Economic Analysis of Managing Multiple Pests in Tobacco

H. WALKER KIRBY and C. E. MAIN, Department of Plant Pathology, and G. A. CARLSON, Department of Economics and Business, North Carolina State University, Raleigh 27650

ABSTRACT

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Field experiments were conducted yearly from 1978 through 1980 to determine the effects of three selected nematicides plus an untreated control in combination with three economic threshold levels for tobacco budworms (*Heliothis virescens*) in tobacco fields known to have low populations of all nematodes, particularly root-knot species (*Meloidogyne* spp.). Effects on yield, value, and leaf quality were studied. Analysis of variance and regression analysis were used to characterize the effects of the combination treatments and pesticide expenditures related to gross returns. No significant differences were detected by analysis of variance, but regression analysis with an expanded model indicated that pesticide expenditures influenced gross returns. Quadratic regression models best fit the data and were used to characterize the relationship between gross returns and pesticide expenditures, postseason root-knot larval population densities, and selected weather variables.

Use of pesticides in production of flue-cured tobacco (*Nicotiana tabacum* L.) in North Carolina constitutes an important crop production expenditure (commonly $200/ha out of $1,200/ha in variable costs). In particular, nematicides are used almost routinely, often without adequate monitoring of nematode population levels. Kirby et al (*unpublished*) found 75% of a randomly selected group of tobacco farmers applying nematicides to their 1980 tobacco crop, with fewer than 10% submitting soil samples for nematode assays. More than half of the respondents indicated they had not experienced losses attributable to nematodes but preferred to use a nematicide to avoid losses from "potential" pests. These results are similar to those of Barker and Todd (1) in 1976, who reported that 68% of a survey group applied a nematicide to their tobacco fields during the survey period.

Although Ferris (5) and Headley (8) reported that control measures are not justified below some economic threshold level, many tobacco farmers believe the threshold level for root-knot nematodes is close to zero. This approach follows that of Wallace (16), who reported that "tolerance" is different for each individual farmer and represents the level of yield loss he can economically tolerate rather than being a function of the plant's ability to respond to pests. This concept is independent of yield and pest number and can shift as the economic situation of the farmer changes.

To investigate the major factors that influence a tobacco farmer's returns on investment in nematicides and the use of the economic threshold level for tobacco budworms (*Heliothis virescens* (F.)), field tests were conducted in tobacco-producing counties in North Carolina in fields known from soil sampling to have low nematode infestations. Because of declining root-knot nematode populations (C. E. Main, *unpublished*), we felt that selection of fields with low populations of root-knot nematodes would more accurately represent conditions encountered by most farmers.

The objectives of these field experiments were to determine 1) the economic returns from the use of nematicides in fields known to have low preseason root-knot nematode population levels, 2) the validity of the currently recommended 10% threshold level (3) for the tobacco budworm, and 3) the economic benefits of using the pesticide combination treatments (nematicide + budworm threshold level).

MATERIALS AND METHODS

Four field locations were selected yearly from 1978 through 1980 on tobacco farms in eastern North Carolina. All locations were free of common wilt diseases and had low population densities of all nematodes, particularly *Meloidogyne* spp.

A randomized complete block design

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of plots (48 × 4 rows) incorporating three economic threshold levels for tobacco budworms superimposed on each of three nematicides plus an untreated control in a 3 × 4 factorial experiment was used, with each treatment having four replicates. Row lengths of plots varied from 13.7 to 15.9 m with row spacing of 107–122 cm, depending on the practices of the cooperator.

Flue-cured tobacco cultivar Coker 48 was used in all experiments. This cultivar is highly resistant to common tobacco wilt diseases and is susceptible to *Meloidogyne incognita* (Kofoid & White) Chitwood, the predominant root-knot nematode in North Carolina tobacco fields (1).

Soil samples were collected from each plot for fertility analysis and nematode assay. Samples containing 20 cores per plot were collected 30 days before transplanting and after final harvest. A 2.5-cm-diameter soil sampling tube was thrust 20 cm into the soil to collect the sample cores. All samples were processed by the North Carolina Department of Agriculture, using standard methods for fertility and nematode analyses.

A sample of 20 root systems from the center two rows of each plot was collected after final harvest. A systematic sampling scheme with a random starting point was used in all plots. Each root system was assessed for root galling induced by root-knot nematodes and rated according to Todd's scale (15), based on the following classes for root area galled: 1 = 0–10% root area galled (very slight damage), 2 = 11–25% root area galled (slight damage), 3 = 26–50% root area galled (moderate damage), and 4 = 51–100% root area galled (severe damage).

The following nematicides were applied at recommended rates and with standard application equipment: 1) a multipurpose (MP) fumigant (1,3-dichloropropene, 91 kg a.i./ha, plus chloropicrin, 21 kg a.i./ha), 2) carbofuran (6.7 kg a.i./ha), and 3) ethoprop (6.7 kg a.i./ha). In each replicate, an untreated control plot was included that was prepared consistent with all other plots but did not receive any nematicide.

Methomyl was used as the foliar insecticide in all experiments and was applied as a 1.8% liquid formulation of 95 ml/11 L water at a spray pressure of 2.1 kg/cm^2 and a ground speed of 6–10 km/hr. Insect populations were evaluated every 7 days using 20 randomly selected plants per plot with insecticide applications made as soon as possible after threshold determinations. Late-season insect pests were controlled according to recommendations of the North Carolina Agricultural Extension Service (3). All applications of insecticides were made to the entire field when controlling late-season pest insects.

Budworm threshold levels used in this experiment were 1) a commonly used threshold of 5% infestation of plants, 2) the recommended threshold for North Carolina (3) of 10% infestation of plants and 3) a high threshold of 40% infestation to allow substantial crop damage without total loss of yields. This last threshold was never reached and served as a no-pesticide treatment control.

Tobacco was harvested three or four times, depending on the practices of the individual cooperator, and cured in bulk or conventional tobacco barns using racks or sticks, respectively. The lower four leaves were not included in the data analysis because some cooperators did not harvest them because of low value and current allotment programs (3).

After curing, a U.S. tobacco inspector assigned standard flue-cured tobacco grades (7) to each plot within each harvest. Plot weights and average market prices paid by individual years were used to calculate crop value by treatment. Quality indices were assigned based on the index developed by Wernsman and Price (17).

Two commonly used statistical techniques, ie, analysis of variance (ANOVA) and multiple regression, were used to determine the most appropriate technique to explain the variation in our field experiments. Limitations in sample size and number of replicates could have reduced the effectiveness of ANOVA in these field studies. Also, the model developed for the ANOVA approach contained only treatment effects and did not account for weather factors. With multiple regression, we developed an expanded model accounting for effects of nematode populations and weather as well as treatment effects. The regression approach also enabled us to calculate an optimal level of expenditures for both treatment components where incremental costs were equal to incremental returns.

Statistical analyses were performed using the Statistical Analysis System (SAS) (2), available at North Carolina State University. Models used in the ANOVA procedure included only treatment (pesticide) effects, whereas models used in the regression analysis included variables for average daily temperature and total monthly precipitation for April through August. Weather data were obtained from the North Carolina weather station closest to each test. Regression models also contained variables for initial root-knot nematode population densities (Pi), postharvest root-knot nematode population densities (Pf), insecticide expenditures, nematicide expenditures, and interaction effects. All independent variables were regressed on gross returns.

The regression model also permitted calculation of optimal levels of expenditures for each treatment component. By finding the expenditure that gave incremental returns equal to incremental costs, an optimal level was found.

RESULTS

Soil sampling and root-knot indices indicated that final root-knot population

Table 1. Mean number of root-knot nematode juveniles (*Meloidogyne* spp.) per 500-cm^3 soil sample from preplant (Pi) and postharvest (Pf) plot samples and mean gall indices after final harvest

Year	County	Pi[a]	Level[b]	Pf[c]	Level[b]	Mean gall index[d]
1978	Lenoir	186	M	904	L	13
	Nash	79	L	698	L	9
	Robeson	178	M	925	L	17
	Sampson	44	L	389	L	7
1979	Chatham	19	L	269	L	2
	Franklin	10	VL	10	VL	1
	Lenoir	24	L	46	L	12
	Moore	10	VL	10	VL	1
1980	Chatham	10	VL	10	VL	1
	Franklin	10	VL	10	VL	1
	Lenoir	10	VL	10	VL	5
	Moore	10	VL	10	VL	1

[a] Sample collected 30 days before transplanting.
[b] Soil nematode population levels by Todd's scale (15): VL = very low, L = low, and M = moderate.
[c] Sample collected after final harvest.
[d] Percentage of root area with galling. Based upon mean sample of 20 root systems.

Table 2. Number of methomyl applications required per season for budworm control in tobacco plots

Treatment[a]	Mean no. applications	Range[b]
Telone + 5%	1.5	0–3
Telone + 10%	0.5	0–2
Telone + 40%	0.0	0
Carbofuran + 5%	1.5	0–5
Carbofuran + 10%	0.7	0–3
Carbofuran + 40%	0.0	0
Ethoprop + 5%	1.7	1–3
Ethoprop + 10%	0.5	0–2
Ethoprop + 40%	0.0	0
None + 5%	2.5	0–3
None + 10%	1.2	0–2
None + 40%	0.0	0

[a] Nematicide application plus one of three budworm threshold levels.
[b] Minimum and maximum number of applications required per season for budworm control across all years and locations.

densities (Pf) were low for all locations and across all years (Table 1). Ten of the 12 locations had mean initial root-knot population densities (Pi) that were considered low (fewer than 100 larvae per 500 cm^3 soil), whereas two locations had mean Pis that were considered moderate (101–300 larvae per 500 cm^3 soil). Nine of the 12 locations had mean root-area galling of less than 10% and the remaining locations had mean root-area galling of 12–17%. Less than 25% root-area galling is considered low (15).

Budworm infestations. Natural infestations of tobacco budworms were extremely variable throughout the 3-yr study. Populations ranged from 0 to 20% infestation of plots, with peak infestations occurring 3–5 wk after transplanting.

Threshold level effects. Application of insecticides at the 5 and 10% threshold level did not improve yields, value, or leaf quality during the 3-yr period as measured by ANOVA (Table 2). Carbofuran, a pesticide with both nematicidal and insecticidal properties, did not reduce the need for foliar applications of methomyl at either the 5 or 10% threshold level (Table 2).

Nematicide effects. No significant differences were detected for any nematicide treatment by ANOVA ($P = 0.05$). Use of MP material and ethoprop produced a slight numerical increase in yield and value as the number of methomyl applications increased (Tables 3 and 4). Gross returns from each of the nematicide treatments were consistently higher (about \$300) than the no-nematicide treatment. This difference was not significantly higher, however, because of the large random component of yields.

Factors affecting gross returns. April and May average daily temperature and total monthly precipitation for May had a positive effect on gross returns, whereas total monthly precipitation for June, July, and August had a detrimental effect on returns when assessed with a quadratic regression model (Table 5). Initial root-knot nematode population densities (variable deleted from model) had no significant effect, but postharvest population densities were influenced by the same set of factors that influence plant development and crop performance. No other average daily temperature, total monthly precipitation, or interaction effects were found significant ($P = 0.05$) and were deleted from the model.

Nematicide expenditures positively influenced gross returns. The economic optimum amount of nematicides (economic threshold) is where the incremental gain in gross returns is equal to the incremental cost. Because nematicide use (N) is measured in \$1 units, this is where the slope of the gross return (GR) curve is equal to 1:$dGR/dN = 3.73 - 0.014N = 1$ or where N = \$266.43/ha (Tables 5 and 6). The optimal level of insecticides (I) is \$21.19/ha ($dGR/dI = 40.56 - 1.911 = 1$),

Table 3. Main effects of treatment components on yield, gross returns, and quality of tobacco combined across all plot locations and years[a]

Treatment component	Mean yield (kg/ha)	Mean gross returns (\$/ha)	Mean quality[b]	Added yield[c] kg/ha	Added returns[c] (\$/ha)	Added quality[b,c]
Nematicide						
Multipurpose material	2,344.04	7,330.60	29.35	117.67	351.92	−0.37
Carbofuran	2,313.11	7,286.00	31.31	86.74	307.47	1.59
Ethoprop	2,306.40	7,266.15	31.66	80.03	287.47	1.94
None	2,226.37	6,978.68	29.72	...	...	...
Threshold level						
5%	2,325.31	7,307.68	30.91	90.91	306.63	1.14
10%	2,332.72	7,337.33	30.86	98.32	336.28	1.09
40%[d]	2,234.40	7,001.05	29.77	...	...	...

[a] Means were not significantly different according to Waller-Duncan multiple range test ($P = 0.05$).
[b] Quality is based on tobacco grade, highest = 100 and lowest = 0. An increase of five to 10 points is necessary to produce a detectable difference in quality.
[c] Calculated as difference between no-pesticide treatment control plots and main-effects components.
[d] Used as no-pesticide treatment controls for comparison with pesticide-treated plots.

Table 4. Effects of combination treatments on main yield, gross returns, and mean quality of tobacco combined across all plot locations and years[a]

Treatment + threshold level[b]	Mean yield (kg/ha)	Mean gross returns (\$/ha)	Mean quality[c]
MP material + 5%	2,434.69	7,600.28	28.56
MP material + 10%	2,343.60	7,340.65	30.32
MP material + 40%	2,253.81	7,050.88	29.18
Carbofuran + 5%	2,308.51	7,296.08	32.36
Carbofuran + 10%	2,339.68	7,360.80	31.02
Carbofuran + 40%	2,291.15	7,201.13	30.56
Ethoprop + 5%	2,381.50	7,470.13	30.32
Ethoprop + 10%	2,330.35	7,383.78	33.66
Ethoprop + 40%	2,207.33	6,944.53	31.02
None + 5%	2,176.53	6,864.42	32.41
None + 10%	2,317.28	7,264.08	28.46
None + 40%	2,185.31	6,807.76	28.33

[a] Means were not significantly different according to Waller-Duncan multiple range test ($P=0.05$).
[b] Nematicide application plus one of three budworm economic threshold levels. MP = multipurpose.
[c] Quality is based on tobacco grade, highest = 10 and lowest = 0. An increase of five to 10 points is necessary to produce a detectable difference in quality.

Table 5. Quadratic regression model of factors influencing gross returns (GR) to tobacco farmers[a,b]

Variable	Parameter estimate[c]
Intercept	−27650.10
Postharvest root-knot nematode population level	0.300**
Nematicide expenditures	3.73*
Nematicide expenditures^2	−0.007
Insecticide expenditures	40.56**
Insecticide expenditures^2	−0.957**
April average daily temperature (C)	720.16**
May average daily temperature (C)	262.04**
May rainfall (cm)	248.73**
June rainfall (cm)	−355.49**
July rainfall (cm)	−50.39*
August rainfall (cm)	−230.15**

[a] Factors regressed on gross returns/ha.
[b] $R^2 = 0.58$, N = 432, GR = \$7,129.00.
[c] * Indicates significant at $P = 0.10$, ** indicates significant at $P = 0.05$.

Table 6. Costs and returns above costs from regression equation for selected tobacco nematicides (all other costs held constant)

Material (amount/ha)	Cost[a] (\$/ha)	Returns (\$/ha)
Ethoprop EC6 (11 L/ha)	131.30	370.19
Carbofuran 4F (16.5 L/ha)	151.70	404.75
Calculated optimum	266.43	496.89
Multipurpose material (46.2 L/ha)	281.73	495.25
Multipurpose material + 1/2-rate carbofuran (piggyback)	358.58	437.44

[a] Based on 1981 budget and chemicals price list currently in use.

Table 7. Costs and returns above cost from regression equation for insecticide applications to control tobacco budworms (all other costs held constant)

No. of applications	Costs[a] (\$/ha)	Returns (\$/ha)
1	18.22	421.31
1.2 (optimum)	21.19	429.75
2	36.44	207.22
3	54.66	−1,291.60

[a] Based on 1981 budgets and prices currently available.

slightly more than a single application per season for budworms. Gross returns less pesticide expenditures declines rapidly at levels beyond the optimal level of use (Tables 6 and 7).

DISCUSSION

Economic responses. Our results indicate that nematicide applications plus adequate budworm management may improve returns to farmers with tobacco fields that have low populations of nematodes, especially root-knot species. The regression model formulated from these experiments indicated that the optimal level for nematicide expenditures was $266.43/ha, a level very close to the cost of applying MP materials (Table 6). This implies that growers who use these more expensive materials may receive the highest net returns when compared with growers who use contact nematicides or no nematicides. Growers who used a 10% damage threshold for insects and spent about $21/ha for insecticides received the highest net returns.

The regression model better explains the variation within these experiments than analysis of variance does. If ANOVA alone had been used, with the resultant acceptance of the null hypothesis of no differences among treatments, a type 2 error would have been made (14) and false conclusions drawn. Use of the expanded regression model, however, demonstrated the effects that uncontrolled weather factors have on pest and pesticide performance under field conditions, indicating that this approach is better suited than ANOVA for dealing with multiple location, year, and pest effects.

Treatment effects. Treatment differences observed in our experiments using regression analysis may explain nematicide use patterns among tobacco growers near the experimental plots. These treatment differences are probably due to factors or causes other than direct control of nematodes. Postharvest nematode population densities and root-knot indices were low, indicating that very little root damage had occurred. Populations of root-knot nematode species appear to be below an economic threshold level (5,6,19), indicating that crop responses from the nematicides are due to other causes.

Carbofuran treatments are known to affect plants directly. Growth responses have been reported for corn (4), soybeans (18), and burley tobacco (13), involving increases in plant size as well as yield. Lee (9,10) has reported that two metabolites of carbofuran interfere with indole-3-acetic acid oxidase metabolism in pea plants, resulting in growth enhancement. The yield responses in our tobacco may have been due to a similar mechanism.

A second possible explanation for yield increases may be control of nontarget organisms. All nematicides used in these experiments can control pests other than nematodes (3,15). The MP material controls tobacco pathogens, especially soil fungi and bacteria (15). Suppression of these organisms early in the season may result in additional yields, but the high cost of MP materials plus the possibility of phytotoxicity in wet soils (11,12) may reduce the overall effectiveness of these types of materials unless high levels of pathogens or nematodes are found within a tobacco field. In these situations, subtle effects on the tobacco plant may be overshadowed by direct control of pathogens or nematodes.

Carbofuran, ethoprop, and methomyl have insecticidal properties (3). Although carbofuran alone did not control budworms adequately, this material plus methomyl resulted in positive yield responses. This supports the role of adequate insect management in increasing yield, as well as the growth-regulating properties of carbofuran.

Ethoprop used without insecticides did not produce yield or value responses when compared with treatments using insecticides (Table 4). This also indicates a primary response from insect management.

Yields and returns from methomyl used without nematicides were quite variable (Table 4). Yield losses observed at the 5% threshold level may have been due to destruction of beneficial insects that were partially controlling pest insect populations. Higher numbers of insecticide applications required at the 5% threshold may have reduced the effectiveness of insect predators and allowed rapid resurgence of pest populations. Control of certain tobacco insects by predators has been noted by Kirby (*unpublished*) in integrated pest management (IPM) programs.

With nematode population levels declining (C. E. Main, *unpublished*), future research is needed to determine the effects of nematicides and other pesticides on crop plants, interacting organisms, and crop physiology. Our experiments indicate that tobacco growers are observing benefits from using nematicides, even in fields with low nematode infestations. Responses we observed, however, were extremely variable during the 3-yr period and were influenced by weather and pesticide expenditures. Additional research is needed under field conditions to determine the nature of tobacco plant responses to nematicides in fields with low nematode population levels.

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