco cultivars Coker 371 Gold (susceptible to both species of root-knot nematodes, site 1) and Northrup King (NK 326) (resistant to *M. incognita* races 1 and 3, site 2) were transplanted on 15 May 1991, 12 May 1992, and 20 May 1993. The tobacco was maintained using standard agronomic practices (Gooden et al., 1994) and received irrigation as needed. Two harvests of mature leaves were collected from each plot. The leaves were weighted and yield calculations were based on fresh leaf weight, assuming a 20% cured leaf weight.

A soil composite of 20 cores (each 2 cm diam. × 20 cm deep) was removed from the rhizosphere of the plot row 60 days after transplanting (midseason) and at the last harvest. A 500-cm^3 soil aliquot was processed by semiautomatic elutriation (Byrd et al., 1976) and centrifugal flotation (Jenkins, 1964) to determine second-stage juvenile (J2) densities of *M. arenaria* and *M. incog-*

nita. At the last harvest, seven plants from each plot row were excavated at random and rated for galling on a 0–10 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).

Data were subjected to analysis of variance and means were compared with planned contrasts when treatment effects were detected ($P \leq 0.05$). Where a significant ANOVA was observed, linear or quadratic regressions were used to compare the response of nematode development and leaf yield to different rates of fosthiazate (Steel and Torrie, 1960). All calculations were performed with SAS-JMP (SAS Institute, Cary, NC).

Results

Fosthiazate application rate: Combined over years (1991–1993), root galling was negatively correlated in a linear relationship with fosthiazate application rate at site 1 (R^2 = 0.98, $P \leq 0.001$) and site 2 (R^2 = 0.88, P = 0.01) (Fig. 1B,D). Plants from fosthiazate-treated plots (89 g a.i./100 m^2) had less root galling (site 1, *M. incognita;* site 2, *M. are-*

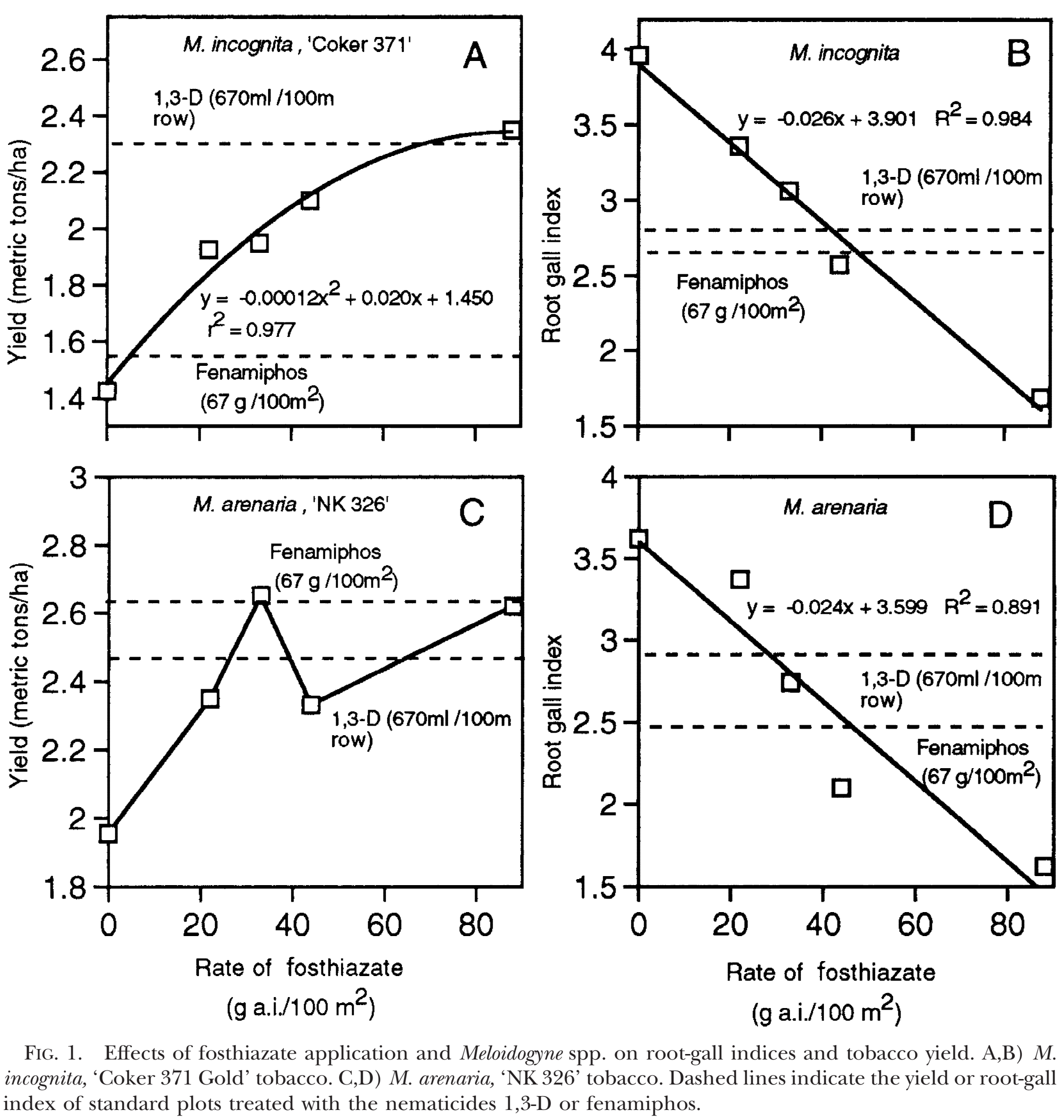

FIG. 1. Effects of fosthiazate application and *Meloidogyne* spp. on root-gall indices and tobacco yield. A,B) *M. incognita,* 'Coker 371 Gold' tobacco. C,D) *M. arenaria,* 'NK 326' tobacco. Dashed lines indicate the yield or root-gall index of standard plots treated with the nematicides 1,3-D or fenamiphos.

naria) than plots treated with 1,3-D (P = 0.007, P = 0.01, respectively) and fenamiphos (P = 0.01, P = 0.09, respectively). The relationship between fosthiazate application rate and root-gall index was similar between nematode species. The root-gall index of plants from fosthiazate-treated plots (44 g a.i./100 m^2) was not different from the root-gall index of plants from plots treated with either 1,3-D or fenamiphos. Leaf yields were positively correlated with fosthiazate application rate at site 1 (*M. incognita*) and could be described with a quadratic equation (R^2 = 0.98, P = 0.02) (Fig. 1A). Yields in fosthiazate-treated plots (88 g a.i./100 m^2) (site 1, *M. incognita*) did not differ from yields in plots treated with 1,3-D. Fosthiazate (44 and 88 g a.i./100 m^2) and 1,3-D-treated plants had greater leaf yields than plants treated with fenamiphos (P = 0.06, P = 0.001, and P = 0.001, respectively). Leaf yields were greater at 33 and 88 g a.i./100-m^2 application rates (site 2) than in the untreated control (Fig. 1C, P = 0.001). Leaf yields in fosthiazate-treated plots (33 and 88 g a.i./100 m^2) infested with *M. arenaria* were not different from plots fumigated with 1,3-D (site 2, P = 0.05).

Juvenile populations increased in all plots, and population densities were not different among treatments at 60 days following transplanting or at final harvest. No phytotoxicity was observed on plots treated with fosthiazate over the 3 years of the study.

Band applications: Similar trends were observed between site 1 (*M. incognita*) and site 2 (*M. arenaria*) in 1993. Data are presented as the average of sites 1 and 2 (Table 1). Application of fosthiazate (40 g a.i./100-m row) in a 30-cm band centered in the root zone reduced root galling when compared to the same amount of fosthiazate broadcast over a 1.2-m-wide row ($P \leq 0.05$, Table 1). Broadcast application of fosthiazate (33 g a.i./100 m^2 or 40 g a.i./100-m row) did not differ in root-gall index from 20 g a.i./100-m row of fosthiazate applied in a 30-cm band (Table 1, P = 0.05). 1,3-D reduced root galling and increased leaf yield over the untreated control (Table 1, $P \leq 0.01$). Application of 40 g a.i./100-m row of fosthiazate gave a root-gall index similar to that of the 1,3-D fumigated control (1.4 vs. 1.6, respectively).

Discussion

Worldwide losses in tobacco to root-knot nematodes have been estimated at 15% of crop yield (Schneider, 1991). Widespread use of fumigant nematicides in South Carolina has maintained losses at 1% or less of total crop production (Gooden et al., 1994). Due to the wide host range of root-knot

Table 1. Tobacco yield and root-gall indices as affected by fumigant and nonfumigant nematicides applied in the spring preceding the tobacco crop in 1993 averaged over sites 1 (*Meloidogyne incognita*) and 2 (*M. arenaria*).[a]

Treatment, application rate (a.i./ha)	Row rate (a.i./100 m row)	Incorporation method	Yield (kg/ha)	Root galling
Fosthiazate, 3.3 kg	40 g	Broadcast	1,327	2.6
Fosthiazate, 3.3 kg	40 g	Band-row	1,396	1.4
Fosthiazate, 1.7 kg	20 g	Band-row	1,383	2.8
Fenamiphos, 6.7 kg	80 g	Broadcast	1,475	2.4
1,3-D, 56 liters	672 ml	In-row	1,807	1.6
Untreated			1,350	4.2
Contrasts:				
Fosthiazate broadcast (40 g) vs. band-row (40 g)			NS	*
Fosthiazate broadcast (40 g) vs. band-row (20 g)			NS	NS
Fosthiazate (40 g) band-row vs. 1,3-D			**	NS
Fenamiphos vs. 1,3-D			NS	NS
1,3-D vs. untreated			**	***

[a] Data are the means of five replications per site averaged across sites 1 and 2 (total of 10 values).Means were compared with planned contrasts after ANOVA. NS = not significant at $P < 0.05$. Site 1 was planted to tobacco cv. Coker 371 Gold and site 2 with cv. NK 326.

nematodes and the wide geographic distribution of species within the genus *Meloidogyne,* crop rotation and host plant resistance cannot assure adequate control of root-knot nematodes (Fortnum and Currin, 1993; Johnson, 1982; Johnson, 1989). Crop rotation can shift populations of root-knot species from less aggressive to more aggressive species, complicating traditional control options and increasing reliance on soil-applied pesticides (Fortnum and Currin, 1993). Fumigants have a minimum waiting period of 21 days between application and planting and cannot be applied under cool, wet conditions. No nematicide labeled for use in the southeastern United States, except fosthiazate, provides control comparable with soil fumigation.

Fosthiazate was effective in reducing root galling caused by *M. incognita* and *M. arenaria,* and increasing leaf yields. At higher application rates, fosthiazate was comparable with soil fumigation. Fenamiphos-treated plots had yields similar to those treated with 1,3-D at site 2 but not at site 1. Site 1 had a history of fenamiphos application preceding the trial (3 years) in contrast to site 2, where fenamiphos had not been used for the decade preceding the trials. Enhanced degradation of fenamiphos may have played a role in the poor yield response at this location (Davis et al. 1993); however, root-gall indices at harvest were similar in 1,3-D and fenamiphos-treated plots.

Application of fosthiazate in a band centered in the plant row reduced root galling when compared to broadcast applications. The improved performance would allow for reduced application rates providing adequate control with a potential for reduced environmental impact. Fosthiazate may provide an alternative to fumigation for control of *M. incognita* and *M. arenaria,* especially during cool, wet springs when fumigation may not be possible.

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