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Control of *Globodera tabacum solanacearum* by Alternating Host Resistance and Nematicide[1]

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Abstract: The feasibility of alternating use of resistant vs. susceptible flue-cured tobacco cultivars to improve control of *Globodera tabacum* subsp. *solanacearum* (TCN) was investigated at two Virginia locations in 1984–86. Post-harvest TCN population densities were reduced in each year of the study when fenamiphos was used with a TCN-resistant cultivar (NC 567), relative to susceptible cultivars (K 326 or Mc 944). Using NC 567 with fenamiphos also reduced preplant TCN population densities in the next growing season. Egg population densities before planting in 1986 were significantly lower in plots planted with NC 567 in 1984, even when a susceptible cultivar had been planted in 1985. Use of fenamiphos with NC 567 in 1984 and 1985 further reduced preplant egg population densities in 1986. Economic returns were significantly greater in 1984 when NC 567 was used with fenamiphos, rather than a susceptible cultivar. Treatments involving fenamiphos and (or) NC 567 in 1984 and 1985 resulted in higher economic returns in 1986 than did treatments using a susceptible cultivar without fenamiphos in both previous years. Economic returns were highest in 1986 when fenamiphos and NC 567 were used in 1984 and 1985 and a susceptible cultivar was planted in 1986.

Key words: fenamiphos, *Globodera tabacum solanacearum,* nematode management, *Nicotiana tabacum,* resistance, tobacco, tobacco cyst nematode.

Tobacco cyst nematodes *Globodera tabacum* subsp. *solanacearum* (Miller and Gray) Stone (TCN) are important pests of flue-cured tobacco (*Nicotiana tabacum* L.) in Virginia. An estimated 339 ha were infested with TCN in 1982 (7), resulting in a loss estimated at $699,184. Continuous tobacco production is the main factor leading to TCN-induced crop losses (7). Rotating tobacco with nonhost crops effectively reduces TCN population densities (8), but the low economic value of rotation crops compared with flue-cured tobacco has discouraged adoption of crop rotation for TCN control. Resistance to TCN has been identified in cultivated tobacco genotypes and in other species of the genus *Nicotiana* (1). The TCN-resistant commercial cultivars that have been identified are not tolerant of nematode parasitism, and significant yield loss occurs in the presence of high TCN populations. The main management tactic used, therefore, is the application of contact nematicides to susceptible cultivars, at an average cost of $139/ha.

Growing TCN-resistant cultivars can significantly reduce TCN densities (6); however, the yield and quality of TCN-resistant cultivars, even when treated with a nematicide, are not significantly greater than yield and quality of agronomically superior TCN-susceptible cultivars treated with the same nematicide. Alternate planting of resistant and susceptible cultivars has been successfully used to control cereal and soybean cyst nematodes (12,13). The objective of these experiments was to determine the effects of alternating use of resistant and susceptible cultivars, with and without a nematicide, on TCN population dynamics and crop losses.

MATERIALS AND METHODS

Field tests were conducted in two TCN-infested commercial flue-cured tobacco fields in 1984, 1985, and 1986. The soil at experimental location 1 was a Durham fine sandy loam (Typic Hapludult, fine-loamy, siliceous, thermic). The soil at location 2 was an Appling sandy loam (Typic Hapludult, clayey, kaolinitic, mesic). Soils at both locations were ca. 60% sand, 20% silt, 20% clay, and 1% organic matter, with a

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TABLE 1. Experimental treatments involving alternating use of fenamiphos and flue-cured tobacco cultivars resistant (NC 567) and susceptible (Mc 944, K 326) to *Globodera tabacum solanacearum.*

	1984		1985		1986	
Treatment	Cultivar	Nematicide	Cultivar	Nematicide	Cultivar	Nematicide
1	Mc 944	No	K 326	No	K 326	No
2	Mc 944	Yes	K 326	Yes	K 326	Yes
3	NC 567	Yes	K 326	No	NC 567	Yes
4	NC 567	Yes	K 326	Yes	NC 567	No
5	NC 567	Yes	NC 567	No	K 326	No
6	NC 567	Yes	NC 567	Yes	K 326	No

slope of 0–7%. A randomized complete block experimental design was used with four replications at each location. Each treatment consisted of a TCN control strategy involving different sets of practices to be conducted over the 3-year period of the study (Table 1). Growing a TCN-resistant cultivar every other year, or for 2 years, followed by a TCN-susceptible cultivar, with and without a nematicide, was compared with planting a TCN-susceptible cultivar every year (with and without a nematicide). The TCN-susceptible cultivars at both locations were Mc 944 in 1984 and K 326 in 1985 and 1986. NC 567 was the TCN-resistant cultivar throughout the study. The nematicide fenamiphos (7.47 kg a.i./ha) was applied preplant using a tractor-mounted hydraulic sprayer calibrated to deliver 327 liters/ha of total solution at a pressure of 172 kPa and an approximate speed of 6.4 km/hour. Plots were disked immediately after nematicide application. Plots at location 1 consisted of four rows 1.2 m apart and 34.4 m long. Plots at location 2 consisted of 4 rows 1.2 m apart and 37.8 m long. TCN populations were monitored each year by removing 16 soil cores (each 2 × 16 cm) from each plot. In 1984 and 1986 soil samples were taken just before nematicide application, 8–10 weeks after transplanting, and after final harvest. In 1985 soil samples were collected before treatment and after final harvest, but not in midseason. Cysts, eggs, and vermiform juveniles were extracted from soil samples by elutriation (3) and centrifugation with sugar-flotation (9). The centrifugal sugar-flotation technique was modified in January 1986 by reducing the duration of the final centrifugation step from 2 minutes to 30 seconds.

When ripe, individual leaves from each plot were harvested and cured. After the final harvest had been cured, all primings from all plots were weighed and graded by USDA marketing service inspectors. A 0–99 quality index that groups federal flue-cured tobacco grades according to equivalent economic value (11) was used to estimate the quality of each harvest or priming. Average market prices were obtained from USDA market news reports. Gross economic values were calculated for each plot by summing the product of priming weight and the average market value of the appropriate grade for each priming. Annual nematicide costs were estimated as the sum of material, application, and incorporation costs. Estimated costs were a combination of local retail chemical costs and application and incorporation costs obtained from the Virginia Cooperative Extension Service. Annual net economic returns to TCN management were estimated by subtracting the annual cost of nematicide treatment from the annual gross economic value of each plot.

TCN population density differences were analyzed using an analysis of variance of square root transformed nematode counts. Means for individual strategies were compared with the Waller–Duncan procedure. Flue-cured tobacco yields, gross and net economic returns, quality indices, and average prices were also compared with anal-

TABLE 2. Population dynamics of cysts and juveniles of *Globodera tabacum solanacearum* on resistant (R) and susceptible (S) flue-cured tobacco cultivars treated or not treated with fenamiphos in 1984, 1985.

Cultivar	Nematicide	Cysts/500 cm³ soil 5/84	7/84	11/84	5/85	Juveniles/500 cm³ soil 5/84	7/84	11/84	5/85
					Location 1				
Mc 944 (S)	No	179 a	71 a	226 a	5 a	428 a	473 a	1,035 a	325 a
Mc 944 (S)	Yes	178 a	51 a	86 b	0 b	628 a	560 a	513 b	368 a
NC 567 (R)	Yes	258 a	83 a	16 c	0 b	602 a	764 a	57 c	61 b
					Location 2				
Mc 944 (S)	No	183 a	105 a	168 a	10 a	348 a	418 a	228 a	585 a
Mc 944 (S)	Yes	247 a	58 a	236 a	23 a	238 a	350 a	193 a	378 a
NC 567 (R)	Yes	267 a	110 a	23 b	7 a	308 a	651 a	43 b	133 a

Means followed by a different letter are significantly different according to the Waller–Duncan procedure (k-ratio = 100; 18 df).

yses of variance and the Waller–Duncan procedure. Economic consequences of TCN control strategies were compared on an annual basis and for the entire 3-year study.

RESULTS

Initial and midseason populations of cysts, eggs, and juveniles were similar among experimental treatments at both locations in 1984 (Tables 2, 3). Use of fenamiphos with Mc 944 reduced final population densities of cysts and juveniles compared with the untreated control at location 1 but not at location 2 (Table 2). Even when fenamiphos was applied to Mc 944, plots with NC 567 had lower cyst and juvenile population densities at the end of the 1984 growing season than did plots with Mc 944. Egg population densities at the end of the 1984 growing season were similar in nematicide-treated and untreated plots planted with Mc 944; however, end-of-season egg population densities were reduced by use of fenamiphos with NC 567, compared with those on Mc 944 (Table 3).

Initial 1985 cyst population densities were lower in plots treated with fenamiphos in 1984 at location 1 but not at location 2 (Table 2). Initial egg population densities from both locations in 1985 were also not significantly different (Table 3). Although initial 1985 juvenile population densities at both locations were lower in plots planted with NC 567 compared with Mc 944 in 1984, these differences were not significant at location 2 (Table 2). At location 1, final 1985 cyst population densities on K 326 without fenamiphos were significantly greater where NC 567, rather than Mc 944, had been planted in 1984 (Table 4). No significant differences in final 1985 cyst population densities were observed at location 2 (Table 4). At location 2, final 1985 juvenile population densities were lower in plots planted with NC 567 in 1984 and 1985, or where NC 567 and fenamiphos were used in 1984 and K 326 was planted and fenamiphos was applied in 1985, than when a TCN-susceptible cultivar was planted in both years (Table 4). Planting NC 567 rather than K 326 in 1985 significantly lowered final 1985 cyst population densities at location 1 and final egg and juvenile population densities at both locations (Tables 3, 4). Initial 1986 egg population densities in plots planted with K 326 and left unsprayed in 1984 and 1985 were greater than egg population densities in plots where NC 567 was planted in 1984 and K 326 was used in 1985 (Table 3). Planting NC 567 in 1984 and 1985 reduced initial 1986 egg populations below the levels associated with planting NC 567 in 1984 and K 326 in 1985 (Table 3). No differences in initial juvenile population densities or in midseason cyst population densities were detected at either location (Table 4). Midseason egg population densities in 1986 were also lowest when NC 567 was planted in the 2 previous years (Table 3). At location 1, use of fenamiphos with NC 567 in 1986 reduced midseason juvenile population densities compared with continuous use of a susceptible cultivar, with or without fenamiphos (Table 4). Planting NC 567 in 1986 also significantly lowered final cyst and egg population densities at location 1 compared with continuous planting of a TCN-susceptible cultivar without fenamiphos or using NC 567 with fenamiphos in 1984 and 1985 and K 326 without fenamiphos in 1986 (Tables 3, 4). Final 1986 TCN juvenile population densities in plots planted with NC 567 in 1986 at location 1 were also lower than in plots planted with K 326, with or without fenamiphos. Differences in final 1986 cyst, egg, and juvenile population densities at location 2 were not significant (Tables 3, 4).

Using NC 567 with fenamiphos significantly increased 1984 yields, gross economic returns, and net economic returns, but not grade indices or average prices (Table 5). Use of fenamiphos with Mc 944 did not result in significant increases in 1984 yields, gross or net economic returns, grade indices, or average prices. Application of fenamiphos, however, increased yields, gross economic returns, and net economic returns for K 326 in 1985 (Table 5). Increased 1985 yields, gross economic returns, and net economic returns were also associated with use of NC 567 in 1984. No significant differences in grade index or average price were observed in 1985. Yields in plots continuously planted with a TCN-susceptible cultivar without fenamiphos were significantly lower in 1986 than in plots where fenamiphos had been applied in 1986 or in plots that had been planted with NC 567 in 1984 and 1985 (Table 5). Yield differences due to use of fenamiphos in 1986 were significant when a TCN-susceptible cultivar had been planted continuously but were not significant when NC 567 was used. Gross economic returns were higher when fenamiphos or NC 567 were used in 1986 or when NC 567 was used with fenamiphos in 1984 and 1985. Differences in net economic returns due to fenamiphos application in 1986 were not

TABLE 3. Numbers of eggs (per 500 cm^3 soil) of *Globodera tabacum solanacearum* from plots on which susceptible or resistant flue-cured tobacco was growing with or without fenamiphos at two Virginia locations in 1984–86.

Treat-	1984			1985		1986		10/86	
ment	5/84	7/84	10/84	5/85	10/85	5/86	8/86	Location 1	Location 2
1	6,375 a	10,688 a	27,500 a	7,731 ab	8,313 a	10,163 a	3,788 b	24,438 a	8,438 a
2	5,875 a	11,363 a	21,938 a	9,563 a	7,969 a	7,625 ab	7,338 a	10,462 ab	3,385 a
3	6,813 a	19,938 a	1,625 b	750 b	8,913 a	5,094 b	2,906 bc	3,113 b	1,313 a
4	5,250 a	14,188 a	1,313 b	3,375 ab	8,813 a	4,463 b	3,500 b	5,445 b	5,938 a
5	7,813 a	20,375 a	1,750 b	2,463 ab	1,094 b	1,594 c	875 d	12,050 ab	1,250 a
6	5,688 a	14,500 a	1,000 b	3,438 ab	2,188 b	1,750 c	1,356 cd	25,375 a	1,125 a

Means followed by a different letter are significantly different according to the Waller–Duncan procedure (k-ratio = 100; 18 df).

TABLE 4. Numbers of cysts and juveniles of *Globodera tabacum solanacearum* on resistant and susceptible flue-cured tobacco with and without fenamiphos at two locations in Virginia in 1985, 1986.

Treatment	Cysts/500 cm³ soil					Juveniles/500 cm³ soil				
	5/85	10/85	5/86	8/86	10/86	5/85	10/85	5/86	8/86	10/86
					Location 1					
1	5 a	113 c	60 ab	158 a	361 a	325 a	225 b	150 a	803 ab	795 a
2	0 b	116 bc	78 a	185 a	255 ab	368 a	205 b	93 a	1,128 a	590 a
3	0 b	260 a	58 ab	126 a	156 b	75 b	338 ab	138 a	240 c	113 b
4	0 b	174 b	69 ab	120 a	104 b	80 b	455 a	110 a	460 abc	75 b
5	0 b	5 d	13 b	249 a	260 ab	55 b	18 c	38 a	500 abc	946 a
6	1 ab	6 d	33 ab	68 a	413 a	33 b	13 c	70 a	303 bc	603 a
					Location 2					
1	10 a	331 a	158 a	74 a	370 a	585 a	233 a	295 a	23 a	65 a
2	23 a	568 a	135 ab	86 a	200 a	378 a	213 a	123 a	35 a	48 a
3	3 a	531 a	85 ab	70 a	174 a	195 a	158 ab	180 a	40 a	43 a
4	1 a	314 a	70 abc	46 a	111 a	28 a	93 bc	215 a	55 a	40 a
5	8 a	208 a	13 c	3 a	106 a	73 a	58 bc	48 a	8 a	20 a
6	15 a	149 a	69 bc	49 a	121 a	235 a	28 c	158 a	28 a	25 a

Means followed by a different letter are significantly different according to the Waller–Duncan procedure (k-ratio = 100; 18 df).

TABLE 5. Yield and returns from flue-cured tobacco resistant and susceptible to *Globodera tabacum solanacearum* with and without fenamiphos over a 3-year period at location 1 in Virginia.

Treatment	Cultivar	Fenamiphos	Yield kg/ha	Gross return ($/ha)	Net return ($/ha)	Grade index (0–99)	Avg. price ($/kg)
				1984			
1	Mc 944	No	2,575 a	9,853 a	9,853 a	47.5 a	3.82 a
2	Mc 944	Yes	2,878 ab	10,990 a	10,776 a	45.8 a	3.80 a
3–6	NC 567	Yes†	3,276 b	12,751 b	12,537 b	49.1 a	3.88 a
Waller–Duncan LSD			421	1,628	1,643	NS	NS
				1985			
1	K 326	No	2,117 a	8,238 a	8,238 a	65.3 a	3.87 a
2	K 326	Yes	3,424 b	13,453 b	13,225 b	65.8 a	3.92 a
3	K 326	No	3,234 b	12,757 b	12,757 b	68.3 a	3.94 a
4	K 326	Yes	3,747 b	14,896 b	14,669 b	68.0 a	3.97 a
5	NC 567	No	3,600 b	14,319 b	14,319 b	65.5 a	3.97 a
6	NC 567	Yes	3,746 b	14,830 b	14,603 b	62.8 a	3.95 a
Waller–Duncan LSD			898	3,331	3,356	NS	NS
				1986			
1	K 326	No	868 a	2,986 a	2,986 a	58.5 b	3.43 a
2	K 326	Yes	1,125 bc	3,981 bc	3,757 abc	71.5 c	3.51 a
3	NC 567	Yes	1,154 bc	4,053 bc	3,830 bc	46.3 a	3.50 a
4	NC 567	No	1,069 ab	3,892 bc	3,892 bc	59.8 b	3.63 a
5	K 326	No	1,087 bc	3,705 ab	3,705 ab	65.5 bc	3.43 a
6	K 326	No	1,300 c	4,520 c	4,520 c	66.5 bc	3.47 a
Waller–Duncan LSD			214	782	790	10	NS

Means in columns within years with different letters are significantly ($P = 0.05$) different according to the Waller–Duncan procedure.

† Each number is the average of four treatments, all identical (treatments 3–6, Table 1).

significant when a TCN-susceptible cultivar had been planted continuously. Increases in net economic returns from use of fenamiphos were significant when NC 567 was planted in 1986 or had been used in 1984 and 1985. Continuous use of a TCN-susceptible cultivar with fenamiphos resulted in the highest grade index in 1986. Use of NC 567 in 1986 resulted in significantly lower grade indices than those associated with continuous use of a TCN-susceptible cultivar with fenamiphos. Grade indices from plots planted with NC 567 in 1984 and 1985 were similar to those for plots continuously planted with a TCN-susceptible cultivar with or without fenamiphos. No significant differences were found in average price in 1986.

Discussion

Analyses of cyst and juvenile populations could not be combined over locations due to heterogeneous error variances and interactions between locations and treatments. Differences in TCN populations were observed among treatments at location 1 in each year of the study. Although similar trends often seemed apparent in treatment means at location 2, treatment effects at location 2 were rarely significantly different. Trends in TCN egg population densities, however, were similar at both locations in 1984 and 1985. Treatment effects on initial and midseason TCN egg population densities were also similar across locations in 1986, but final 1986 TCN egg population densities followed different trends in each experiment. Differences among treatments in flue-cured tobacco yield, gross economic value, net economic return, quality index, and average price were observed at location 1. Differences in agronomic characteristics could not be attributed to TCN control at location 2 because high incidences of tobacco mosaic virus-infected plants were observed at this site and the flue-cured tobacco cultivars used differed in susceptibility to tobacco mosaic virus, as well as to TCN.

The results of this study confirm those

from previous work (4) demonstrating a reduction in final season TCN population densities after planting a TCN-resistant cultivar and indicate that this reduction in TCN populations persists through the winter into the beginning of the next growing season. These results were particularly striking when TCN egg population densities were compared with cyst or juvenile population densities (2). Planting NC 567 appears, therefore, to be a very effective method for reducing TCN populations in severely infested fields.

Use of NC 567 may enable tobacco producers to increase yields and gross and net economic returns in either of two ways. When fenamiphos was used, yields from NC 567 were at least as high as those obtained using agronomically superior, TCN-susceptible cultivars. The best 1986 yields and gross and net economic returns, however, were observed in plots planted with a TCN-susceptible cultivar after two consecutive years of fenamiphos and NC 567. Use of such a cultivar rotation strategy for TCN management may be more attractive to Virginia flue-cured tobacco producers than planting NC 567 every year because NC 567 is considered difficult to cure by many Virginia producers. Lower quality characteristics due to curing difficulty can cause a producer to sell his crop for much less than current market prices. A cultivar rotation strategy would enable producers with TCN-infested fields to reduce TCN populations and increase the productivity of their fields while minimizing any risk of reduced economic returns due to deleterious agronomic characteristics in NC 567.

While the results of this study are promising, further work is needed to confirm our tentative conclusions regarding the economic benefits of planting NC 567 for TCN management. The lack of statistical significance among treatment effects on TCN populations at location 2, perhaps due to TCN distribution at that location, suggests that using NC 567 in a cultivar rotation strategy should be tested in additional years or fields. Flue-cured tobacco yield and quality data were obtained from only one location. The structure of the treatments in this study also did not allow a direct comparison of planting NC 567 for 1 vs. 2 years in order to decrease TCN populations. Other strategies for TCN management are also being explored. The feasibility of using TCN-resistant cultivars other than NC 567 in a cultivar rotation strategy and of reducing nematicide rates with TCN-resistant cultivars is currently being investigated.

In summary, this study has demonstrated that planting NC 567 in TCN-infested fields can significantly reduce TCN populations at the end of the current year's growing season and at the beginning of the next growing season. Use of NC 567 with fenamiphos for 2 years, rather than 1, may reduce TCN populations even further. When fenamiphos was used, net economic returns from use of NC 567 were at least as high as those associated with use of an agronomically superior but TCN-susceptible cultivar. Using fenamiphos and (or) NC 567 in 1984 and 1985 resulted in increased economic returns in 1986 compared with using a susceptible cultivar without fenamiphos in both years. Economic returns were highest in 1986 when fenamiphos had been used with NC 567 in 1984 and 1985 and a susceptible cultivar was planted in 1986.

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