# Metalaxyl and Fenamiphos Applied Through Irrigation Water to Control Black Shank/Root-Knot Complex on Tobacco

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**ABSTRACT**

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Tobacco (*Nicotiana tabacum*) was transplanted in 1983–1984 in a field site heavily infested with *Phytophthora parasitica* var. *nicotianae* (*P. p. nicotianae*) and *Meloidogyne* spp. (about 90% *M. incognita* race 1 and 10% *M. javanica*). NC 2326 (low resistance to *P. p. nicotianae* and no resistance to *M. incognita*), Coker 48 (moderate resistance to *P. p. nicotianae* and no resistance to *M. incognita*), NC 95 (low resistance to *P. p. nicotianae* and high resistance to *M. incognita*), and Speight G-28 (moderate resistance to *P. p. nicotianae* and high resistance to *M. incognita*) were tested. Metalaxyl (2.24 kg a.i./ha), fenamiphos (6.7 kg a.i./ha), both chemicals applied together, and a nontreated control were the treatments. Chemicals were applied by two methods, with a tractor-powered sprayer-Rototiller and incorporated into the top 15-cm soil layer and via an experimental irrigation simulator with 2.5 mm of water. The black shank/root-knot complex was best managed where both chemicals were applied together. Resistance to *M. incognita* races 1 and 3 and *P. p. nicotianae* limited loss from *P. p. nicotianae*, but resistance to *P. p. nicotianae* did not prevent damage from *Meloidogyne* spp. Roots of cultivars without resistance to *M. incognita* contained a mixed population of nematodes (81–100% *M. incognita* and 0–19% *M. javanica*), and roots of cultivars with resistance to *M. incognita* contained 100% *M. javanica*. Cultivars resistant to *M. incognita* may selectively shift soil populations to other species of *Meloidogyne* from polyspecific communities. Application of metalaxyl + fenamiphos through irrigation water was equally effective and more economical than application with conventional tractor-powered equipment in reducing the black shank/root-knot complex.

Application of agrichemicals through irrigation water (chemigation) has been under investigation for several years. Chemigation using fertilizers and several pesticides for control of nematodes, weeds, insects, and disease organisms has been successful (2–4,8,10–12,15). Chemigation has several advantages over application with tractor-powered equipment, particularly that of reduced cost of pesticide application. Application costs for aircraft or boom sprayers range from \$5.75 to \$12.50/ha compared with \$0.75/ha for center-pivot irrigation systems delivering 2.5 mm of water (3). Costs of pesticides and application often amount to 25% of crop production expense, which may be more than \$1,822/ha. Because about 95% of tobacco grown in Georgia is irrigated each year, the economical advantage of chemigation over conventional methods warrants study.

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Fenamiphos and metalaxyl control nematodes and *Phytophthora parasitica* Dastur var. *nicotianae* (Breda de Haan) Tucker (*P. p. nicotianae*), respectively, in tobacco (6,13,19,20) and are recommended in Georgia for black shank control (1). Few data are available on the efficacy of fenamiphos applied through irrigation water for nematode management on crops (10–12). No data are available on control of nematodes or *P. p. nicotianae* in tobacco with these chemicals applied through irrigation water. Currently, about 10% of tobacco in Georgia is produced under center-pivot irrigation systems. Consequently, growers have questions about application and efficacy of pesticides applied through these systems.

This research compares the efficacy of both fenamiphos and metalaxyl for control of root-knot nematodes (*Meloidogyne* spp.) and *P. p. nicotianae* applied through irrigation water with conventional application via tractor-powered sprayer-Rototiller.

## MATERIALS AND METHODS

The soil in the test area consisted of Fuquay loamy sand (88% sand, 8% silt, and 4% clay, pH 5.5) infested with *P. p. nicotianae* and with *Meloidogyne incognita* (Kofoid & White) Chitwood (about 90%) and *M. javanica* (Treub) Chitwood (about 10%). A randomized complete block design was used with four replicates. Metalaxyl and/or fenamiphos treatments and methods of application were the main plots. Each plot was 9.8 m long with transplants spaced 46 cm apart in rows spaced 1.2 m apart. In 1983, plots consisted of two rows each of NC 95 (high resistance to *M. incognita*, low resistance to *P. p. nicotianae*) and Coker 48 (no resistance to root-knot nematodes, moderate resistance to *P. p. nicotianae*) transplanted on 20 April. Only the interior row of each cultivar was used for data collection. In 1984, four-row plots consisting of NC 95, Coker 48, NC 2326 (no resistance to root-knot nematodes, low resistance to *P. p. nicotianae*), and Speight G-28 (high resistance to *M. incognita*, moderate resistance to *P. p. nicotianae*) bordered by one row of NC 2326 were transplanted on 13 April. Fertilizers, herbicides (isopropalin, napropamide, and pebulate), insecticides (chlopyrifos, methomyl, and acephate) and growth regulators (maleic hydrazide and fatty alcohols) were used according to University of Georgia Extension Service recommendations (14). Plots were irrigated as required.

Metalaxyl (2.24 kg a.i./ha) and fenamiphos (6.7 kg a.i./ha) were applied broadcast alone and combined as a tank mix with a tractor-powered sprayer-Rototiller to a depth of 15 cm in 280 L of spray per hectare or injected alone or simultaneously through an irrigation simulator. The irrigation simulator, a hydraulically-driven unit, was equipped with injection pumps, control valves, and a boom to deliver water and chemicals (5,24). Water was pumped from a nurse tank through the simulator, and chemicals were applied to plots in 2.5 mm of water. All applications were made just before bedding and transplanting.

Leaves were harvested from plants four times in 1983 and three times in 1984 as they ripened. Total green weight was converted to dry weight using a 0.20 factor, and yield per hectare was calculated for each plot. Every 2 wk, numbers of dead plants were recorded from each plot and percent disease (at final harvest) and disease index (a weighted system of disease analysis and disease progression) were calculated (6). A plant was considered dead when permanent wilting and a black stem lesion was observed at or above ground level.

Soil samples (20 cores 21 × 20 cm) containing both rhizospheric and nonrhizospheric soil were collected between plants in the row for nematode assays 2 and 17 wk after planting in 1983 and 22 wk after planting in 1984. A 150-$cm^3$ aliquot of mixed soil was processed by a centrifugal-flotation method (9). Two plants per plot were uprooted and rated for root-knot nematode damage 12 wk after transplanting in 1983. All plants were removed from the soil and rated for galls 17 and 22 wk after transplanting in 1983 and 1984, respectively. The root-gall index ratings were based on a scale of 1–5 as follows: 1 = no galling, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% of roots galled. After final harvest, root samples were collected from the cultivars in control plots for nematode species identification. Eighty mature females each from NC 95 and Coker 48 in 1983 and 20 females each from NC 95, Coker 48, Speight G-28, and NC 2326 in 1984 were examined for species determination using perineal patterns (22). Data were analyzed using ANOVA, Duncan's multiple range test, regression analysis, and least-squares means.

## RESULTS

The 1983 growing season was hot and dry with 37.3 cm of rain. Tobacco plots required irrigation in June and July. Black shank and root-knot nematode damage developed to a severe level in nontreated plots. Rainfall in 1984 was abundant (56.9 cm) except in June, and disease expression was lower than in 1983.

**1983 Test.** Numbers of juveniles of *Meloidogyne* spp. were low and did not differ among treatments in Coker 48 plots 2 wk after transplanting. Numbers in NC 95 plots treated with metalaxyl + fenamiphos via simulator (S) and fenamiphos via conventional (C) methods of application were lower than those in control plots (Table 1). At final harvest, 17 wk after transplanting, plots treated with metalaxyl (C) had a higher number of juveniles in Coker 48 plots than did nontreated plots. Numbers of *Meloidogyne* spp. juveniles in plots planted to NC 95 were not affected by treatments 17 wk after planting. Root-gall indices of NC 95 were low and not affected by chemical treatments 12 and 17 wk after transplanting; those of Coker 48 were reduced in all treatments containing fenamiphos for both methods of application 12 and 17 wk after transplanting.

Percent disease (at final harvest) and disease index were lower in all treatments except fenamiphos (C) on both Coker 48 and NC 95 (Table 2). Percent disease in Coker 48 was lower in metalaxyl + fenamiphos (C and S) than fenamiphos (C and S) treatments, but did not differ from metalaxyl (C or S) treatments. All plots treated with metalaxyl resulted in lower disease indices than those treated with fenamiphos (C or S) in Coker 48 and fenamiphos (C) in NC 95. Yield was increased by all treatments in NC 95 and by all treatments except fenamiphos (C) in Coker 48. Yields from plots treated with metalaxyl + fenamiphos (C) and (S) were higher than those from plots treated with metalaxyl (C) and higher than those from plots treated with fenamiphos (C and S) in Coker 48. Similarly, yields for NC 95 from all plots treated with metalaxyl were higher than those from plots treated with fenamiphos (C).

Using the least-squares means as a

**Table 1.** Effects of metalaxyl and/or fenamiphos applied by two application methods on numbers of *Meloidogyne* spp. juveniles and root-gall indices of two cultivars of tobacco (1983)

| Treatment and rate (kg a.i./ha) | Application method[w] | Coker 48: *Meloidogyne* spp. juveniles/150 $cm^3$ soil | | Coker 48: Root-gall index[x] | | NC 95: *Meloidogyne* spp. juveniles/150 $cm^3$ soil | | NC 95: Root-gall index | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2 wk[y] | 17 wk | 12 wk | 17 wk | 2 wk | 17 wk | 12 wk | 17 wk |
| Metalaxyl (2.24) + fenamiphos (6.7) | S | 3 a[z] | 63 b | 2.0 bc | 2.1 b | 3 b | 3 a | 1.1 a | 1.0 a |
| Metalaxyl (2.24) + fenamiphos (6.7) | C | 1 a | 13 b | 1.1 c | 1.7 b | 11 ab | 0 a | 1.0 a | 1.0 a |
| Metalaxyl (2.24) | S | 10 a | 203 b | 3.0 ab | 4.3 a | 11 ab | 6 a | 1.3 a | 1.3 a |
| Metalaxyl (2.24) | C | 13 a | 668 a | 3.9 a | 4.7 a | 13 ab | 25 a | 1.3 a | 1.5 a |
| Fenamiphos (6.7) | S | 0 a | 140 b | 2.1 bc | 1.9 b | 10 ab | 6 a | 1.1 a | 1.1 a |
| Fenamiphos (6.7) | C | 0 a | 3 b | 1.1 c | 1.8 b | 0 b | 1 a | 1.0 a | 1.0 a |
| Control | ··· | 9 a | 278 b | 3.9 a | 4.4 a | 16 a | 16 a | 1.2 a | 1.0 a |

[w] Conventional (C) application was with a tractor-powered sprayer-Rototiller, and materials applied with an irrigation simulator (S) were injected into the water and applied with 2.5 mm of water.
[x] Scale of 1–5, where 1 = no galling, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100% of roots galled.
[y] Intervals are weeks after transplanting.
[z] Means in columns followed by the same letter are not significantly different according to Duncan's multiple range test ($P = 0.05$).

**Table 2.** Disease incidence and yield of Coker 48 and NC 95 treated with metalaxyl and/or fenamiphos applied conventionally or through irrigation water (1983)

| Treatment and rate (kg a.i./ha) | Application method[x] | Coker 48: Disease (%) | Coker 48: Disease index[y] | Coker 48: Yield (kg/ha) | NC 95: Disease (%) | NC 95: Disease index | NC 95: Yield (kg/ha) |
|---|---|---|---|---|---|---|---|
| Metalaxyl (2.24) + fenamiphos (6.7) | S | 3.8 d[z] | 0.5 c | 3,283 a | 6.3 b | 1.6 c | 2,610 a |
| Metalaxyl (2.24) + fenamiphos (6.7) | C | 1.3 d | 1.1 c | 3,246 a | 4.9 b | 1.2 c | 2,658 a |
| Metalaxyl (2.24) | S | 10.2 d | 0.6 c | 2,704 ab | 6.6 b | 2.1 c | 2,503 a |
| Metalaxyl (2.24) | C | 15.8 cd | 4.6 c | 2,585 bc | 9.9 b | 2.5 c | 2,433 a |
| Fenamiphos (6.7) | S | 31.8 bc | 11.7 b | 2,552 bc | 24.8 b | 11.6 bc | 2,209 ab |
| Fenamiphos (6.7) | C | 47.0 ab | 21.7 a | 2,029 cd | 52.8 a | 23.0 ab | 1,743 b |
| Control | ··· | 62.0 a | 24.7 a | 1,661 d | 66.9 a | 32.8 a | 1,172 c |

[x] Conventional (C) application was with a tractor-powered sprayer-Rototiller, and materials applied with an irrigation simulator (S) were injected into the water and applied with 2.5 mm of water.
[y] Calculated as a weighted system of disease analysis and progression (6).
[z] Means in columns followed by the same letter are not significantly different according to Duncan's multiple range test ($P = 0.05$). Percent disease was taken at final harvest.

method of analysis, no differences occurred in yield and root-gall indices for any of the treatments between methods of application on either Coker 48 or NC 95. On NC 95, however, percent disease was higher ($P = 0.05$) in plots treated with fenamiphos (C) than in those treated with fenamiphos (S). No other differences occurred between methods of application for percent disease on either cultivar.

Examination of 80 females from galled roots in control plots of each of the two tobacco cultivars yielded 100% *M. javanica* and 0% *M. incognita* in NC 95 and 19% *M. javanica* and 81% *M. incognita* in Coker 48.

Correlation coefficients for percent disease and disease index vs. yield were −0.93 and −0.86 for Coker 48 and −0.92 and −0.93 for NC 95, respectively. No significant negative correlations occurred between nematode populations or root-gall indices and yield for either cultivar.

**1984 Test.** None of the treatments reduced ($P = 0.05$) the numbers of juveniles of *Meloidogyne* spp. in cultivars resistant to *M. incognita* (NC 95 and Speight G-28), but numbers of juveniles from NC 95 plots treated with metalaxyl (S) were greater than those from the control plots (Table 3). Only fenamiphos (C) reduced numbers of juveniles in plots planted with Coker 48. All treatments containing fenamiphos reduced numbers of juveniles in plots planted with NC 2326. All treatments containing fenamiphos (C or S) reduced root-gall indices on Coker 48 and NC 2326, but chemical treatments did not reduce root-gall indices on NC 95 and Speight G-28.

All treatments except metalaxyl (S) reduced percent disease on Coker 48 (Table 4). All treatments except metalaxyl (S) and fenamiphos (S) reduced percent disease on NC 2326. None of the treatments reduced percent disease on NC 95 or Speight G-28. All treatments reduced disease index on Coker 48, whereas none reduced disease index on Speight G-28. All treatments except metalaxyl (S) and fenamiphos (S) reduced disease index on NC 2326 and NC 95.

Yield was increased by metalaxyl + fenamiphos (C) and (S) and fenamiphos (C) on Coker 48 and by metalaxyl + fenamiphos (S) on NC 2326 and Speight G-28 but not by any treatment on NC 95 (Table 4).

The least-squares means method of analysis was used to detect differences in root-gall indices, percent disease, and yield between methods of application. Root-gall indices on Coker 48, percent disease on NC 95, and yield of NC 2326 were lower from plants grown in plots treated with fenamiphos (C) than in those grown in plots treated with fenamiphos (S). No other differences were detected between methods of application for any other parameters among the cultivars.

Species identification of *Meloidogyne* collected from galled roots of the four cultivars across treatments and replicates indicated the following species recovery: 0% *M. javanica* and 100% *M. incognita* on NC 2326, 100% *M. javanica* and 0% *M. incognita* on Speight G-28, 100% *M. javanica* and 0% *M. incognita* on NC 95, and 70% *M. javanica* and 30% *M. incognita* on Coker 48.

**Table 3.** Numbers of *Meloidogyne* spp. juveniles and root-gall indices for four tobacco cultivars treated with metalaxyl and/or fenamiphos applied conventionally or through irrigation water (1984)[w]

| | | Coker 48 | | NC 2326 | | NC 95 | | Speight G-28 | |
|---|---|---|---|---|---|---|---|---|---|
| Treatment and rate (kg a.i./ha) | Appl. method[x] | *Meloidogyne* spp. juveniles (no.) | Root-gall index[y] | *Meloidogyne* spp. juveniles (no.) | Root-gall index | *Meloidogyne* spp. juveniles (no.) | Root-gall index | *Meloidogyne* spp. juveniles (no.) | Root-gall index |
| Metalaxyl (2.24) + fenamiphos (6.7) | C | 283 bc[z] | 1.78 cd | 469 c | 1.65 b | 5 b | 1.02 b | 8 a | 1.04 b |
| Metalaxyl (2.24) + fenamiphos (6.7) | S | 403 abc | 2.57 bc | 578 c | 2.31 b | 20 b | 1.16 b | 13 a | 1.15 b |
| Metalaxyl (2.24) | C | 740 abc | 3.24 ab | 1,930 a | 3.92 a | 90 b | 1.35 ab | 45 a | 2.23 ab |
| Metalaxyl (2.24) | S | 1,303 a | 3.26 ab | 1,513 ab | 4.14 a | 245 a | 1.70 a | 103 a | 2.61 a |
| Fenamiphos (6.7) | C | 63 c | 1.46 d | 83 c | 1.74 b | 5 b | 1.03 b | 14 a | 1.09 b |
| Fenamiphos (6.7) | S | 450 abc | 2.42 bc | 771 bc | 2.49 b | 23 b | 1.12 b | 55 a | 1.45 ab |
| Control | ··· | 1,085 ab | 3.71 a | 1,898 a | 4.03 a | 80 b | 1.35 ab | 105 a | 2.11 ab |

[w] Larval numbers and root-knot indices were determined at final harvest, 22 wk after transplanting.
[x] Conventional (C) application was with a tractor-powered sprayer-Rototiller, and materials applied with an irrigation simulator (S) were injected into the water and applied with 2.5 mm of water.
[y] Scale of 1–5, where 1 = no galling, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 100% of roots galled.
[z] Means in columns followed by the same letter are not significantly different according to Duncan's multiple range test ($P = 0.05$).

**Table 4.** Disease incidence and yield of four tobacco cultivars treated with metalaxyl and/or fenamiphos applied conventionally or through irrigation water (1984)

| | | Coker 48 | | | NC 2326 | | | NC 95 | | | Speight G-28 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment and rate (kg a.i./ha) | Appl. method[x] | Disease (%) | DI[y] | Yield (kg/ha) | Disease (%) | DI | Yield (kg/ha) | Disease (%) | DI | Yield (kg/ha) | Disease (%) | DI | Yield (kg/ha) |
| Metalaxyl (2.24) + fenamiphos (6.7) | C | 11.7 c[z] | 4.1 c | 3,665 a | 10.7 b | 3.1 b | 3,642 ab | 5.9 b | 3.1 b | 3,821 a | 16.8 a | 5.4 a | 3,632 ab |
| Metalaxyl (2.24) + fenamiphos (6.7) | S | 2.9 c | 0.7 c | 3,980 a | 5.9 b | 2.1 b | 4,186 a | 10.0 ab | 2.1 b | 3,562 a | 4.5 a | 2.1 a | 4,479 a |
| Metalaxyl (2.24) | C | 17.6 bc | 4.9 bc | 2,619 bc | 13.3 b | 4.3 b | 3,358 ab | 0.0 b | 4.3 b | 3,023 a | 2.9 a | 1.3 a | 3,466 ab |
| Metalaxyl (2.24) | S | 33.9 ab | 10.8 b | 3,135 abc | 35.3 ab | 10.9 ab | 2,503 b | 17.9 ab | 10.9 ab | 2,731 a | 15.2 a | 3.1 a | 3,286 b |
| Fenamiphos (6.7) | C | 4.5 c | 1.4 c | 3,641 ab | 10.3 b | 4.0 b | 3,802 ab | 1.5 b | 4.0 b | 3,533 a | 7.4 a | 1.3 a | 3,961 ab |
| Fenamiphos (6.7) | S | 14.8 bc | 3.7 c | 3,137 abc | 30.9 ab | 11.3 ab | 2,807 b | 33.1 a | 11.3 ab | 3,102 a | 27.3 a | 9.2 a | 3,334 b |
| Control | ··· | 51.9 a | 19.5 a | 2,195 c | 54.3 a | 19.0 a | 2,805 b | 18.3 ab | 19.0 a | 3,018 a | 4.2 a | 0.8 a | 3,374 b |

[x] Conventional (C) application was with a tractor-powered sprayer-Rototiller, and materials applied with an irrigation simulator (S) were injected into the water and applied with 2.5 mm of water.
[y] Disease index: calculated as a weighted system of disease analysis and disease progression (6).
[z] Means in columns followed by the same letter are not significantly different according to Duncan's multiple range test ($P = 0.05$). Percent disease was taken at final harvest.

Correlation coefficients for NC 2326 and Coker 48, the two cultivars susceptible to *M. incognita*, indicated a positive ($P = 0.05$) relationship between root-gall indices vs. disease indices and root-gall indices vs. percent disease and a significant negative relationship with yield. Significant correlation coefficients for root-knot juveniles vs. yield and root-knot juveniles vs. root-gall indices were, respectively, −0.39 and 0.60 for Coker 48, 0.38 and 0.78 for NC 95 and Speight G-28, and 0.69 for numbers of root-knot juveniles vs. root-gall indices for NC 2326. Correlation coefficients for root-gall indices vs. yield, disease index, and percent disease were, respectively, −0.69, 0.69, and 0.72 and −0.54, 0.38, and 0.42 for Coker 48 and NC 2326. The correlation coefficient for root-gall indices vs. yield was −0.42 for NC 95. No significant correlations occurred among root-gall indices vs. yield, disease index, and percent disease for Speight G-28. Correlation coefficients for yield vs. disease index and percent disease were −0.73 and −0.77 for Coker 48, −0.69 and −0.67 for NC 2326, −0.52 and −0.51 for NC 95, and −0.61 and −0.59 for Speight G28.

## DISCUSSION

The black shank/root-knot disease complex was controlled on all cultivars tested in both years with the combination of metalaxyl + fenamiphos applied either by a conventional method or applied through irrigation water. Root-gall indices, percent disease, disease indices, and yields did not differ ($P = 0.05$) between the two methods of application. Differences that occurred between the methods of application for specific treatments occurred where nematodes or black shank were not controlled purposely. Recommendations for control of these pests would have included resistant cultivars and the use of metalaxyl + fenamiphos. Our data demonstrated that application of metalaxyl + fenamiphos through irrigation water is as effective as application with a tractor-powered sprayer-Rototiller in controlling the disease complex.

Tobacco cultivars have resistance to *M. incognita* (races 1 and 3), which is among the most common *Meloidogyne* species in the Southeast. Powell and Nusbaum (17) reported that *M. incognita incognita* and *M. incognita acrita* were the only two species important as pathogens of tobacco in North Carolina in 1960. More recently, *M. javanica* and *M. arenaria* have been reported to be important pathogens on flue-cured tobacco in the Coastal Plain (7,18,20,21). Our data demonstrated that a selection from predominantly *M. incognita* to *M. javanica* occurred when a cultivar had resistance to *M. incognita*.

Effects of nematode damage on severity of black shank have been demonstrated (17,20) and further substantiated throughout these data. Cultivars containing resistance to *M. incognita* showed lower black shank disease levels than cultivars without resistance to *M. incognita*. Also, with a number of cultivars, fenamiphos alone reduced ($P = 0.05$) disease levels. Cultivars with no resistance to *M. incognita* had significant positive correlations for root-gall indices vs. disease index and percent disease, whereas cultivars with resistance to *M. incognita* did not.

Application of pesticides through irrigation water is an effective and economical method of pesticide delivery (23). Cost of application of a pesticide is dependent on whether incorporation is required. Materials such as nematicides and soil fungicides require time and energy expenditures for soil incorporation. Estimated cost of mechanical incorporation of a pesticide ranges from $7.86 to $25.28/ha, whereas the cost of applying 1.3 cm of water is $5.60/ha (16,23). Thus if pesticides are applied through an irrigation system, savings of 29–78% in application costs could result. As the need for greater return on investment increases, we expect that more high-value crops like tobacco and vegetables will be produced under irrigation systems. Application technology, as described here, will help reduce unit production cost of tobacco and help reduce the need for expensive, inefficient power equipment to apply and incorporate metalaxyl and fenamiphos without sacrificing efficacy.


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