# Control of Tobacco Black Shank with Combinations of Systemic Fungicides and Nematicides or Fumigants

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**ABSTRACT**

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In 1979, field plots were established in an area heavily infested with *Phytophthora parasitica* var. *nicotianae* and lightly infested with *Meloidogyne incognita* to compare fungi-specific systemic fungicides alone and with fumigant and nonfumigant nematicides/insecticides applied by several methods for control of tobacco black shank. Metalaxyl at 2.24 kg a.i./ha preplant incorporated reduced black shank when used alone or with a fumigant or nonfumigant nematicide, although disease control was greater when combinations were used. Regardless of the nematicide used, propamocarb, RE26940, or RE26745 did not decrease disease severity or increase yield compared with the control. Phenamiphos in 1979 and ethoprop-disulfoton in 1981 increased yield over the control and ethoprop in 1981 decreased disease index. Yields of plants in plots treated with EDB-C30 and EDB-C45 in 1979 and 1980 were greater than yields from untreated controls. Root-gall evaluations and numbers of *M. incognita* juveniles in the soil were erratic and differences among treatments were not significant ($P = 0.05$). Data indicated that metalaxyl tank mixed with nonfumigant nematicides or used in combination with fumigants or granular nematicides had no adverse effect on plant growth and increased disease control and yield.

Additional key words: oomycete-specific fungicides, root-knot nematodes

Black shank of tobacco (*Nicotiana tabacum* L.) caused by *Phytophthora parasitica* Dastur var. *nicotianae* (Breda de Haan) Tucker is one of the most serious soilborne diseases of tobacco. Direct losses from the disease average $1 million annually in Georgia and $16–49 million annually in the United States.

Black shank of tobacco is more severe in Georgia and Florida than in some of the tobacco-growing states farther north. The soil temperature appears to remain favorable (6) for disease development longer and is usually accompanied by abundant moisture, either rainfall or irrigation, and may increase the production of zoospores, which may be the predominant inoculum (4). In addition, mild winters probably favor propagule survival.

Procedures to manage tobacco black shank have consisted of long rotations, sanitation, multipurpose fumigants, and resistant cultivars (1,7). In 1980, metalaxyl became available for control of black shank and blue mold caused by *Peronospora tabacina* Adam on tobacco. Metalaxyl is specific against oomycetes and is very effective against *P. parasitica* var. *nicotianae* in vitro (3,10) and in vivo (3,8).

Tank mixing pesticides has become increasingly popular because of the energy and time savings associated with reduction of trips across fields with equipment. There are no reports, however, of comparisons of tank mixing metalaxyl with nonfumigant nematicides/insecticides, although Rich et al (9) demonstrated its use as a transplant water treatment when used with a fumigant. We report results of a 3-yr study of tank mixing metalaxyl and other systemic oomycete-specific fungicides with nematicides/insecticides and of using metalaxyl with soil fumigants on control of tobacco black shank.

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## MATERIALS AND METHODS

Field tests (1979–1981) were conducted in a Fuquay loamy sand (88% sand, 8% silt, and 4% clay) heavily infested with *P. parasitica* var. *nicotianae*. The test area was artificially infested with the fungus in the spring of 1978. A randomized complete block design was used; four replicates with two 9.8-m long rows were spaced 1.2 m apart. Plots were separated by two border rows in 1979 and by a vacant row in 1980 and 1981. Plants of *N. tabacum* 'NC2326,' a cultivar with low resistance to black shank, were planted 50 cm apart in each row with a tractor-mounted transplanter adjusted to deliver 1,870 L of water per hectare on 10 and 24 April and 31 March in 1979, 1980, and 1981, respectively.

**Chemical treatments.** Soil fumigant treatments were 1) DD-MENCS, 28.0 and 46.7 L/ha; 2) EDB-C30 (36% ethylene dibromide and 30% chloropicrin), 56.1 L/ha; 3) EDB-C45 (54% ethylene dibromide and 45% chloropicrin), 28.0 L/ha; and 4) EDB-90 (90% ethylene dibromide), 37.4 L/ha. All fumigants were injected 20 cm deep in the row with a single chisel and sealed with disk bedders 3–6 wk before transplanting. Nonfumigant nematicide/insecticide treatments were: 1) ethoprop, 9.0 kg a.i./ha; 2) ethoprop-disulfoton, 9.0+4.5 kg a.i./ha; 3) fensulfothion plus disulfoton, 9.0 + 4.5 kg a.i./ha; 4) fensulfothion plus phenamiphos, 4.5 + 2.25 kg a.i./ha; 5) phenamiphos, 6.7 kg a.i./ha; 6) phenamiphos plus carbofuran, 5.0 + 5.0 kg a.i./ha; 7) aldicarb, 3.4 kg a.i./ha; and 8) chlorpyrifos, 2.2 kg a.i./ha. Nonfumigant nematicides/insecticides were broadcast in 280 L/ha of water with a tractor-mounted sprayer or with a tractor-mounted granular applicator, depending on formulation, and incorporated with a tractor-powered rototiller into the top 15-cm soil layer before transplanting. Aldicarb was applied with a granular applicator but incorporated only with the normal bedding-planting procedure. Fungicides used in the test were 1) metalaxyl; 2) propamocarb; 3) RE26745, 2-methoxy-*N*-(2,6-dimethylphenyl)-*N*-(tetrahydro-2-oxo-3-furanyl) acetamide (Chevron); and 4) RE26940, 2-methoxy-*N*-(2,6-dimethylphenyl)-*N*-(tetrahydro-2-oxo-3-thiofuranyl) acetamide (Chevron). Rates of fungicides are shown in Tables 1–3. Fungicides were applied either separately, in combinations, or tank mixed (TM) with nonfumigant nematicides/insecticides with a power sprayer in 280 L of water per hectare and incorporated into the top 15-cm soil layer with a tractor-powered rototiller. Exceptions were fungicides applied to plots treated with fumigants. In these treatments, the fungicides were sprayed over the beds and incorporated only by the bedding and transplanting procedure to avoid contaminating the fumigated soil. Fungicides applied at transplanting were delivered through the transplant water (TPW). Layby (L) treatments were applied with a knapsack sprayer 5–6 wk after transplanting, in 280 L of water per hectare as a directed spray to the base of the plants in a 30-cm band and incorporated into the soil by cultivation. Fertilization, cultivation, insect control, and sucker control followed Georgia Extension recommendations (7). Plots were irrigated as required.

**Data collection.** Observations for phytotoxicity were made throughout the growing season. Height measurements were made in 1979 and 1980 on 20 plants per replicate before terminal bud removal. Numbers of living plants per plot were determined 2–4 wk after transplanting (initial stand count), then every 2 wk until final harvest. Percent disease was calculated by determining the percentage of plants that were dead at final harvest. Leaves were harvested three times as they ripened and green weights were recorded and converted to dry weight basis.

Disease index was calculated as a weighted system of disease analysis and disease progression. Plants that died early in the season were weighted heavier than plants that died late in the season. From the data collected on numbers of living plants at each 2-wk interval, the following formula was used to determine disease index:

$$DI = \frac{\sum_{i=1}^{n} Xi\,(100 - (i\text{-}1)\,\frac{100}{n})}{I}$$

where $i$ = ordinal evaluation number, $n$ =

**Table 1.** Control of tobacco black shank with combinations of fungicides and nematicides/insecticides in 1979

| Fungicide and formulation | Rate (kg a.i./ha) | Application method[y] | Nematicide/insecticide and formulation | Disease index[z] | Disease (%) | Yield (kg/ha) |
|---|---|---|---|---|---|---|
| Metalaxyl 2E | 2.24 | PPI (TM) | Ethoprop-disulfoton 4-2EC | 0.0 a | 0.0 a | 4,393 a |
| Metalaxyl 2E | 2.24 | PPI | EDB-90 | 3.7 abcd | 7.2 abcde | 4,370 a |
| Metalaxyl 2E | 1.12 + 0.56 | PPI + L (TM) | Phenamiphos 3SC | 0.8 a | 0.8 ab | 4,310 ab |
| Metalaxyl 2E | 2.24 | PPI | EDB-C30 | 2.9 abc | 3.9 abc | 4,159 ab |
| Metalaxyl 2E | 2.24 | PPI (TM) | Ethoprop 6E | 1.8 ab | 6.8 abcd | 4,063 abc |
| Propamocarb 6SC | 4.48 | TPW | Ethoprop 10G | 5.7 abcdef | 14.2 abcdefg | 3,965 abcd |
| Metalaxyl 2E | 0.14 + 1.12 | TPW + L | Phenamiphos 3SC | 1.5 ab | 1.6 ab | 3,941 abcd |
| RE26940 50WP | 0.56 + 0.56 | TPW + L | Phenamiphos 3SC | 4.8 abcde | 13.3 abcdefg | 3,936 abcd |
| Metalaxyl 2E | 0.56 + 0.56 | PPI + L (TM) | Phenamiphos 3SC | 1.2 ab | 3.1 abc | 3,927 abcd |
| Metalaxyl 2E | 2.24 | PPI (TM) | Fensulfothion-phenamiphos 4-2EC | 2.2 ab | 3.9 abc | 3,912 abcd |
| Metalaxyl 2E | 2.24 | PPI (TM) | Phenamiphos 3SC | 0.7 a | 3.1 abc | 3,874 abcd |
| Propamocarb 6SC | 4.48 | TPW | DD-MENCS (28 L/ha) | 6.2 abcdef | 17.2 cdefgh | 3,801 abcde |
| Metalaxyl 2E | 1.12 + 0.14 | PPI + TPW (TM) | Phenamiphos 3SC | 3.6 abcd | 10.7 abcdef | 3,771 abcde |
| Propamocarb 6SC | 4.48 | TPW | EDB-C30 | 7.8 bcdefg | 22.6 efghi | 3,639 abcde |
| Propamocarb 6SC | 4.48 | TPW | DD-MENCS (46.7 L/ha) | 6.2 abcdef | 20.4 cdefghi | 3,638 abcde |
| Propamocarb 6SC | 4.48 | TPW | Phenamiphos 3SC | 5.9 abcdef | 14.9 abcdefg | 3,594 abcde |
| RE26745 50WP | 0.56 + 0.56 | TPW + L | Phenamiphos 3SC | 5.5 abcdef | 13.0 abcdefg | 3,543 abcde |
| Control | | | Phenamiphos 3SC | 10.9 efgh | 25.3 fghij | 3,422 abcde |
| Propamocarb 6SC | 4.48 | TPW | Fensulfothion-phenamiphos 4-2EC | 8.1 bcdefg | 16.1 bcdefgh | 3,410 abcde |
| Control | | | EDB-C30 | 14.4 gh | 32.8 ij | 3,399 abcde |
| Propamocarb 6SC | 2.24 | TPW | DD-MENCS (28 L/ha) | 12.1 fgh | 30.5 hij | 3,295 bcdef |
| Propamocarb 6SC | 3.36 | TPW | DD-MENCS (28 L/ha) | 12.4 fgh | 33.0 ij | 3,062 cdef |
| Propamocarb 6SC | 4.48 | TPW | Ethoprop-disulfoton 10-5G | 9.9 cdefgh | 27.6 ghij | 2,989 def |
| Propamocarb 6SC | 4.48 | TPW | EDB-90 | 11.2 efgh | 32.9 ij | 2,981 def |
| Control | | | EDB-90 | 10.4 defgh | 23.5 fghij | 2,969 def |
| Control | | | Ethoprop 10G | 11.8 efgh | 26.7 ghij | 2,944 def |
| Control | | | Ethoprop-disulfoton 10-5G | 10.5 efgh | 22.1 defghi | 2,819 ef |
| Control | | | | 15.8 h | 38.8 j | 2,296 f |

[y] PPI is preplant incorporated; L is layby, TM is tank mixed with nematicides as in PPI treatment, and TPW is transplant water.
[z] Means in columns followed by common letters are not significantly different according to Waller-Duncan K-ratio $t$ test ($P = 0.05$).

**Table 2.** Control of tobacco black shank with fungicide and nematicide/insecticide combinations in 1980

| Fungicide and formulation | Rate (kg a.i./ha) | Application method[y] | Nematicide/insecticide and formulation | Disease index[z] | Disease (%) | Yield (kg/ha) |
|---|---|---|---|---|---|---|
| Metalaxyl 2E | 2.24 | PPI (TM) | Phenamiphos 3SC | 2.5 a | 3.5 a | 5,757 a |
| Metalaxyl 2E | 2.24 | PPI | EDB-C45 | 4.1 a | 11.3 a | 5,171 ab |
| Metalaxyl 2E | 2.24 | PPI | EDB-90 | 5.2 a | 15.5 ab | 4,912 ab |
| Metalaxyl 2E | 2.24 | PPI (TM) | Ethoprop-disulfoton 4-2EC | 7.5 abc | 19.5 abc | 4,896 ab |
| Metalaxyl 2E | 2.24 | PPI | Aldicarb 15G | 8.6 abc | 22.0 abc | 4,733 ab |
| Metalaxyl 2E | 2.24 | PPI (TM) | Fensulfothion-disulfoton 4-2SC | 6.9 ab | 20.0 abc | 4,707 ab |
| Metalaxyl 2E | 2.24 | PPI (TM) | Ethoprop 6E | 11.2 abcd | 33.0 bcd | 4,518 b |
| Propamocarb 6L | 3.36 | TPW | EDB-C45 | 20.2 efgh | 48.3 defg | 3,008 c |
| Propamocarb 6L | 3.36 | TPW | Ethoprop 6E | 17.7 ef | 48.3 defg | 2,915 cd |
| Control | | | EDB-C45 | 20.7 efgh | 46.3 defg | 2,855 cd |
| Propamocarb 6L | 3.36 | TPW | EDB-90 | 15.9 bcde | 41.5 def | 2,723 cd |
| Propamocarb 6L | 3.36 | TPW | Aldicarb 15G | 23.4 efgh | 59.0 efg | 2,516 cde |
| Propamocarb 6L | 3.36 | TPW | Phenamiphos 3SC | 24.6 efgh | 62.3 g | 2,330 cdef |
| Control | | | Ethoprop 6E | 18.3 defg | 38.8 cde | 2,325 cdef |
| Control | | | Ethoprop-disulfoton 4-2EC | 26.1 fgh | 58.3 efg | 2,270 cdef |
| Propamocarb 6L | 3.36 | TPW | Ethoprop-disulfoton 4-2EC | 22.6 efgh | 57.8 efg | 2,103 cdef |
| Control | | | Aldicarb 15G | 28.5 gh | 63.3 g | 1,839 cdef |
| Control | | | Phenamiphos 3SC | 28.4 gh | 60.7 fg | 1,785 cdef |
| Control | | | EDB-90 | 27.4 gh | 58.5 efg | 1,736 def |
| Control | | | | 29.8 h | 62.3 g | 1,421 ef |
| Propamocarb 6L | 3.36 | TPW | Fensulfothion-disulfoton 4-2SC | 28.3 gh | 61.3 g | 1,214 f |

[y] PPI is preplant incorporated, TM is tank mixed with nematicide as a PPI treatment, and TPW is transplant water.
[z] Means in columns followed by common letters are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

number of evaluations (excluding initial stand count), X = number of dead plants since last count, and I = initial number of plants in plot.

**Nematode evaluations.** Ten 2.5-cm diameter soil cores per plot were collected in 1979 and 1981 from the root zone to a depth of 15 cm at planting and at harvest. Nematodes were extracted from 150 $cm^3$ of soil by the centrifuge-sugar-flotation method (2). Root-knot ratings (percent roots galled) were recorded at midseason (plants sacrificed) and at final harvest in 1979 and at final harvest in 1981. Nematode damage was not evaluated in 1980.

## RESULTS

The test area was uniformly infested with *P. parasitica* var. *nicotianae* as judged by disease levels in the control plots. Disease levels increased during the test period, which was indicated by the increase in percent disease and disease index over three years (Tables 1–3). Although irrigation was required each year, less rainfall occurred during the growing season in 1980 than in 1981 and 1979; however, this did not appear to interfere with evaluation of the chemicals. Disease control ranged from 47 to 100%, depending on the rate, method of application, and nematicide/insecticide or fumigant used (Tables 1–3).

The best disease control generally occurred when metalaxyl was preplant incorporated at 2.24 kg a.i./ha regardless of the nematicide/insecticide or fumigant used (Tables 1–3). In plots treated with metalaxyl and EDB-C30 or fensulfothion-phenamiphos or phenamiphos, however, yields were not greater than in appropriate controls (Table 1). In 1980, black shank in plots treated with metalaxyl plus ethoprop and metalaxyl plus fensulfothion-disulfoton was not reduced over the control, although yield was increased in the metalaxyl with ethoprop treatment (Table 2). In 1981, all treatments including metalaxyl were lower in disease index and percent disease and higher in yield than the appropriate controls (Table 3). When metalaxyl was used in combination with phenamiphos plus carbofuran, ethoprop, phenamiphos, and ethoprop-disulfoton, however, disease incidence was lower and yields were higher than with metalaxyl alone.

The disease incidence in plots treated with phenamiphos and split applications of metalaxyl applied as PPI and L was less than in the control, but yields were not greater (Table 1). A split application of metalaxyl applied as PPI and TPW, however, did not reduce disease or increase yield compared with the phenamiphos control. In 1979, treatments with propamocarb did not influence yield or disease compared with appropriate controls (Table 1). In 1980, lower disease indices were recorded from plots treated with propamocarb and EDB-90 than from the EDB-90 control, but percent disease and yields between the treatments were not significantly different (Table 2). Yields and disease incidence of all other treatments with propamocarb were not significantly different from that of the nematicide/insecticide control. RE26940 or RE26745 did not decrease disease incidence or increase yield compared with the phenamiphos control (Table 1).

Yields of plants from the phenamiphos and EDB-C30 controls in 1979 (Table 1), the EDB-C45 control in 1980 (Table 2), and the ethoprop-disulfoton control in 1981 (Table 3) were significantly greater than the yield from the untreated control, but disease indices and percent disease were not affected by treatments. The disease index in plots treated with ethoprop in 1981 (Table 3) was less than in the untreated control, but yield and percent disease were not affected by treatment.

Correlation coefficients between yield versus percent disease and yield versus disease index were $r = -0.64$ and $r = -0.64$ (1979), $r = -0.97$ and $r = -0.91$ (1980), and $r = -0.94$ and $-0.95$ (1981), respectively.

Population levels of root-knot nematodes (*Meloidogyne incognita* (Kofoid & White) Chitwood) in 1979 and 1981 were relatively low in the soil and distribution was erratic (*unpublished*), but appreciable damage occurred in some plots as indicated by root-knot galling (*unpublished*). The percent of the root system galled at final harvest ranged from 4.7 for the phenamiphos control to 49.1 for the propamocarb (2.24 kg a.i./ha) (TPW) plus DD-MENCS (28.1 L/ha) treatment in 1979 and from 20.8 for the ethoprop-disulfoton control to 43.5 for metalaxyl (2.24 kg/ha) treatments in 1981.

Height measurements of plants from plots in 1979 indicated that DD-MENCS at 7.6 L/ha significantly increased the height of plants over the control at 8 wk, but the differences were not evident at the end of the season. In 1980, measurements taken 7 and 9 wk after planting indicated that none of the treatments were significantly different in height compared with the control.

**Table 3.** Control of black shank with preplant incorporated tank mixes[y] of nematicides/insecticides with metalaxyl in 1981

| Fungicide and formulation | Rate (kg a.i./ha) | Nematicide/insecticide and formulation | Disease index[z] | Disease (%) | Yield (kg/ha) |
|---|---|---|---|---|---|
| Metalaxyl 2E | 2.24 | Phenamiphos 3SC + carbofuran 4F | 1.5 a | 7.2 a | 5,051 a |
| Metalaxyl 2E | 2.24 | Ethoprop 6EC | 0.9 a | 5.6 a | 5,024 a |
| Metalaxyl 2E | 2.24 | Phenamiphos 3SC | 1.1 a | 5.0 a | 5,001 a |
| Metalaxyl 2E | 2.24 | Ethoprop-disulfoton 4-2EC | 1.3 a | 6.7 a | 4,861 a |
| Metalaxyl 2E | 2.24 | Fensulfothion-phenamiphos 4-2EC | 3.2 ab | 12.3 ab | 4,685 ab |
| Metalaxyl 2E | 2.24 | Chlorpyrifos 4EC | 9.3 b | 31.7 c | 4,040 bc |
| Metalaxyl 2E | 2.24 | | 7.7 b | 26.9 bc | 3,864 c |
| Control | | Ethoprop-disulfoton 4-2EC | 21.8 cd | 61.8 d | 2,914 d |
| Control | | Ethoprop 6EC | 20.8 c | 64.0 d | 2,858 de |
| Control | | Control | 27.2 de | 71.6 d | 2,322 ef |
| Control | | Chlorpyrifos 4EC | 30.4 e | 73.7 d | 2,073 f |

[y] All treatments of metalaxyl followed by a nematicide/insecticide were preplant incorporated tank mixes.

[z] Means in columns followed by common letters are not significantly different from each other ($P = 0.05$) according to Waller-Duncan K-ratio $t$ test.

## DISCUSSION

Although propamocarb was not included in our trials in 1981, other tests in 1981 with propamocarb (*unpublished*) indicated trends similar to those obtained in 1979 and 1980. Reilly (8) in Virginia and Rich et al (9) in Florida found that propamocarb decreased disease incidence over the controls. The discrepancy may be caused by different environmental conditions inherent to the flue-cured tobacco regions, cultivars used in testing, or virulence or population levels of the pathogens in the test areas.

The test area had an erratic distribution of *M. incognita* juveniles and the percentage of root systems galled did not differ significantly among treatments. However, a high percentage of plants (38.8–71.6%) in the control plots were dead at the end of the season, apparently from *P. parasitica* var. *nicotianae*, so it was difficult to evaluate for root-knot damage. It is unlikely that nematodes would increase on a decaying root system. These observations indicate that any differences in the amount of nematode control that may have been caused by nematicides was obscured by disease caused by *P. parasitica* var. *nicotianae*. Phenamiphos in 1979 and ethoprop-disulfoton in 1981 increased yield over the control, and in 1981, ethoprop decreased disease index. These results indicate that in these treatments, nematodes were controlled and damage to root systems and predisposition to black shank were reduced (5) or that the nematicides may have some fungicidal properties. Additional evidence of decreased black shank when nematodes are controlled is indicated in the 1981 data (Table 3). In four of the six treatments that had a nematicide/insecticide tank mixed with metalaxyl, disease incidence was lower and in five of the six, yields were higher than metalaxyl alone. Nematicide/insecticide mixes with metalaxyl that did not decrease disease or increase yield over metalaxyl alone may reflect poor nematode control. Plots treated with EDB-C30 in 1979 and EDB-C45 in 1980 also increased yield over the control, but these materials contain chloropicrin, which is fungicidal.

Metalaxyl, propamocarb, RE26940, and RE26745 represent a new class of oomycete-specific systemic fungicide. Past recommendations for control of black shank include long rotations, sanitation, use of multipurpose fumigants, and resistant cultivars that are inferior in quality (7). Metalaxyl, which has demonstrated excellent control of black shank of tobacco when used in tank mixes or in combinations with commonly used nematicide/insecticides and soil fumigants, will be an important consideration in tobacco black shank control programs.

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