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Applying the Economic Threshold Concept to Control Lesion Nematodes on Corn

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Abstract

Determining economic thresholds for various lesion nematode controls can help corn producers decide whether to apply aldicarb and estimate the profit-maximizing dosage. The economic threshold, the population density at which a pesticide dosage is economically justified, is a key concept in pest management economics; few economists have applied it empirically. Optimal dosages of aldicarb are usually profitable and increase at a decreasing rate as nematode populations or corn prices increase. Aldicarb alleviates the problem of predicting nematode populations, as dosages can vary from the optimum amount without greatly decreasing profits.

Keywords

Aldicarb, Corn, Economic threshold, Kill-efficiency equation, Nematodes, Optimal pesticide dosage, Population dynamics, Pratylenchus spp., Yield equation.

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Preface

This report applies the economic threshold concept, a widely recognized concept in pest management economics, to the problem of controlling nematodes in corn. The research for this report was undertaken by the Economic Research Service at the request of the Agricultural Research Service. Nematodes can severely reduce corn yields; optimal dosage levels and application methods are difficult for farmers to determine. The economic threshold concept is applied to tell farmers how and when to apply pesticides to maximize profits. Results should advance work in pest management, since the threshold concept has been addressed theoretically by both economists and nematologists but has been applied empirically in only a few cases. Results also should have timely significance for farmers. Nematodes are a severe problem for several crops and in several regions of the country. This report, which undertakes research on a single crop in a single season, could provide the basis for multicrop, multiseason investigations.

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Contents

Summary

Researchers can use the concept of the economic threshold, the population density at which a pesticide dosage is economically justified, to estimate the optimal aldicarb dosages to control lesion nematodes on corn. Aldicarb can be profitably applied on the sandier soils of the southeastern coastal plain over a wide range of nematode populations, dosages, and relative prices of corn and aldicarb.

Using data collected at the Coastal Plain Experiment Station in Tifton, Ga., this study statistically estimates three equations: a corn-yield equation, an aldicarb kill-efficiency equation, and an equation to predict lesion nematode populations at harvest.

The yield equation includes nematode damage and is estimated with a corrected coefficient of regression (R^2) of 0.832. This equation shows that lesion nematodes can be an economic pest for corn and that nematode damage increases at a decreasing rate when populations increase. A population density of 100 nematodes per 150 cubic centimeters (cm^3) of soil can reduce corn yield by 18.5 bushels per acre, while a density of 200 nematodes per 150 cm^3 can reduce yield by 34 bushels per acre. Above a density of 500 nematodes per 150 cm^3, nematodes cause little additional damage.

The kill-efficiency equation is exponential and is estimated with non-linear, statistical methods. This equation accounts for aldicarb dosages and application methods. It demonstrates that the proportion of the nematode population killed increases at a decreasing rate as dosage increases. A dosage of 1 pound of active ingredient applied infurrow would reduce the nematode population by 45 percent, whereas a dosage of 3 pounds would reduce the population by 83 percent. Banded, incorporated treatments are more effective than infurrow treatments.

The population equation predicts lesion nematode populations at harvest with corrected $R^2 = 0.658$. When corn follows corn or soybeans in rotation, the coefficient for lesion nematodes at planting is not significantly different from 1, indicating that the rate of

population increase is independent of the population at planting. Analysis also shows that the population at harvest is poorly explained by the population at previous harvest. However, increasing weed control increases both corn yield and the nematode population at harvest.

This study employs these three equations to estimate profit-maximizing aldicarb dosages for each lesion nematode population at harvest. The optimal aldicarb dosages reported vary from 0 to 3 pounds of active ingredient and increase at a decreasing rate as nematode populations or corn prices increase. Banded, incorporated treatments are generally more profitable than infurrow treatments. Thus, farmers can afford to apply aldicarb at lower populations with banded, incorporated treatments than with infurrow treatments.

The nematode population equation is relatively weak, and it is difficult to relate dosages to populations at planting. Dummy variables in the equation account for important, unmonitored factors which vary from year to year and greatly affect the optimal aldicarb dosage when populations are observed at planting. Nematologists need to identify factors explaining population growth better. With aldicarb, this presents no important economic problem. If farmers have a lesion nematode problem, they can probably apply 2-3 pounds of active ingredient infurrow without greatly reducing their profits.

Applying the Economic Threshold Concept to Control Lesion Nematodes on Corn

Craig Osteen, A.W. Johnson, and Clyde C. Dowler*

Introduction

Some species of plant-parasitic nematodes at certain population levels can reduce crop yields. However, farmers can use crop rotation and nematicides to control these nematodes. An important means of pest management is the development of a system of crop rotation, nematicide applications, and population monitoring to control nematodes. Our study investigates a one-pest, one-crop problem in a single growing season and its solution: the application of profit-maximizing nematicide dosages to control lesion nematodes (*Pratylenchus spp.*) that attack field corn in southern Georgia. This report presents optimal aldicarb dosages for different population levels of lesion nematodes, different relative prices for corn and aldicarb, and two application methods.[1] We estimate a corn-yield equation, an aldicarb kill-efficiency equation, and population-prediction equations with data collected at the Coastal Plain Experiment Station in Tifton, Ga. We present the method, the results and their implications for nematode management, and the needs for future research.

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[1] This work is the first step in studying a multiple-pest, multiple-crop problem in a dynamic framework. We want to extend this work to peanuts and soybeans and then investigate the best combination of rotation and nematicide applications.

Introduction

The method and results should help both biological and economic researchers. This research should be useful to economists as little empirical work concerned with optimal pesticide dosages has been done. Few economists have addressed the area of nematode management.

The method and results should be useful to biologists for two reasons. First, nematologists have not estimated economic thresholds, population densities at which pesticide dosages are economically justified, for nematodes by considering the value of crop damage, nematicide efficacy, and population dynamics, although Ferris *(5)* discusses the problem.[2] Second, aldicarb is not currently registered for use on corn; Union Carbide, a producer, requested such a registration for aldicarb.[3]

The Literature on Optimal Pesticide Use

Many authors include pest population dynamics, pesticide kill-efficiency, pest damage, crop value, and pesticide costs in their theoretical and empirical analyses of optimal dosages and timing of pesticide applications. These authors sometimes include pest population forecasting, pest damage forecasting, or pest resistance to pesticides in their studies. Much of this literature has concentrated on the economic threshold concept, decision theory, optimal control theory, and dynamic programming.

Headley *(7, 8, 9)*, Hillebrandt *(10)*, Norgaard *(14)*, and Norton *(15)* present theoretical discussions of the economic threshold. They emphasize the profit maximizing decision to apply pesticides at a single point. Norton analyzes the case of the fixed application rate, while the others allow the application rate to vary. Headley emphasizes the level to which the pest population should be reduced, while the others emphasize the population level before the pesticide is applied. Of particular interest to our study, Ferris *(5)*, a nematologist, integrates the concepts of the economic

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[2] Italicized numbers in parentheses in the text refer to references listed at the end of this report.

[3] Personal correspondence with Mr. N Abdalla, Temik Product Development Leader, Union Carbide Corporation, Jacksonville, Fla.

threshold with the biological concepts of nematode growth and damage. Talpaz and Frisbie *(23)* regress cotton profits on damage levels of cotton fleahopper collected from scouting reports to estimate an economic threshold.

Headley *(8, 9)* and Norton *(15)* discuss how one can use decision theory to analyze the impact of uncertainty, pest population monitoring, damage forecasts, and crop insurance when choosing a pest control strategy from a finite, discrete set of alternatives. This method uses farmers' perceptions of the probabilities of gains and losses from each strategy and farmers' utility functions, which are expressions of profit-maximizing and risk-averting preferences. The applications of decision theory show how pest population monitoring and damage forecasts can modify perceptions of probabilities of gains and losses, can change farmers' choices, and can increase farmers' utilities. Feder *(4)* discusses the impacts of information and uncertainty on pesticide use in a continuous, rather than a discrete, framework.

Carlson *(1)* applies decision theory to controlling peach disease. He estimates the impacts of fruit maturity, rainfall forecasts, and a disease index on peach damage. He uses decision theory to show how this information affects farmers' perceptions and their choice of pesticide strategy, assuming different risk-averting preferences. Webster *(25)* conducted a study similar to Carlson's for controlling wheat disease. However, he interviewed farmers, estimated their utility functions, and compared pest control strategies that maximized utility.

Economists have expanded their theoretical discussions to include the dynamic aspects of pest populations, predator-prey interactions, and pest resistance. Hall and Norgaard *(6)* expand the economic threshold concept to account for the timing and dosage of a single pesticide application to maximize profits. Chatterjee *(2)* formulates an abstract, optimal control model to determine the optimal timing and dosage of multiple pesticide applications. He assumes that pesticide costs are independent of the desired pest survival rate. Hueth and Regev *(11)* formulate an abstract, optimal control model that considers the development of pest resistance in determining the optimal timing and dosage of multiple pesticide applications. Shoemaker *(20)* develops a discrete-time and discrete-state dynamic programming model which includes a parasite-prey relationship, pest damage on a single crop, insecticide effectiveness, and insecticide costs. The model determines optimal pesticide dosages at each point for each combination of parasite and pest populations.

Several economists have applied these dynamic concepts in empirical studies. Talpaz and Borosh *(21)* develop a model of the optimal timing and dosage of multiple treatments. They consider pest population dynamics, an explicit kill-efficiency function, a pest damage function, and pesticide application costs. They then apply the model to a semirealistic cotton system. Talpaz and others *(22)* investigate the optimal timing and dosage of multiple treatments to control boll weevils on cotton. They construct a simulation model of boll weevil populations, cotton production, and a kill function. They then use a nonlinear, optimizing technique to determine the optimal methyl-parathion dosage in each time period. Regev, Gutierrez, and Feder (16) model optimal spraying practices for the alfalfa weevil from the viewpoint of the operator and of society. They simulate pest and plant growth components and a kill function and use a nonlinear, optimizing technique to determine the optimal carbofuran and heptachlor dosage in each time period. Reichelderfer and Bender *(17)* compute and compare benefit-cost ratios for several chemical pesticides (carbaryl and disulfoton), biological options (parasitic wasps), and integrated chemical and biological options to control three infestation levels of Mexican bean beetles on soybeans. They include scouting of pest damage in some of their options. Their method involves a deterministic, single-season, dynamic simulation of pest and parasite population dynamics, pest-parasite interactions, soybean growth, pest damage, chemical control, and yield. They assume that chemical pesticides are applied at fixed, recommended dosages with one application of disulfoton at planting and one or more applications of carbaryl when necessary. They use the simulation model to find the optimal timing of multiple applications of fixed, carbaryl dosages and the optimal release date of parasitic wasps.

The Method

Our study estimates the profit-maximizing dosages of aldicarb at one point—at or before planting—assuming that pest populations are monitored. For safety, aldicarb must be applied in a granular form on the soil, and it is often incorporated into the soil. The growth of corn foliage makes such applications difficult shortly after planting. Nematicides were also applied at or before planting in all the tests we consider here. Therefore, this work is more closely related to the economic threshold analyses than to the studies of optimal timing of pesticide applications. Most studies of optimal timing are concerned with applying foliar insecticides on cotton, alfalfa, or soybeans where multiple applications are feasible and desirable. However, foliar insecticides are applied directly to the plant and not to the soil as aldicarb is. Dynamic methods are more appropriate for the multiple-season problem of choosing the optimal crop rotation to control nematodes, the problem we will investigate in the future. Our study concentrates on developing quantitative relationships for a pest management system and not on farmers' risk preferences, the economic feasibility of nematode monitoring, or pest resistance to pesticides.

Our approach to developing a nematode management system is to statistically estimate a corn-yield equation which includes nematode damage, a lesion nematode population-prediction equation, and a nematicide kill-efficiency equation from data collected at Tifton, Ga. It uses data collected for an earlier study of the relationships among crop rotation, nematode populations, and weed control to estimate the yield and population equations. The data from that study are useful for our long-term objective of finding the optimal crop rotation.

As the earlier study includes no nematicide treatments, our study estimates the kill-efficiency equation from data collected for nematicide tests on different plots in different years. These nematicide tests were not concerned with crop rotation or weed control. Because data were not collected on the same variables in the rotation study and nematicide tests, we did not pool the results of the two studies to estimate the yield and population prediction equations. However, as both were conducted on similar soil types, we assumed the nematicide would behave similarly on both sets of plots.

Our analysis estimates the impact of an aldicarb application on nematode damage, the profit-maximizing aldicarb dosage for each nematode population at harvest, and the population levels where total profits of the application cover costs. The analysis combines the kill-efficiency equation with the yield equation and computes the incremental decrease in nematode damage resulting from an incremental increase in aldicarb dosage, assuming different relative prices for corn and aldicarb and using two different application methods. Finally, our analysis uses the population-prediction equation to project the lesion nematode population at planting from lesion nematode population levels at harvest.

Our method neither directly measures the impact of aldicarb on corn yield nor directly computes the profitability of aldicarb. One could do so by including a variable for aldicarb applications in a yield equation and by using data from nematicide tests to estimate the equation. This approach has two problems. First, aldicarb applications would not be related to pest populations. Second, aldicarb controls other soil pests in addition to nematodes. So, the use of aldicarb might well include benefits other than those from nematode control. Our study is concerned with nematode management and not with the overall profitability of aldicarb. We chose aldicarb only after examining several nematicides. However, the method conservatively estimates aldicarb benefits without accounting for the benefits of controlling other pests. Basing aldicarb applications upon the observed population levels of more than one pest is an interesting problem, but it is beyond the scope of our study.

The Data

The Coastal Plain Experiment Station in Tifton, Ga., provided all data to estimate the yield, population-prediction, and kill-efficiency equations. A 1968-71 study of the impact of crop rotation on weed control and nematode populations provides data for estimating the yield and population equations.

Corn, soybeans, peanuts, and cotton were planted in a variety of rotations on a Tifton sandy-loam soil. However, corn always followed corn or soybeans in rotation. The experimental design was a randomized, complete block with six replications that provided 96 observations. Two weed-control treatments were applied: (1) recommended herbicide applications and (2) mechanical cultivation. Fertilizer applications and tillage practices for each crop were held constant over all plots and years. The plots were not irrigated. Monthly soil samples were collected to monitor ring *(Macroposthonia ornata),* lesion *(Pratylenchus spp.),* stubby root *(Paratrichodorus minor),* spiral *(Helicotylenchus diysteria),* and root-knot *(Meloidogyne incognita)* nematode populations. Visual methods were used to estimate the percentage of weed control at harvest *(3, 12, 13).*

Nematicide efficacy tests on corn plots provide the data for estimating kill functions. The tests were conducted on Tifton sandy-loam soil from 1977 through 1980. The test plots had different locations than those in the earlier experiments. The sample design was a randomized, complete block with four replications. The nematicides with a sufficient number of observations for estimating kill-efficiency equations are: ethoprop 6EC and 10G (52 observations), terbufos 15G (68 observations), and aldicarb 15G (60 observations). We ultimately chose aldicarb for further analysis because it was the only nematicide that had a good data fit of a kill-efficiency equation. Two methods of aldicarb application were used: (1) infurrow at planting and (2) banding and incorporating with a tractor-mounted roto-tiller before planting. These experiments provide 12 observations with no nematicide treatments, 16 observations of infurrow treatments, and 32 observations of banded treatments. Aldicarb dosages were varied from 0 to 3 pounds active ingredient (a.i.) per acre.

Fertilizer and herbicide applications were held fairly constant over all field tests. Researchers irrigated the test plots to maintain adequate soil moisture for corn growth. Analysts collected soil samples to monitor nematode populations at planting and harvest, and usually once or twice during the growing season. These experiments did not measure weed control.

The Coastal Plain Experiment Station also provided climate data.

Estimates of the Equations

In this section, we present the yield, population, and kill-efficiency equations that we estimated from the data collected at Tifton, Ga.

Yield Equation

The corn-yield equation contains lesion nematode population at harvest, percentage of weed control at harvest, and rainfall during the crop year as independent variables. Although lesion, root-knot, and ring nematodes increased significantly when corn was planted, only lesion nematodes were statistically significant in decreasing corn yields. Because some biologists believe that nematode damage is greater in dry years than in wet years, we considered an interaction term between annual rainfall and lesion nematode population. This term increases the coefficient of regression very little, probably because rainfall varied only slightly over the 4 years of observation. The best yield equation contains a quadratic form for nematode population (*t*-statistics are in parentheses below the estimated coefficients):

$$Y = [\,\underset{(11.18)}{-12412.2} - \underset{(5.87)}{12.54\,X_1} + \underset{(3.36)}{0.0098X_1^2} + \underset{(4.4)}{20.97\,X_2} + \underset{(18.43)}{363.5X_3}\,] \times 0.01593\text{[4]} \tag{1}$$

where:

Y = corn yield (bushels per acre),
X_1 = population density of lesion nematodes at harvest (number/150 cm^3 of soil),[5]
X_2 = percentage of weed control, and
X_3 = rainfall (inches per crop year).

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[4] The constant, 0.01593, converts kilograms per hectare to bushels per acre assuming that a bushel of corn weighs 56 pounds *(24)*.

[5] We estimated the nematode population at harvest by averaging the July and August observations on each plot.

This model fits the data with the coefficient of regression (R^2) = 0.832, the corrected R^2 (CR^2) = 0.824, and the standard error of regression (SER) = 18.8. With 91 degrees of freedom (d.f. = 91), all the coefficients are significant at the 99.5-percent level and their signs appear reasonable. Increasing rainfall or weed control increases corn yield. Over the range of observations, increasing nematode populations decreases corn yields. The form of the yield equation approximates other empirical studies and theoretical relationships relatively well. Nematode damage increases at a decreasing rate as Ferris *(5)* and Seinhorst *(19)* reported (see fig. 1). Seinhorst *(19)* and Ferris *(5)* indicate that log and quadratic forms provide good, empirical explanations of nematode damage, whereas Seinhorst postulates a sigmoidal form as the ideal. Over the range of observations, the quadratic form fits the data better than the log or sigmoidal forms.

Population-Prediction Equation

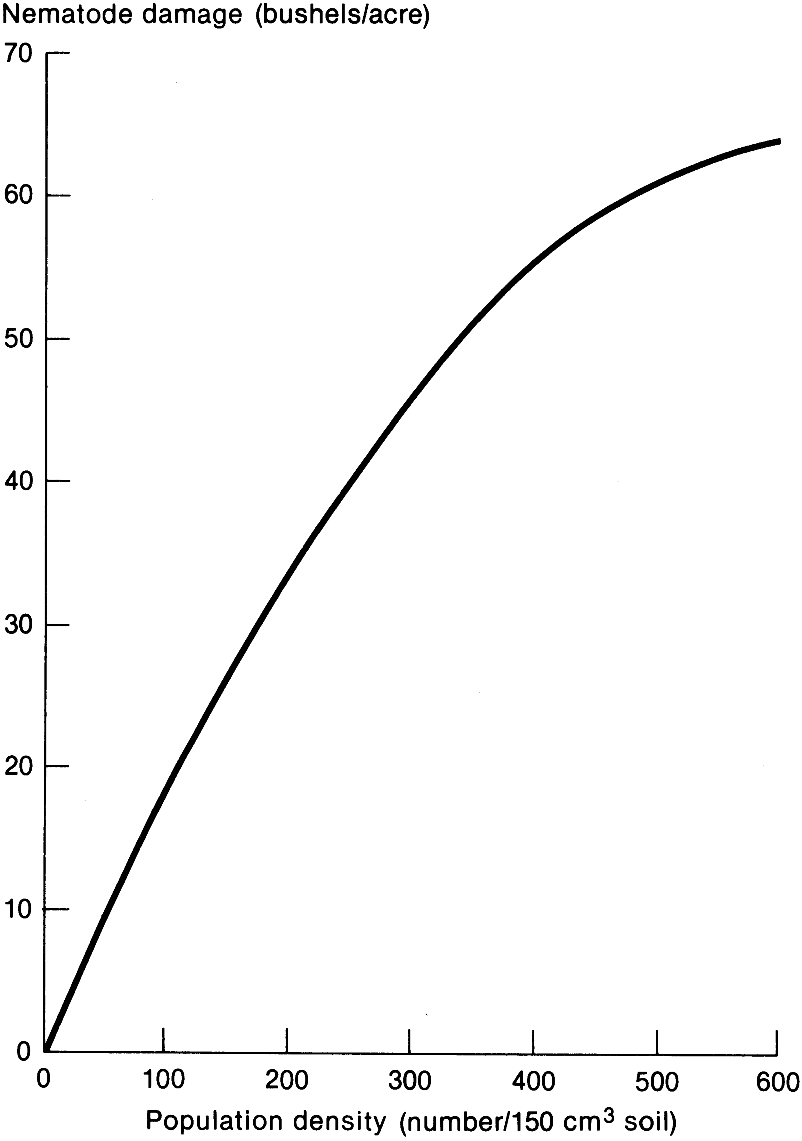
Monitoring pest populations to project pest damage before pesticide applications is essential in deciding whether applications are needed. Because many nematicide applications are made at or before planting, there are two logical times to sample nematode populations: (1) just before planting or (2) during the previous harvest when nematode populations are at their highest level. We estimate prediction equations for each sampling time.

Based on the data collected from 1968 to 1971, the best population equations using nematode observations at planting time are weed control and dummy variables that identify each year during which observations were collected:

$$\begin{aligned} X_1 = \underset{(8.13)}{358.56} &+ \underset{(2.29)}{1.326X_2} - \underset{(8.44)}{294.72\,X_4} - \underset{(11.68)}{430.32X_4} - \\ &\underset{(9.78)}{365.42X_6} + \underset{(3.15)}{1.085X_{10}} \end{aligned} \qquad (2)$$

Figure 1

Nematode Damage Function



where:

X_1 = lesion nematode population at harvest,
X_2 = percentage of weed control,
X_4 = dummy variable for second year,[6]
X_5 = dummy variable for third year,
X_6 = dummy variable for fourth year, and
X_{10} = lesion nematode density before planting (number/150 cm^3 soil).[7]

This model fits the data with $R^2 = 0.675$, $CR^2 = 0.658$, and SER = 117. With d.f. = 90, all coefficients are significantly greater than zero at the 97.5-percent level, and except for the coefficient for the second year, all are significantly greater than zero at the 99.5-percent level. The hypothesis that the coefficient for nematode population at planting equals 1 cannot be rejected at the 90-percent level ($t = 0.247$). This information indicates that when corn follows corn or soybeans in rotation on these experimental plots, the increase of lesion nematodes during the growing season is independent of the population density at planting. The weed control and dummy variables define a carrying capacity or equilibrium population density for each plot in each year. Our findings agree with the concept that nematode population growth follows a logistic model where several initial populations could result in the same equilibrium population at a later time *(18)*. In our model, variables which affect carrying capacity seem to be more important than the population density at planting in determining the population density at harvest.

The best population-prediction model which includes the observed population at the previous harvest is similar in form to equation (2).

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[6] To avoid a singular data matrix, we have the intercept represent the impacts of the first year. Hence, the dummy variables represent yearly shifts in the intercept.

[7] The population at harvest is the average of July and August observations on each plot, and the population at planting is the average of March and April observations on each plot.

Equations

To include the population at previous harvest, we could only use 3 years of data instead of 4 years:

$$\begin{aligned} X_1 = {} & \underset{(10.49)}{425.07} + \underset{(1.36)}{0.822X_2} - \underset{(8.2)}{308.52X_4} - \underset{(11.06)}{429.74X_5} + \\ & \underset{(0.999)}{0.0896X_{11}} \end{aligned} \tag{3}$$

where:

X_{11} = population density of lesion nematodes at the previous harvest (number/150 cm³ soil).

This model fits the data nearly as well as does equation 2 with $R^2 = 0.69$, $CR^2 = 0.671$, and $SER = 121.3$. With d.f. = 67, only the intercept and the coefficients for each year are significantly greater than zero at the 99.5-percent level. The coefficient for weed control is significantly greater than zero at the 90-percent level. However, the coefficient for the nematode population at the previous harvest is not significantly greater than zero at the 90-percent level. Hence, when corn follows corn or soybeans in rotation on these experimental plots, the lesion nematode population at the previous harvest does not seem to be an important factor in predicting lesion nematode populations.

With both population-prediction equations, the dummy variables identifying years are important. On these experimental plots, some important variables which explain annual growth and change of lesion nematode populations were apparently not monitored. A population-prediction equation which includes annual rainfall, weed control, growing-degree days, and the populations of lesion, ring, and root-knot nematodes at planting further illustrates this point:

$$\begin{aligned} X_1 = {} & \underset{(2.53)}{-487.57} + \underset{(4.41)}{11.46X_2} - \underset{(4.93)}{0.108X_2^2} + \underset{(7.66)}{0.0024X_3.X_{12}} \\ & - \underset{(2.00)}{0.196\,X_{10}.X_{12}} - \underset{(1.4)}{0.965X_{13}} + \underset{(2.07)}{0.0028X_7^2} \\ & + \underset{(2.11)}{10.5X_{10}} \end{aligned} \tag{4}$$

where:

X_3 = annual rainfall,
X_7 = ring nematode population at planting (number/150 cm^3 soil),
X_{12} = growing-degree days,[8] and
X_{13} = population density of root-knot nematodes at planting.

The fit of this model is much poorer than the previous two models, equations (2) and (3), with an $R^2 = 0.44$, $CR^2 = 0.392$, and SER = 156. With d.f. = 88, the coefficients are all significantly greater than zero at the 97.5-percent level except for the coefficient for root-knot nematodes which is significantly greater than zero at the 90-percent level. Weed control has an impact on population at harvest similar to that in equation 2. The lesion nematode population at planting seems to greatly affect the population at harvest, but this effect is offset by the interaction between degree-days and lesion nematode population at planting. The poor fit of this model shows that variables which were monitored do not explain very well the population at harvest on these experimental plots.

Currently, we have a poor idea of what these unmonitored factors might be. One possibility is the presence of a predator, parasite, or disease that controls the nematode population more in some years than in others. There might be a competitive organism which has a greater advantage over lesion nematodes in some years than others. Some factors directly affecting nematodes might vary differently from the variables actually included in the model. For example, soil moisture might not vary from year to year in exactly the same way as does annual rainfall.

All three population models have a positive sign for the weed control variable—an interesting phenomenon. The positive sign indicates that as weed control is improved, nematode populations increase. Thus, improved weed control increases both corn yield

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[8] For each day between planting and harvest, we compute and accumulated: $T_h + T_L)/2-50$, where T_h and T_L are the high and low temperatures respectively, in degrees Fahrenheit.

and nematode populations. One reasonable explanation is that improved weed control improves growth of the corn root-system and increases yield which, in turn, increases the food supply for nematodes. The overall impact of weed control is to increase corn yield even though nematode populations increase.

Kill-Efficiency Equation

An equation estimated with 1976-79 data shows the impact of aldicarb applied at planting on the nematode population at harvest. This equation provides both the kill-efficiency function and some additional information about nematode population dynamics. This equation includes the aldicarb dosage, the method of application, the ring-nematode population at planting, and dummy variables identifying years as independent variables. The aldicarb equation is an exponential function:

$$\begin{array}{rl} X_1^* = & [\underset{(2.5)}{31.7}\, X_4 - \underset{(1.15)}{43.3}\, X_5 + \underset{(6.47)}{1.87}\, X_7] \\ & [\exp(-\underset{(2.01)}{0.588}\, X_8 - \underset{(3.03)}{0.989} X_9)] \end{array} \qquad (5)$$

where:

X_1^* = population density of lesion nematodes at harvest,
X_4 = dummy variable for second year,
X_5 = dummy variable for third year,
X_7 = population density of ring nematodes at planting,
X_8 = rate of aldicarb application (pounds a.i. per acre), and
X_9 = dummy variable for application method (0 = infurrow planting or no pesticide, 1 = banded and incorporated).[9]

The model fits the data with $R^2 = 0.74$, $CR^2 = 0.72$, and SER = 30.2. With d.f. = 55, all coefficients except that for the second year are significantly greater than zero at the 97.5-percent level. The coefficient for the second year is not significantly greater than zero at the 90-percent level.

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[9] We did not average planting or harvest populations in this equation.

When no aldicarb is applied, equation (5) becomes a population prediction equation with a form similar to that for equation (2). Dummy variables identifying years explain a high portion of the lesion nematode population at harvest. Although lesion nematodes at planting are highly significant when included in this equation, only 2 of the 60 observations are greater than zero, making the significance of the variable questionable. For the analysis, we assume:

$$X_1^* = X_1 [\exp(-0.588X_8 - 0.989 X_9)] \tag{6}$$

The term, $\exp(-0.588X_8 - 0.989X_9)$, is a kill-efficiency function and expresses the proportion of the untreated nematode population at harvest that would survive if aldicarb had been applied at rate X_8 by method X_9. This term approximates very well the exponential, kill-efficiency equations used by Regev, Gutierrez, and Feder *(16)* and Talpaz and others *(22)* and the ideal logistic function discussed by Shoemaker *(20)* and Hillebrandt *(10)*.

A somewhat different aldicarb equation that does not include dummy variables indicating years but that does highlight the relationship between ring and lesion nematodes is:

$$X_1^* = \underset{(2.53)}{[23.73} + \underset{(10.42)}{1.39X_7]}\,[\exp(-\underset{(2.33)}{0.497X_8} - X_9)] \tag{7}$$

The model fits the data with $R^2 = 0.72$, $CR^2 = 0.71$, and SER = 30.9. With d.f. = 56, all the coefficients are significantly greater than zero at the 97.5-percent level. On these experimental plots, it appears either that ring nematodes have a large impact on lesion nematodes or that important, unmeasured factors affect the population of both species causing their variations to be highly correlated.

Reliability of the Estimates

The most important problem with the data used in this study is that the variances of the equations might be correlated with an independent or a dependent variable (heteroskedasticity) which violates a basic assumption of ordinary-least-squares regression. The variances of yield (equation (1)) and nematode populations at harvest in the population prediction and in the kill-efficiency equations could be functions of nematode populations at harvest or of other variables. High correlations between, or linear combinations of, independent variables (multicollinearity) do not appear to be major problems in any of the equations. However, some of the coefficients may include the impacts of excluded, independent variables which are closely correlated to independent variables in the models. The specifications of the equations appear reasonable with the yield and kill-efficiency equations corresponding well to theoretical models used in other studies. Thus, the estimators of the coefficients should be unbiased and consistent, but not necessarily efficient or assymtotically efficient.[10]

Two important problems arise in estimating optimal dosages from these equations. First, our method requires using a kill-efficiency function estimated with data collected from different plots and in different years than were the data we used to estimate the yield and population-prediction equations. We cannot be sure that the kill-efficiency equation is valid on both sets of plots in both periods of time. Our method assumes that it is. However, Regev, Gutierrez, and Feder *(16)* and Talpaz and others *(22)* make similar assumptions in their studies. Second, the range of nematode populations in the plots used to estimate the kill-efficiency equations was generally narrower than the populations in the plots used to estimate the yield and population-prediction equations. Therefore, the kill-efficiency equation may be less reliable in estimating the impacts of nematicides at higher populations than at lower populations.

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[10] Econometricians consider unbiasedness, consistency, and efficiency as the "desirable properties" of estimators. The properties of the estimators here indicate that the expected values of the estimators equal the expected values of population parameters for the experimental plots when they were sampled. Furthermore, the variances of the estimator approach zero as sample size increases. If heteroskedasticity is not a problem, the distributions of the sample distributions approach normality and the estimators approach those with minimum variance as sample size increases.

Estimates of Optimal Dosages

In this section we show profit-maximizing and break-even aldicarb dosages for two application methods over a range of lesion nematode populations at harvest and the relative prices for corn and aldicarb. Then, we present a profit function assuming one price of corn and of aldicarb. Finally, the lesion nematode populations at planting are associated with population levels at harvest for each year that data were collected.

The Decision Rule

Our analysis assumes that the proportion of the nematode population killed by an aldicarb application does not depend on population levels. Hillebrandt *(10)*, Regev, Gutierrez, and Feder *(16)*, Shoemaker *(20)*, and Talpaz and others *(22)* make the same assumptions in their discussions of optimal pesticide use. Our method of estimating the impact of aldicarb on corn yield substitutes X_1 in equation (1) with X_1^* or $X_1[\exp(-0.588X_8 - 0.989X_9)]$ (see equation (6)). Hence, the corn yield equation becomes:

$$\begin{aligned} Y = \; & [-12412.2 - 12.54X_1[\exp(-0.588X_8 - 0.989X_9)] \\ & + 0.0098\,X_1^2\,[\exp(-1.18X_8 - 1.98X_9)] + 20.97X_2 \\ & + 363.5X_3]\,0.01593 \end{aligned} \qquad (8)$$

To define the optimal dosage, we assume that the farmer wishes to apply the dosage of aldicarb that maximizes profits. To determine this dosage, we differentiate the profit function which accounts for the price of corn, corn yield, and the material and application costs of aldicarb. This procedure defines the marginal profit which is the incremental increase in profit attributed to an additional increment of aldicarb dosage. The optimal (profit-maximizing) pesticide dosage at a fixed point occurs where the marginal profit of aldicarb per pound per acre is zero and is defined as follows:

$$\delta R/\delta X_8 = P_c(\delta Y/\delta X_8) - P_t = 0 \qquad (9)$$

where:

R = profit (dollars per acre),
P_c = price of corn (dollars per bushel),
P_t = price of aldicarb (dollars per pound a.i.), and
$\delta Y/\delta Y_8$ = incremental change in corn yield per acre (reduction in nematode damage) attributed to an additional increment of aldicarb

$$= [-\delta 12.54X_1[\exp(-0.588X_8 - 0.989X_9)]/\delta X_8 + \delta\, 0.0098X_1^2 [\exp(-1.18X_8 - 1.98X_9)]/\delta X_8]\ 0.01593$$

$$= 0.1175\, X_1 [\exp(-0.588X_8 - 0.989X_9)] - 0.000184\, X_1^2 [\exp(1.18X_8 - 1.98X_9)]$$

For any pesticide to be applied, the total increase in profit attributed to the application, which is the difference between total profit when aldicarb is applied and when it is not applied, must be greater per acre than zero; therefore:

$$\Delta R = P_c(\Delta Y) - P_t(X_8) - C > 0 \tag{10}$$

where:

ΔR = change in profit per acre attributed to an aldicarb dosage of X_8 (dollars per acre),
C = application cost per acre excluding the cost of aldicarb, and
ΔY = change in yield (decrease in nematode damage) attributed to an aldicarb dosage of X_8

$$= [-12.54\, X_1 [\exp(-0.588X_8 - 0.989X_9)] + 0.0098X_1^2 [\exp(1.18X_8 - 1.98X_9)] + 12.54X_1 - 0.0098X_1^2]\ 0.01593$$ [11]

$$= 0.1999X_1 [1-\exp(-0.588X_8 - 0.989X_9)] - 0.000156X_1^2 [1-\exp(-1.18X_8 - 1.98X_9)]$$

Although our study does not explicitly consider farmers' risk preferences, it can indicate where their preferences would have

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[11] This equation is obtained by subtracting equation (1) from equation (8). The intercept and the terms for X_2 and X_3 cancel out.

an impact. Assuming our model specifications, variance (which is a measure of risk) is independent of corn yield or of any production inputs. Therefore, farmers' risk preferences would not change the optimal dosage for a nematode population unless they did not believe population and damage forecasts, but felt damage would be higher than predicted. However, the farmers' risk preferences might change the break-even nematode population. Risk-averse farmers might apply nematicides even if the analysis shows that the profits would be less per acre than zero.

Optimal and Break-Even Dosages

The results of equation (9) are a series of curves for each application method showing the optimal dosage for each nematode population level at harvest. Each curve represents a different corn price relative to the aldicarb price. Equation (10) finds the population on each curve where profits per acre are zero. The analysis assumes P_t = \$14.40 per pound a.i. and varies P_c from \$1.50 per bushel to \$4.00 per bushel in \$0.50 increments.[12] The analysis assumes the cost of applying aldicarb infurrow to be negligible and uses University of Georgia budgets to estimate the costs of incorporating aldicarb.[13]

Figure 2 illustrates the results of applying aldicarb infurrow, while figure 3 illustrates the result of banding aldicarb. In each figure, a curve shows the optimal dosage for a set of relative prices. Corn price increases in \$0.50 increments, with P_c = \$1.50 for curve A and P_c = \$4.00 for curve F. Line B/E shows the

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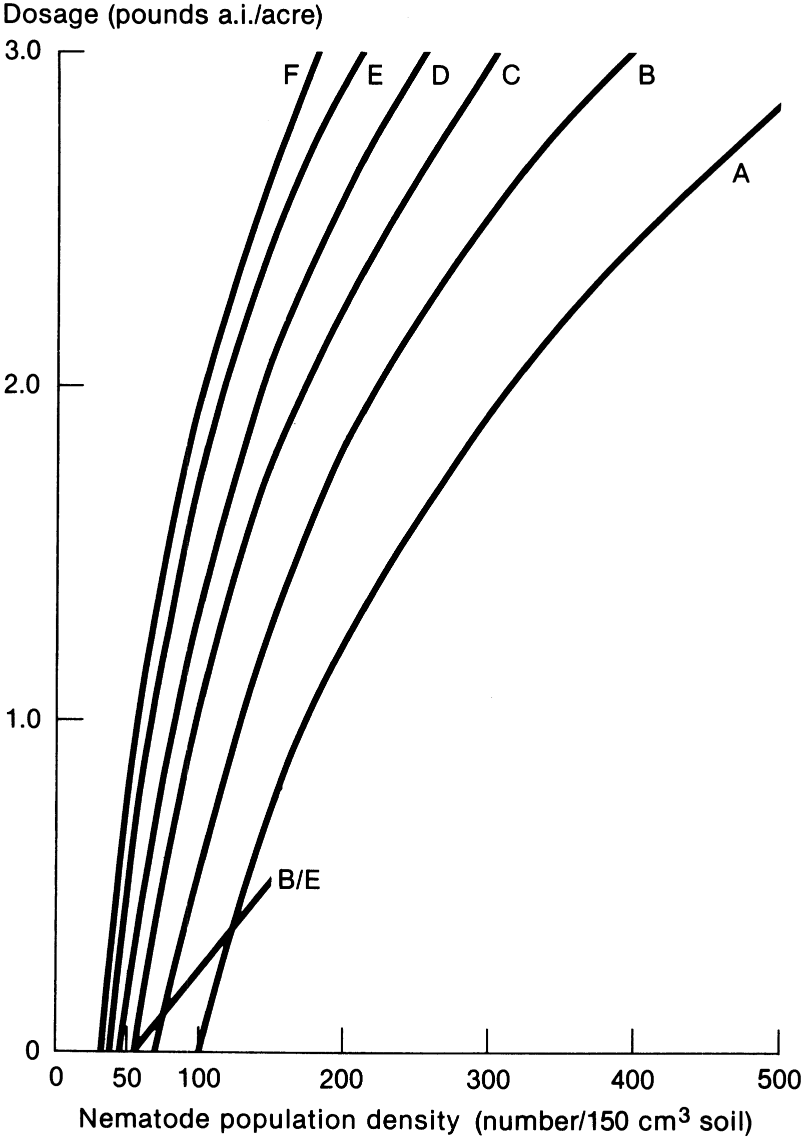
[12] When aldicarb is applied banded and incorporated in the soil, P_t effectively becomes \$2.50 per pound a.i. because the dosages the graphs use for this method are "broadcast equivalent." The actual quantity applied is one-sixth the "broadcast equivalent" dosage because aldicarb is applied over one-sixth of the field in a 6-inch band.

[13] The Department of Agricultural Economics at the University of Georgia assumes interest to be 10 percent, the price of gasoline to be \$0.955 per gallon, the price of diesel fuel to be \$0.855 per gallon, and the price of the farmer's labor to be \$3.50 per hour. If the farmer can roto-till at a rate of 0.31 hour per acre as assumed at the University, the marginal cost is \$1.94 per acre if that farmer already owns a roto-tiller, and \$3.18 per acre if a new one must be purchased. If the farmer is less efficient and roto-tills at a rate of 1 hour per acre, the marginal cost is \$6.24 per acre if the farmer owns a roto-tiller, but \$10.23 per acre if a new one must be purchased (personal correspondence with Bernie Tews, Research Associate).

Figure 2

Optimal Aldicarb Dosages, Infurrow Applications



populations and dosages on these curves where profits per acre are zero.[14] Below this line, applications are not profitable.

The optimal dosage curves for both methods of application show several important characteristics. The optimal dosage increases at a decreasing rate as nematode populations increase. Increasing corn price shifts the curves of optimal dosage upward with the new curve parallel to the old. These shifts become smaller as corn price increases. So, as the price of corn increases relative to the price of aldicarb, the threshold population for a given aldicarb dosage decreases as predicted by Hall and Norgaard *(6)*, Headley *(7)*, Hillebrandt *(10)*, and Talpaz and Borosh *(21)*. For example, when aldicarb is applied infurrow at a dosage of 1 pound per acre (fig. 2), the optimal nematode population density at harvest is 160 per 150 cm^3 of soil when P_c is \$1.50 (curve A) and is 55 per 150 cm^3 of soil when P_c is \$4.00 (curve F). Furthermore, as the price of corn increases relative to the price of aldicarb, the nematode population below which no aldicarb should be applied decreases. For example, when aldicarb is applied infurrow (fig. 2), the population density below which no aldicarb should be applied is 90 per 150 cm^3 of soil when P_c is \$1.50 (curve A) and is 57 per 150 cm^3 of soil when P_c is \$4.00 (curve F). Because banding and incorporating aldicarb are more effective in reducing nematode populations than is applying it infurrow, aldicarb can be applied at lower populations when banded and incorporated. For example, when $P_c = \$1.50$ (curve A), the population density below which no aldicarb is applied is 90 per 150 cm^3 of soil for infurrow treatments (fig. 2) and is 48 per 150 cm^3 of soil for banding and incorporating (fig. 3).

The break-even line, B/E, for both application methods demonstrates other interesting characteristics. The population and optimal dosage where profits per acre are zero decreases as corn price increases relative to aldicarb price. Based on the data used in our study, aldicarb applications are profitable over a wide range of corn prices, nematode populations at harvest, and application dosages. For example, when aldicarb is applied infurrow

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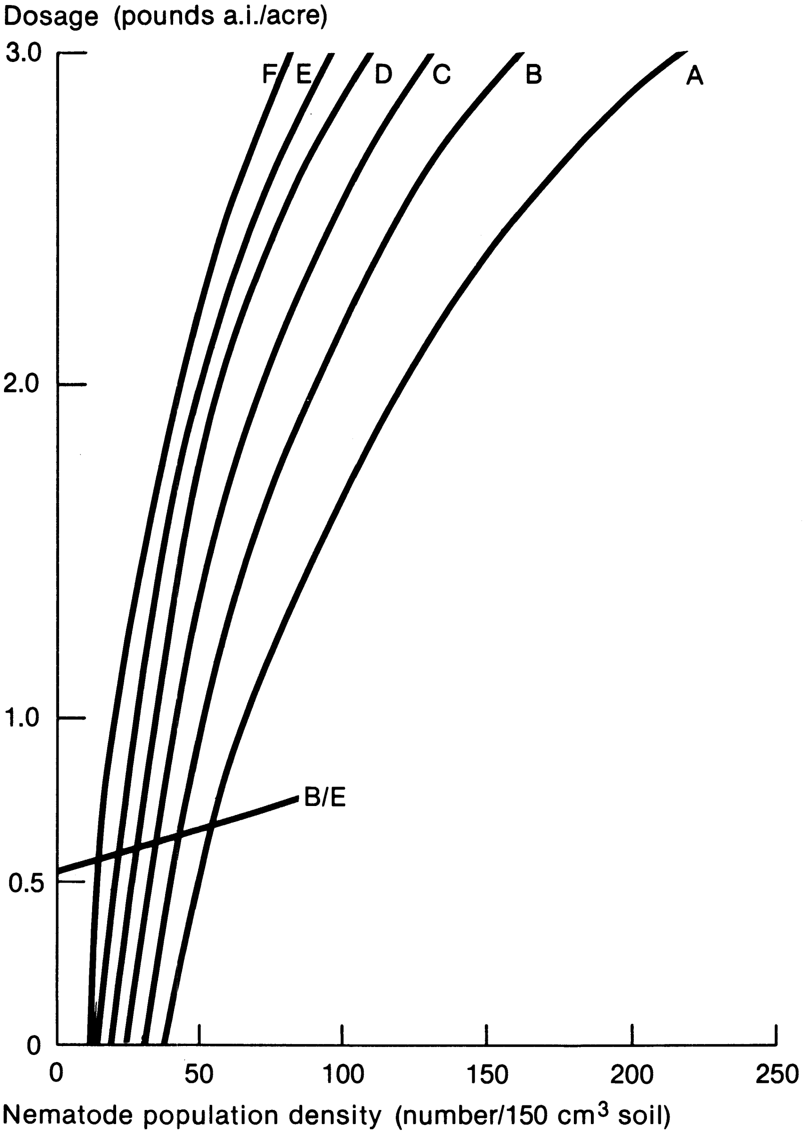
[14] Curve B/E in figure 3 assumes that the farmer purchases a roto-tiller and operates it at a rate of 1 hour per acre.

Figure 3

Optimal Aldicarb Dosages for Band Applications



(fig. 1) and P_c = \$1.50 (curve A), the break-even population density is approximately 105 per 150 cm^3 of soil and the optimal dosage is about 0.29 pound per acre. When P_c increases to \$2.50 (curve C), all optimal aldicarb applications are profitable.

These results show banding and incorporating aldicarb to be more profitable than applying aldicarb infurrow, even though application costs for banding and incorporating are greater. When aldicarb is banded and incorporated, nematode populations are reduced more than when aldicarb is applied infurrow. If the farmer can roto-till at a rate of 0.31 hour per acre, all the optimal dosages are profitable regardless of whether the farmer owns a roto-tiller or buys a new one. All the optimal dosages are profitable if the farmer owns a roto-tiller and operates it at a rate of 1 hour per acre. Only when the farmer must buy a roto-tiller and then operate it at a rate of 1 hour per acre (the situation shown by B/E in fig. 3) are some of the optimal dosages unprofitable.

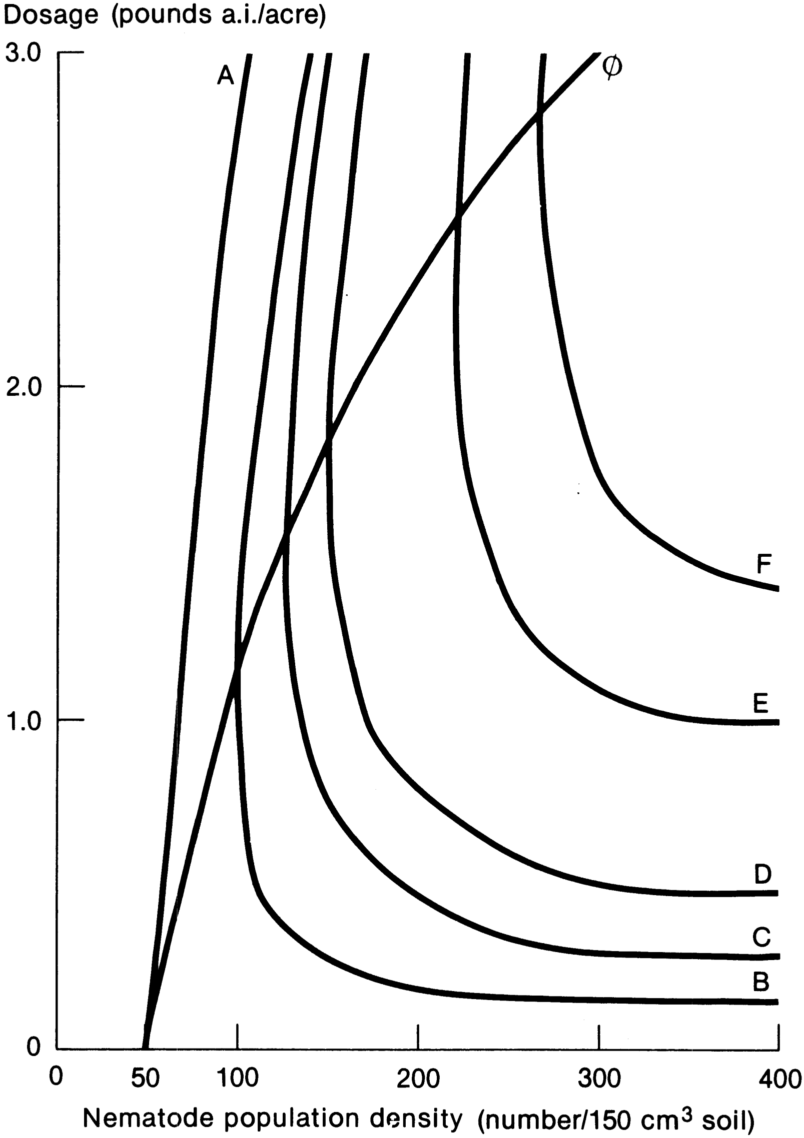
The Profit Function

Figure 4 shows a profit function for aldicarb applied infurrow, derived with equations (9) and (10) and assuming P_c is \$2.50. Curve Φ is the curve of optimal dosages and corresponds to curve C in figure 2. Curves A through F are iso-profit curves computed with equation (10). Curve A shows all dosages and nematode population densities where profits per acre are zero. Profits are \$5/acre for curve B, \$10/acre for curve C, \$15/acre for curve D, \$30/acre for curve E, and \$40/acre for curve F. For a given untreated population, profit increases at a decreasing rate as the nematicide dosage increases. For a given dosage, profit increases at a decreasing rate as nematode population density increases.

The nematode population density where the profit of a certain dosage per acre is zero (curve A) coincides with the economic threshold concept defined by Norton *(15)* where he holds dosage constant. The population density where a dosage is optimal (curve Φ) coincides with the economic threshold concepts discussed by Headley *(7, 8)*, Hillebrandt *(10)*, and Norgaard *(14)*, where they allow the application rate to vary. Curves A and Φ intersect

Figure 4

Aldicarb Profit Function, Infurrow Applications



where the dosage per pound a.i. per acre is zero. The two curves intersect at the horizontal axis for this application method only when the price of corn is $2.50/bushel or greater. However, as nematode populations approach the break-even point on curve Φ, the economic thresholds based on each concept converge.

At a given population density, a farmer's profits on these plots would be quite stable over a fairly wide range of dosages above and below the optimal one. The range over which profits vary little is narrower at the lower population levels. The shape of the iso-profit curves shows that profits for dosages less than the optimal one decrease more rapidly than do profits for dosages greater than the optimal one. Therefore, if farmers know they have a nematode problem but are not sure how high the infestation is, they can probably apply 2-3 pounds a.i. of aldicarb infurrow without significantly reducing their profits. However, if farmers do not have a nematode problem, they would be wasting their money to apply aldicarb.

Projections of Nematode Populations at Planting

Farmers need to know nematode populations at planting for the optimal dosages to be useful. Using equation (2), we find nematode populations at planting that would project nematode populations at harvest for each of the 4 years when data were collected, assuming 100-percent weed control (see table). Notice that the nematode population at planting which would predict a certain population at harvest varies widely from year to year. For example, in year 1, equation (2) projects 500 lesion nematodes per 150 cm^3 of soil at harvest from 8 per 150 cm^3 of soil at planting. In year 3, equation (2) projects the same harvest population from 405 lesion nematodes per 150 cm^3 of soil. So, if P_c is $1.50/bushel and aldicarb is applied infurrow, the farmer should have applied 3 pounds a.i. when nematode density at planting was 8 per 150 cm^3 in year 1 and 405 in year 3. These variations indicate that unmonitored factors affecting nematode populations (as discussed) can significantly affect both projected nematode damage and the decision to apply aldicarb.

Relationship between nematode populations at harvest and at planting

Density at harvest	Density at planting[1]			
	Year 1	Year 2	Year 3	Year 4
	Number per 150 cm^3 of soil			
50				
100			36	
150			82	22
200		3	128	68
250		49	174	115
300		95	220	161
350		142	267	207
400		188	313	253
450		234	359	299
500	8	280	405	345
550	54	326	451	391
600	100	372	497	437
650	146	418	543	483
700	192	464	589	529

Note: A blank means no planting population would grow to a harvest population this small.

[1] Computed using equation 2 and assuming 100-percent weed control. Note that populations do not accumulate from year to year.

Implications for Nematode Management

Lesion nematodes can be an economic pest for corn in the southeastern coastal plain, but economic methods can be used to estimate nematicide dosages to control these nematodes. Our results show that aldicarb can be profitably applied to control lesion nematode infestations in corn fields on sandy soils. The aldicarb applications are profitable over a wide range of nematode populations, dosages, and relative prives of corn and aldicarb. The optimal aldicarb dosage increases at a decreasing rate as the population level of lesion nematodes or the relative price of corn to aldicarb increases.

Both banded, incorporated treatments and infurrow treatments of aldicarb are profitable over a wide range of lesion nematode populations and corn prices. Our results indicate that banded, incorporated treatments control nematodes better than infurrow treatments. As a result, banded, incorporated treatments are more profitable than infurrow treatments except when a farmer purchases a roto-tiller to incorporate aldicarb and operates it inefficiently.

Our analysis shows that nematode population prediction is the weakest component of the management system. We encountered more difficulty in estimating the population-prediction equation than the yield or the kill-efficiency equations. Factors which have not been monitored that vary from year to year seem to greatly affect population increases during the growing season. These unmonitored factors could significantly affect projected populations and damages as well as the decision to apply nematicides. When corn follows corn or soybeans in rotation on the experimental plots, the population increase in lesion nematodes is independent of the population both at planting and at the previous harvest. In fact, the population at the previous harvest is not an important factor in explaining the population at the current harvest.

The population-prediction problem is alleviated somewhat with aldicarb. Aldicarb dosages can be varied from the optimal dosage without greatly decreasing profits. Hence, recommendations for aldicarb could be related to generalized categories of nematode infestations such as low, moderate, and severe.

Needs for Research

We feel that researchers should extend economic analysis to other crops and nematicides. Economists should study the optimal crop rotation and nematicide application problem. If appropriate, researchers should consider heteroskedasticity and the impacts of pest control practices on risk when studying optimal pesticide use. Finally, economists need to look at nematode monitoring costs, expected population levels, and expected damage levels to determine if the value of monitoring justifies the cost.

Needs for Research

We believe biologists need to identify more of the factors which explain nematode population growth and carrying capacities and then incorporate them into models to predict populations and damage. They could also investigate using a generalized classification of nematode infestations (such as low, moderate, or severe) to recommend specific nematode management practices.

References

(1) Carlson, G.A. "A Decision Theoretic Approach to Crop Disease Prediction and Control," *American Journal of Agricultural Economics*, Vol. 52, No. 2, May 1970.

(2) Chatterjee, S. "A Mathematical Model for Pest Control," *Biometrics*, Vol. 29, No. 4, Dec. 1973, pp. 727-34.

(3) Dowler, C.C., E.W. Hauser, and A.W. Johnson. "Crop-Herbicide Sequences on a Southeastern Coastal Plain Soil," *Weed Science*, Vol. 22, No. 5, 1974, pp. 500-05.

(4) Feder, Gershon. "Pesticides, Information, and Pest Management Under Uncertainty," *American Journal of Agricultural Economics*, Vol. 61, No. 1, Feb. 1979, pp. 97-103.

(5) Ferris, H. "Nematode Economic Thresholds: Derivation, Requirements, and Theoretical Considerations," *Journal of Nematology*, Vol. 10, No. 4, 1978, pp. 341-50.

(6) Hall, D.C., and R.B. Norgaard. "On the Timing and Application of Pesticides," *American Journal of Agricultural Economics*, Vol. 55, No. 2, May 1973, pp. 198-201.

(7) Headley, J.C. "Defining the Economic Threshold," *Pest Control Strategies for the Future.* Washington, D.C.: National Academy of Sciences, 1972, pp. 100-08.

(8) ______________. "The Economics of Pest Management," *Introduction to Insect Pest Management* (ed. R.L. Metcalfe and W.H. Luckman). New York: John Wiley, 1975.

(9) ______________. "The Economics of Pest Management by Individual Growers," *Iowa State Journal of Research*, Vol. 49, No. 4, May 1975, pp. 623-28.

(10) Hillebrandt, P.M. "The Economic Theory of the Use of Pesticides," *Journal of Agricultural Economics*, Vol. 13, 1960, pp. 464-72.

References

(11) Hueth, D., and V. Regev, "Optimal Agricultural Pest Management with Increasing Pest Resistance," *American Journal of Agricultural Economics*, Vol. 56, No. 3, Aug. 1974, pp. 543-52.

(12) Johnson, A.W., C.C. Dowler, and E.W. Hauser, "Seasonal Population Dynamics of Selected Plant-Parasitic Nematodes on Four Mono-cultured Crops," *Journal of Nematology*, Vol. 6, No. 4, 1974, pp. 187-90.

(13) ______________. "Crop Rotation and Herbicide Effects on Population Densities of Plant-Parasitic Nematodes," *Journal of Nematology*, Vol. 7, No. 2, 1975, pp. 158-68.

(14) Norgaard, R.B. "Integrating Economics and Pest Management," *Integrated Pest Management* (ed. J.L. Apple and R.F. Smith). New York: Plenum Press, 1976.

(15) Norton, G.A. "Analysis of Decision Making in Crop Protection," *Agro-Ecosystems*, Vol. 3, 1976, pp. 27-44.

(16) Regev, U., A.P. Gutierrez, and G. Feder. "Pests as a Common Property Resource: A Case Study of Alfalfa Weevil Control," *American Journal of Agricultural Economics*, Vol. 58, No. 2, May 1976, pp. 186-97.

(17) Reichelderfer, K.H., and F.E. Bender, "Application of a Simulative Approach to Evaluating Alternative Methods for the Control of Agricultural Pests," *American Journal of Agricultural Economics*, Vol. 61, No. 2, May 1979, pp. 258-67.

(18) Seinhorst, J.W. "Dynamics of Plant Parasitic Nematodes, " *Annual Review of Phytophathology*, Vol. 10, 1970, pp. 131-56.

(19) ______________. "The Relationship Between Nematode Density and Damage to Plants," *Nematologica*, Vol. 11, 1965, pp. 137-54.

(20) Shoemaker, Christine. "Optimization of Agricultural Pest Management, Parts I, II, and III," *Mathematical Biosciences*, Vol. 16, 1973, pp. 143-75; Vol. 17, 1973, pp. 357-65; and Vol. 18, 1974, pp. 1-22.

(21) Talpaz, H., and I. Borosh. "Strategy for Pesticide Use: Frequency and Application," *American Journal of Agricultural Economics*, Vol. 56, No. 4, Dec. 1974, pp. 769-75.

(22) Talpaz, H., G.L. Curry, P.J. Sharpe, D.W. DeMichele, and R.E. Frisbie. "Optimal Pesticide Application for Controlling the Boll Weevil on Cotton," *American Journal of Agricultural Economics*, Vol. 60, No. 3, Aug. 1978, pp. 469-75.

(23) Talpaz, H., and R.E. Frisbie. "An Advanced Method for Economic Threshold Determination: A Positive Approach," *Southern Journal of Agricultural Economics*, Vol. 7, No. 2, Dec. 1976, pp. 19-26.

(24) U.S. Department of Agriculture. *Agricultural Statistics. 1980.*

(25) Webster, J.P.G. "The Analysis of Risky Farm Decisions: Advising Farmers About the Use of Pesticides," *Journal of Agricultural Economics*, Vol. 28,, 1977, pp. 243-59.

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