Management of the Tobacco Black Shank–Root-Knot Complex with Combinations of Soil Fumigants and Metalaxyl

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ABSTRACT

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When applied preplant incorporated and at last cultivation (lay-by), 1,3-dichloropropene (1,3-D) at 56 L/ha, 1,3-D/17% chloropicrin (C-17) at 65.5 L and 93.5 L/ha, and fenamiphos at 6.7 kg a.i./ha + metalaxyl at 0.56 kg a.i./ha were equally effective in reducing tobacco black shank on cultivars K-326, Speight G-70, and Coker 371 Gold. Methyl bromide at 112 kg/ha injected into the soil prior to transplanting was not effective in reducing black shank but reduced damage from root-knot nematodes in all cultivars. All treatments reduced final root-gall indices compared to the untreated control in 1990 and 1991. In 1991, final root-gall indices were higher for Coker 371 Gold, a cultivar with no resistance to *Meloidogyne incognita*, than for Speight G-70 or K-326, cultivars with resistance to *M. incognita*. Yields were increased over the untreated control by 1,3-D/C-17 treatments at either rate for all cultivars in both years. Yields were higher with 1,3-D/C-17 than with other treatments in 1990 and higher with fenamiphos treatments in 1991 for K-326 and Coker 371 Gold. Yields for K-326 were usually higher than those for the other cultivars in all treatments both years.

Additional keywords: *Meloidogyne javanica, Phytophthora parasitica* var. *nicotianae*

Tobacco black shank, incited by *Phytophthora parasitica* var. *nicotianae* (Breda de Haan) Tucker, is one of the most serious and persistent diseases on tobacco (*Nicotiana tabacum* L.) (6,11, 12,14,15). Although some resistance to the disease is available in commercial cultivars, the disease is managed by combinations of resistant cultivars, cultural practices, and a fungicide. In Georgia, Coker 371 Gold, released in 1986, has the most resistance but has undesirable agronomic characteristics. Crop rotations are used to a limited extent but are typically too short for effective disease control. The use of metalaxyl (19) for control of the disease is common in Georgia and provides excellent control when used as recommended (14).

Meloidogyne incognita (Kofoid & White) Chitwood, *M. javanica* (Treub) Chitwood, and *M. arenaria* (Neal) Chitwood are common root-knot nematodes in the southeastern coastal plain and are serious pathogens of tobacco (2,4,5,8,9,16,18). Although some commercial tobacco cultivars have resistance to races 1 and 3 of *M. incognita*, many production fields have mixed species of root-knot nematodes, and these cultivars provide no protection against *M. arenaria* and *M. javanica*. Cultivars with resistance to races 2 and 4 of *M. incognita* are not commercially available. Crop rotations are used to a limited extent for nematode management, but short rotations do not eradicate nematodes. *M. incognita* can survive in clean-fallow soil under mild winter temperatures in Georgia (10). Volatile soil fumigants and nonvolatile nematicides are used on the majority of tobacco in Georgia (14). In instances where root-knot nematodes and *P. p. nicotianae* are present, a synergistic disease complex occurs (16), even on cultivars with high resistance to black shank.

Although multipurpose fumigants are recommended for use in North Carolina for nematode and disease control (15), their performance has been poor for disease control under Georgia conditions (2).

A study was conducted over a 2-yr period to evaluate the use of a soil fumigant nematicide and a multipurpose soil fumigant in combination with metalaxyl for management of the black shank–root-knot complex on tobacco in an area heavily infested with *Meloidogyne* spp. and *P. p. nicotianae.*

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MATERIALS AND METHODS

The tests were established at the Coastal Plain Experiment Station near Tifton, Georgia, on Fuquay loamy sand (loamy, siliceous, thermic Arenic Plinthic Paleudult; 88% sand, 8% silt, and 4% clay, pH 5.5–6.0 in water, and <2% organic matter) in an area infested with *P. p. nicotianae* (races 0 and 1), *M. incognita*, and *M. javanica.* A split-plot experimental design was used. Whole plots consisted of chemical treatments, with three rows 10 m long and 1.2 m apart and with plants spaced 46 cm apart. Subplots were one row each of Coker 371 Gold, K-326, and Speight G-70.

Soil fumigants 1,3-dichloropropene (1,3-D) and 1,3-D/17% chloropicrin (C-17) were injected 25 cm deep in the row on 8 and 9 March 1990 and 20 March 1991 and sealed by bedding soil over the chisel furrow with disk hillers. Fenamiphos, a nonvolatile nematicide, and metalaxyl, a fungicide, were applied in 280 L/ha of aqueous spray. They were broadcast preplant incorporated with a tractor-powered sprayer-Rototiller to a depth of 15 cm. Also, metalaxyl was applied as a last cultivation lay-by spray treatment to the base of plants at rates noted in Tables 1 and 2.

Fertilization was based on soil tests, and supplemental irrigation was used to provide water as needed during the season. Insecticides (methomyl, chlorpyrifos, and acephate), herbicides (pendimethalin, pebulate, and isopropalin), and growth regulators (maleic hydrazide and fatty alcohols) were used according to recommendations of the University of Georgia Cooperative Extension Service (14).

Numbers of living plants in each plot were counted and recorded every 2 wk starting 4 wk after transplanting, and percent black shank and a disease index were calculated (2). Disease index is a weighted measurement of disease progression based on time of death and severity and is calculated as the average percent disease every 2 wk. A plant was considered dead when it was permanently wilted and had a black lesion on the stem extending from the soil surface. Plants that were not killed by black shank were not included in the calculations.

Soil samples for nematode assay (7) consisted of 20 cores (2.5 cm diameter × 25 cm deep) and were taken before soil treatment on 24 May and 31 August 1990. Root-gall indices were determined by uprooting and rating two plants from each plot about 10 wk after transplanting in 1990. All plants were uprooted and rated for galls after the final harvest. The root-gall index (RGI) was based on a scale of 1–5, where 1 = no galling, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% of roots galled. After the final root-gall rating, root samples from each cultivar in control plots were collected for identification of *Meloidogyne* species. Eighty *Meloidogyne* females from each cultivar were examined for species determination using perineal patterns (20). Plant height data were collected on 21 May 1991.

Leaves were hand-harvested three times as they ripened and were weighed for each plot. Total fresh weight was converted to dry weight using a 0.2 conversion factor (1,2), and yield per hectare was calculated for each plot.

Data were analyzed using ANOVA,

Table 1. Effect of soil fumigants and fenamiphos plus metalaxyl on yield, disease, and nematode damage on three cultivars of tobacco (K-326, G-70, and C-371) in 1990

			Black shank (%)[y]			Disease index			Root-gall index[z] 21 May			Root-gall index[z] 5 September			Yield (kg/ha)		
Treatment	Rate/ha[w]	Method[x]	K-326	G-70	C-371	K-326	G-70	C-371	K-326	G-70	C-371	K-326	G-70	C-371	K-326	G-70	C-371
1,3-D/C-17 + metalaxyl	93.5 L + 0.56 kg + 0.56 kg	I P L	2.8 b	6.1 c	9.0 b	1.9 c	3.6 c	6.2 ab	1.0 b	1.0 a	1.0 c	1.0 b	1.0 b	1.1 b	5,098 a	3,926 a	3,544 a
1,3-D/C-17 + metalaxyl	65.5 L + 0.56 kg + 0.56 kg	I P L	8.8 b	4.5 c	3.0 b	5.9 bc	4.1 c	1.7 b	1.0 b	1.0 a	1.0 c	1.1 b	1.0 b	1.3 b	5,038 a	3,784 a	3,835 a
1,3-D + metalaxyl	56 L + 0.56 kg + 0.56 kg	I P L	12.4 b	15.0 c	4.5 b	6.5 bc	7.2 c	2.3 c	1.0 b	1.0 a	1.0 c	1.0 b	1.0 b	1.1 b	4,558 a	3,677 a	3,321 ab
Fenamiphos + metalaxyl	6.7 kg + 1.12 kg + 0.56 kg	P P L	5.6 b	8.6 c	7.2 b	3.0 bc	4.1 c	2.8 b	1.0 b	1.0 a	1.6 bc	1.3 b	1.1 b	3.1 a	4,705 a	3,167 a	2,895 abc
Methyl bromide	112 kg	I	60.0 a	64.2 a	25.9 ab	27.7 a	27.1 a	11.5 ab	1.0 b	1.0 a	2.1 ab	1.4 b	1.2 b	3.1 a	2,172 b	1,229 b	2,026 bc
Control	...	...	54.8 a	43.9 b	46.1 a	19.4 ab	14.8 b	18.5 a	1.4 a	1.3 a	2.5 a	2.0 a	1.8 a	3.8 a	1,614 b	1,864 b	1,743 c

[w] All kilogram designations are kg a.i./ha. The fumigants are 1,3-dichloropropene (1,3-D) and 17% chloropicrin (C-17). Data are means of four replications. Means in columns followed by the same letter and those underscored by the same line are not different ($P \leq 0.05$) according to the Waller-Duncan multiple range test.

[x] I = inject single chisel in row, P = preplant incorporated with sprayer Rototiller, and L = application at last cultivation.

[y] Percentage of black shank was determined at final harvest. Disease index is a weighted system designed to assess both severity and time of incidence.

[z] Root-gall index is based on a 1–5 scale of root system galled, where 1 = no galling, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% of roots galled.

Table 2. Effect of soil fumigants and fenamiphos plus metalaxyl on height, yield, disease, and nematode damage on three cultivars of tobacco (K-326, G-70, and C-371) in 1991

			Height (cm)[x]			Black shank (%)[y]			Disease index			Root-gall index[z] 20 August			Yield (kg/ha)		
Treatment	Rate/ha[v]	Method[w]	K-326	G-70	C-371	K-326	G-70	C-371	K-326	G-70	C-371	K-326	G-70	C-371	K-326	G-70	C-371
1,3-D/C-17 + metalaxyl	93.5 L + 0.56 kg + 0.56 kg	I P L	78 a	81 ab	81 ab	6.1 a	12.1 ab	7.8 b	2.8 a	5.6 ab	3.3 b	1.0 d	1.1 d	1.9 b	4,542 ab	3,485 ab	3,950 a
1,3-D/C-17 + metalaxyl	65.5 L + 0.56 kg + 0.56 kg	I P L	77 a	85 a	83 a	10.8 a	7.8 b	7.7 b	5.3 a	3.3 ab	3.4 b	1.1 cd	1.0 d	1.9 b	5,058 a	3,646 a	3,774 a
1,3-D + metalaxyl	56 L + 0.56 kg + 0.56 kg	I P L	68 b	77 ab	83 ab	9.0 a	9.3 b	4.5 b	3.4 a	3.7 ab	3.5 b	1.3 bcd	1.2 cd	2.3 b	3,919 bc	3,285 abc	3,223 ab
Fenamiphos + metalaxyl	6.7 kg + 0.56 kg + 0.56 kg	P P L	67 b	76 abc	70 abc	13.2 a	3.0 b	14.1 b	9.2 a	0.4 b	2.7 b	1.6 ab	1.7 b	2.7 b	3,670 c	3,331 abc	2,499 bc
Fenamiphos + metalaxyl	6.7 kg + 1.12 kg + 0.56 kg	P P L	66 b	72 bc	68 bc	9.1 a	6.0 b	13.9 b	3.2 a	2.3 b	3.5 b	1.4 bc	1.4 bc	2.4 b	3,526 c	2,684 bc	2,408 bc
Control	...	...	61 b	66 c	60 c	16.4 a	24.2 a	46.3 a	7.2 a	9.1 a	17.3 a	2.0 a	2.1 a	4.2 a	3,396 c	2,524 c	1,575 c

[v] All kilogram designations are kg a.i./ha. The fumigants are 1,3-dichloropropene (1,3-D) and 17% chloropicrin (C-17). Data are means of four replications. Means in columns followed by the same letter and those underscored by the same line are not different ($P \leq 0.05$) according to the Waller-Duncan multiple range test.

[w] I = inject single chisel in row, P = preplant incorporated with sprayer Rototiller, and L = application at last cultivation.

[x] Plant height data were collected on 31 May 1991.

[y] Percentage of black shank was determined at final harvest. Disease index is a weighted system designed to assess both severity and time of incidence.

[z] Root-gall index is based on a 1–5 scale of root system galled, where 1 = no galling, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% of roots galled.

multiple-stepwise regression, and the Waller-Duncan multiple range test. All differences reported are significant ($P = 0.05$) except where noted. Correlation coefficients (r) were calculated for certain comparisons.

RESULTS

Rainfall for the 1990 and 1991 growing seasons varied greatly. Plots received 31 cm of water through rainfall and irrigation in 1990 and 58 cm in 1991. The amount of water affected both plant growth and disease incidence.

In 1990, all treatments except methyl bromide reduced percent black shank on all tobacco cultivars (Table 1). Percent black shank and disease index were less for Coker 371 Gold than for the other two cultivars only in the methyl bromide treatment. Disease index was reduced by 1,3-D/C-17 at 93.5 L/ha + metalaxyl in K-326, by all treatments except methyl bromide in Speight G-70, and by 1,3-D/C-17 at 93.5 L/ha + metalaxyl and methyl bromide in Coker 371 Gold.

All treatments reduced both early and final RGIs on K-326 but only the final RGI on Speight G-70 (Table 1). All treatments except methyl bromide reduced early RGI in Coker 371 Gold. Both early and final RGIs were greater on Coker 371 Gold than on the other cultivars in untreated, methyl bromide treated, and fenamiphos + metalaxyl treated plots.

All treatments except methyl bromide increased yield of K-326 and Speight G-70, and all treatments except methyl bromide and fenamiphos + metalaxyl increased yield of Coker 371 Gold over that of the untreated control (Table 1). Yields of K-326 were greater than those of the other two cultivars for all treatments except methyl bromide and the untreated control. However, the yield of K-326 was greater than the yield of Speight G-70 in the methyl bromide treated plots.

In 1990, yield of K-326 was negatively correlated with early RGI ($r = -0.51$, $P = 0.01$), final RGI ($r = -0.74$, $P = 0.0001$), percent black shank ($r = -0.90$, $P = 0.0001$), and disease index ($r = -0.84$, $P = 0.0001$). Percent black shank was positively correlated with early RGI ($r = 0.46$, $P = 0.02$), final RGI ($r = 0.71$, $P = 0.0002$), and disease index ($r = 0.96$, $P = 0.0001$).

In 1990, yield of Speight G-70 was negatively correlated with final RGI ($r = -0.56$, $P = 0.005$), percent black shank ($r = -0.85$, $P = 0.0001$), and disease index ($r = -0.85$, $P = 0.0001$). Percent black shank was positively correlated with final RGI ($r = 0.50$, $P = 0.016$) and disease index ($r = 0.93$, $P = 0.0001$).

In 1990, yield of Coker 371 Gold was inversely correlated with early RGI ($r = -0.58$, $P = 0.003$), final RGI ($r = -0.59$, $P = 0.002$), percent black shank ($r = -0.65$, $P = 0.0006$), and disease index ($r = -0.72$, $P = 0.0001$). Percent black shank was positively correlated with early RGI ($r = 0.70$, $P = 0.0001$), final RGI ($r = 0.60$, $P = 0.002$), and disease index ($r = 0.93$, $P = 0.0001$).

In 1991, K-326 plants were taller in plots treated with 1,3-D/C-17 at either rate than with the other treatments (Table 2). Plants of Speight G-70 and Coker 371 Gold in plots treated with 1,3-D/C-17, at either rate, or 1,3-D were taller than those in the untreated control. Plant heights among cultivars were similar in all treatments except 1,3-D at 56 L/ha + metalaxyl, where plants of Speight G-70 and Coker 371 Gold were taller than those of K-326.

All treatments decreased percent black shank and disease index of Coker 371 Gold. All treatments except 1,3-D/C-17 at 93.5 L/ha + metalaxyl decreased percent black shank in Speight G-70. The disease index for Speight G-70 was decreased only in plots treated with fenamiphos + metalaxyl. Percentage disease and disease index were higher in Coker 371 Gold than in the other cultivars in the untreated control plots. Disease index was lower for Speight G-70 than for the other cultivars in the fenamiphos + metalaxyl at 0.56 kg a.i./ha preplant + 0.56 kg a.i./ha lay-by treatment.

Final RGI was decreased by all treatments for Speight G-70 and Coker 371 Gold and by all treatments except fenamiphos + metalaxyl at 0.56 kg a.i./ha preplant + 0.56 kg a.i./ha lay-by for K-326. Final RGIs of Coker 371 Gold were greater than those of the other cultivars for all treatments.

Yields of K-326 and Speight G-70 were higher in plots treated with 1,3-D/C-17 than in the untreated plots. Yields of Coker 371 Gold in plots treated with either 1,3-D/C-17 or 1,3-D were higher than those in untreated plots. Yield of K-326 plants was greater than yield of Speight G-70 or Coker 371 Gold except in plots treated with fenamiphos + metalaxyl 0.56 kg a.i./ha preplant + 0.56 kg a.i./ha lay-by. Yield of K-326 was greater than that of Speight G-70, and both cultivars had higher yields than Coker 371 Gold in the untreated plots.

In 1991, yield of K-326 was inversely correlated with plant disease ($r = -0.52$, $P = 0.010$) and disease index ($r = -0.43$, $P = 0.035$) and directly correlated with plant height ($r = 0.71$, $P = 0.0001$). Percent disease was directly correlated with disease index ($r = 0.83$, $P = 0.0001$).

In 1991, yield of Speight G-70 was negatively correlated with final RGI ($r = -0.41$, $P = 0.046$) and directly correlated with plant height ($r = 0.45$, $P = 0.029$). Plant height was inversely correlated with final RGI ($r = -0.61$, $P = 0.002$), and percent disease was inversely correlated with plant height ($r = -0.42$, $P = 0.04$) and directly correlated with disease index ($r = 0.81$, $P = 0.0001$).

In 1991, yield of Coker 371 Gold was inversely correlated with final RGI ($r = -0.74$, $P = 0.0001$), percent disease ($r = -0.71$, $P = 0.0001$), and disease index ($r = -0.64$, $P = 0.0008$) and positively correlated with plant height ($r = 0.75$, $P = 0.0001$). Plant height was inversely correlated with final RGI ($r = -0.58$, $P = 0.003$). Percent disease was directly correlated with final RGI ($r = 0.67$, $P = 0.0003$) and disease index ($r = 0.88$, $P = 0.0001$) and inversely correlated with plant height ($r = 0.54$, $P = 0.006$).

Root-gall samples collected in 1990 for determination of *Meloidogyne* species indicated that Speight G-70 and K-326 were infected 100% with *M. javanica* in all replications. Coker 371 Gold was infected 100% with *M. incognita* in replications one and four, 100% with *M. javanica* in replication two, and 40% with *M. incognita* and 60% with *M. javanica* in replication three.

Root-gall samples collected in 1991 indicated that 100% of samples from all replications of Speight G-70 and K-326 were infected with *M. javanica.* Roots of Coker 371 Gold were infected as follows: replicate one = 90% *M. javanica* + 10% *M. incognita*, replicate two = 100% *M. incognita*, replicate three = 100% *M. javanica*, and replicate four = 10% *M. javanica* + 90% *M. incognita.*

DISCUSSION

Plots treated with 1,3-D/C-17 at either rate and 1,3-D + metalaxyl were near or significantly superior to the standard fenamiphos + metalaxyl treatment for disease and nematode damage reduction and yield increase. Although the soil fumigants have been available to growers, only 1,3-D has been used for nematode control. In North Carolina, recommendations for management of fields with black shank include the use of 1,3-D/C-17 at 93.5 L/ha or 1.12–2.24 kg a.i./ha of metalaxyl (15,21). In fields with a history of severe black shank, use of both materials is recommended. In South Carolina, recommendations consist of using a multipurpose soil fumigant such as 1,3-D/C-17, chloropicrin, or metalaxyl + a nematicide (6). The use of multipurpose soil fumigant 1,3-D/C-17 alone has not been successful in Virginia (17). Under the disease pressures encountered in Georgia, the application of 1,3-D/C-17 alone has not provided adequate disease control for growers. However, our data suggest that the use of 1,3-D and, even to a greater extent, of 1,3-D/C-17 in combination with metalaxyl at 0.56 kg a.i./ha preplant incorporated and 0.56 kg a.i./ha at lay-by provides good control of the black shank/root-knot nematode complex.

A nonspecific stimulation in growth was observed with the use of both 1,3-D and 1,3-D/C-17 on Speight G-70 and Coker 371 Gold and with 1,3-D/C-17 on K-326 in 1991 over the untreated control. Similar early growth response was not observed in the standard fenamiphos +

metalaxyl treatments. Neither the black shank incidence nor the nematode data provided insight to the early stimulation in growth. However, the yield and height measurements were significantly and directly correlated for all the cultivars. For Speight G-70 and Coker 371 Gold, plant height was significantly and negatively correlated with final RGI. In 1990, Coker 371 Gold, which does not have resistance to *M. incognita*, showed some early root-knot damage in fenamiphos-treated plots but not in those treated with 1,3-D or 1,3-D/C-17. We speculate that the fumigants may have been more effective in reducing nematode populations than fenamiphos, thus providing the stimulation in growth over the untreated control. However, Elliot et al (3) demonstrated the inhibition of nitrification with 1,3-D and 1,3-D/C-17. This delay in loss of nitrogen through leaching may contribute to plant vigor and stimulation in growth.

Black shank incidence was generally lower and nematode damage higher in 1991 than in 1990. In 1991, the disease levels in Coker 371 Gold, a cultivar recommended for management of black shank, were higher than those in Speight G-70, a cultivar with moderate resistance, and in K-326, a cultivar with low resistance in the untreated control plots. Powell and Nusbaum (16) reported that root-knot nematode damage increases the incidence of black shank. The lack of nematode resistance in Coker 371 Gold in the presence of high densities of root-knot nematodes predisposes the cultivar to increased levels of black shank. In treatments where nematodes were controlled, black shank incidence was not significantly different from that in the other two cultivars. In 1990, incidence of black shank in Coker 371 Gold was lower than in the other cultivars and was significantly lower in the methyl bromide treatment, where that treatment tended to control nematodes.

The value of using a volatile nematicide or multipurpose fumigant in combination with the fungicide metalaxyl to manage the black shank/root-knot complex on tobacco is apparent from this research. Past studies with multipurpose fumigants alone for control of the black shank/nematode complex have shown unsuccessful results (2,17). Environmental conditions in the Georgia tobacco growing belt favor the development of severe pest pressures (13), and the use of a multipurpose soil fumigant before transplanting tobacco does not provide the season-long protection needed in this area. The addition of metalaxyl to the soil fumigant treatment at planting and lay-by (1) provides the needed protection from *P. p. nicotianae*.

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