

Nematode Economic Thresholds: Derivation, Requirements, and Theoretical Considerations

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Abstract: Determination and use of economic thresholds is considered essential in nematode pest management programs. The economic efficiency of control measures is maximized when the difference between the crop value and the cost of pest control is greatest. Since the cost of reducing the nematode population varies with the magnitude of the reduction attempted, an economic (optimizing) threshold can be determined graphically or mathematically if the nature of the relationships between degree of control and cost, and nematode densities and crop value are known. Economic thresholds then vary according to the nematode control practices used, environmental influences on the nematode damage function, and expected crop yields and values. A prerequisite of the approach is reliability of nematode population assessment techniques. *Key Words:* Pest management, population dynamics, control costs, damage functions, sampling, optimizing thresholds.

In any pest management program, an obvious concern is not only the type of control measure to be used, relative to pest and environmental considerations, but also the necessity for such control. Economic thresholds are variously defined (1, 3, 14, 18) but might be summarized as the population density of a pest at which the value of the damage caused is equal to the cost of control. Thus, at densities up to the economic threshold, there would be no (or negative)

economic advantage to pest control since control costs would exceed crop loss due to the pest. This important concept has been largely ignored in nematology for several reasons: 1) lack of information on the relationship between nematode densities and plant damage, and damage functions generally; 2) difficulties in assaying nematode densities in a field; 3) work involved in arriving at the decision; 4) ready availability of low-cost pesticides.

Headley (7) elaborated on the economic threshold concept by considering the differential cost of pest control relative to the level of control achieved. Chemical reduction of the pest population by 50% may be relatively inexpensive, whereas a 99%

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reduction, if possible, may be astronomical in cost. Thus, there is an optimum level of control at which profits (crop value less nematode control cost) will be maximized. The dosage/control curve for nematicides is linear within certain limits (13); however, the cost of achieving higher dosages may be multiplicative. Similar observations have been made for insect control, such that costs (c) may be described by:

$$c = \frac{a}{P} \quad [1]$$

where a is a constant and P is the level to which the population is to be reduced. The level of control usually achieved is 80 to 90% (23) for which the cost will be an application overhead (B) and a cost of material (A) from which a hypothetical, unsubstantiated model for the cost of control (y) can be developed:

$$y = (A \times Q)(N/P) + B \quad [2]$$

where A is the cost of material required to reduce the population to a proportion Q, N is the population in the field, and P is the level to which the population is reduced. Quantifying this relationship, if the cost of material (A) to reduce the field population to 0.1 is \$150, with an application overhead (B) of \$50, and the starting population (N) in the field is 1,000, then the cost of reducing the population to 250 nematodes/volume of soil would be:

$$(150 \times 0.1 \times 1,000/250) + 50 = \$110$$

Now, in attempting to maximize profits from nematode control, consider Seinhorst's (20) damage function $y = CZ^{(P-T)}$ relating crop value (y) to numbers of nematodes, where C represents potential crop value, Z is the proportion of the plant not damaged by one nematode, P is the nematode population level, and T is the tolerance level below which damage is not measurable. Assume these parameters to have values C = 1,000, Z = 0.995 and T = 20 (line A in Fig. 1) and the control cost function to have values given above (line B in Fig. 1). The population level at which the crop value less the cost of suppressing the population to that level is maximized, is the point at which the rate of decrease in control cost per nematode (line D, Fig. 1) is closest to the rate of decrease in crop

value per nematode (line C, Fig. 1). In other words, with the two continuous models, crop value (line A) and control cost (line B), the optimizing threshold occurs at the point where the difference between the functions is at a maximum. This is the point at which the difference between the slope of the lines is at a minimum. If the derivatives of the functions intersect, it is a difference of zero. If the derivatives do not intersect below the population level in the field, the optimizing threshold for the management or control practice under consideration is above the current population level (N), so the point of minimum difference in slope is at N and this control option is rejected. Note that with another control approach, the threshold might be below N, depending on the shape and position of the control cost function. In the case of the damage and control cost functions considered, the respective derivatives are:

$$\frac{dy}{dP} = C \ln Z (Z^{(P-T)}) \quad [3]$$

and

$$\frac{dy}{dP} = - \frac{AQN}{P^2} \quad [4]$$

The point of intersection of these lines is determined graphically (lines C and D, Fig. 1), or by equating the derivatives and solving for P. Note the correspondence of the optimizing threshold with the maximum point on the line depicting the difference between the damage and control cost functions (line E, Fig. 1).

Using the above values in the crop value and control cost functions, the optimizing threshold is 61 nematodes/volume of soil (point F, Fig. 1), which can be achieved by a control expenditure of \$295.90, including the \$50.00 application overhead (point G, Fig. 1). The treatment should result in a crop value of \$814.23 (point H, Fig. 1) and a net profit of \$518.33 (point I, Fig. 1). Note that the function used for crop value, $y = CZ^{(P-T)}$, calculates gross crop value without considering production overheads (M). Net crop value would be given by $y = CZ^{(P-T)} - M$, assuming no change in production overheads relative to yield. The addition of the constant causes no change to the derivative of the function or to the point of intersection

of the cost and damage derivatives and hence to the threshold estimate. It will, however, cause a shift in curve A (Fig. 1) resulting in a reduction M in the crop value estimate and the benefit of treatment. The production overheads should be considered in the damage function since they may shift it so much that it does not intersect the control cost function, and the treatment will never be profitable. This concept can be visualized by considering constant crop production overheads of \$600 in Fig. 1.

In Fig. 1, a field population of 1,000 nematodes/volume soil was assumed; the effect of a lower N value (say 150) is to shift the control cost function to the left (line A, Fig. 2), whereas a greater N (say 3,000) shifts it to the right (line B, Fig. 2). This results in points of intersection of the derivatives at C and D, respectively (Fig. 2) producing economic threshold estimates of 22 and 125 for the control practice considered.

By manipulation and consideration of the curves in Figs. 1 and 2, some principles relating to economic thresholds become apparent:

1) The economic benefit and practical suitability of a control or management practice is related to the magnitude of the area under the damage function (considering production overheads) less the area under the control cost function; or the difference between the integrals of the two functions. If this difference is negative, the population is below the economic threshold for that practice.

2) The optimizing threshold is the population level at which the derivatives of the two functions are equal.

3) For management practices resulting in anything less than pest population eradication, the control cost function shifts, relative to the damage function, with different field population densities.

4) If the derivatives of the cost and damage functions intersect at a population level below the tolerance level, the optimizing threshold will be at the tolerance level; that is, profits will be maximized by controlling the population down to the tolerance level or the point below which nematode damage is not measurable.

The foregoing considerations relate to the economics of the current crop year, not to effects on succeeding crops. Nor do they

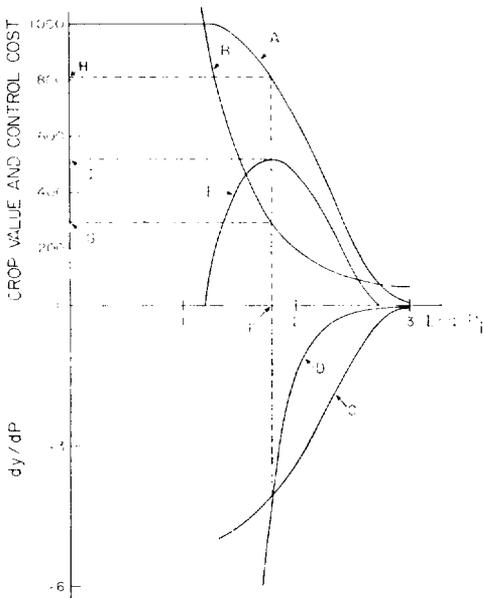


FIG. 1. Determination of the economic threshold by maximizing the difference (curve E) between the nematode-damage function (curve A) and the control-cost function (curve B). The optimizing threshold is the population level at which the derivatives of the damage function (curve C) and the control-cost function (curve D) intersect.

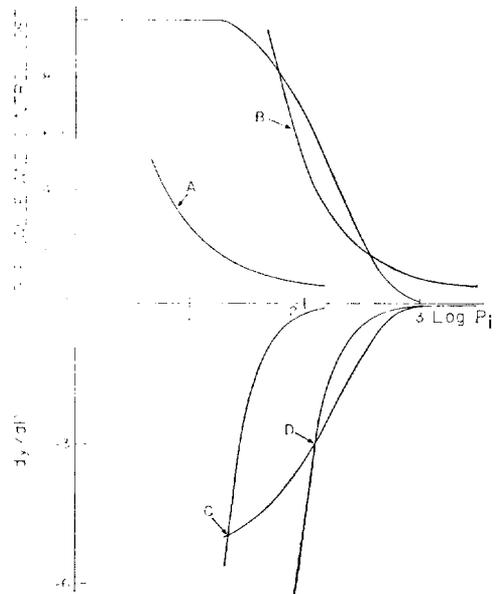


FIG. 2. The effect of initial population densities of 150 (curve A) and 3,000 (curve B) on the magnitude of the optimizing threshold as determined by intersection of the derivatives at C and D, respectively.

include environmental and sociological implications.

Not all pest control or management practices can be described by a continuous model as in Figs. 1 and 2. The use of a crop rotation system, whereby population reduction is in discrete steps at the end of each crop season, results in a discontinuous model (Fig. 3). In this case, the economic threshold is reached when the average cost of control per nematode for a step reduction in the population changes from positive to negative. An iterative procedure, readily adaptable to programmable calculators and mini-computers, can be used to determine the threshold level. The average cost per nematode for successive decreases in the population is calculated from the increase in cost divided by the number of nematodes controlled. From Fig. 3, if the fractional reduction in population per year of nonhost crop is 0.5, the annual population series (N, P_1, P_2, P_3 , etc.) will be $N, 0.5N, 0.25N, 0.125N \dots$ etc. At time zero, the population is N , which would result in the crop value at intersection 1, a net value of $y = C_1Z^{(N-T)} - C_2$ where C_1 is the value per acre of the primary crop and C_2 is the production overhead for this crop. If the alternate nonhost crop were grown, with price A_1 and overhead A_2 , the nematode population would be reduced to $0.5N$ at a cost: $y - (A_1 - A_2)$ or $C_1Z^{(N-T)} - C_2 - A_1 + A_2$ (value at intersection 1 less that at inter-

section 2). If this value is positive, the population level (N) is below the optimizing threshold for the control measure selected, and returns would be maximized by growing the primary crop despite the nematode population, or by selecting another alternate crop for which the population reduction cost would be negative and profits would be maximized by this selection. If the value is negative and the alternate crop is continued a second year, the population will be reduced to $0.25N$ at a cost for this second reduction of $C_1Z^{(0.5N-T)} - C_2 - A_1 + A_2$ and a total cost of achieving $0.25N$ of:

$$y = C_1Z^{(N-T)} - C_2 - A_1 + A_2 + C_1Z^{(0.5N-T)} - C_2 - A_1 + A_2$$

$$\therefore y = C_1Z^{(N-T)} + C_1Z^{(0.5N-T)} - 2C_2 - 2A_1 + 2A_2$$

If the value $C_1Z^{(0.5N-T)} - C_2 - A_1 + A_2$ (intersection 3 less intersection 4) is positive, the economic threshold for this management practice was passed in the second year and profits will now be maximized by reverting to the primary crop. Any expected annual fluctuations in crop prices and overheads can be adjusted at each step in the iterative process. In Fig. 3, the threshold is reached during the third year, after which the cost of further population reduction by this approach is positive (intersection 8 less intersection 7).

Generalizing the concepts for the discontinuous model, the net returns from the primary crop for any year are $Y_c = C_1Z^{(P_k-T)} - C_2$, where C_1 is the expected gross crop value in the absence of nematodes, C_2 is the production overhead, Z is the damage function constant, T is the tolerance limit, and P_k is the initial population at year k . The population after k years of the alternate nonhost crop is given by $P_k = N(1 - b)^k$, where N is the initial population measured in the field, and b is the annual fractional reduction in the absence of a host. The cost of reducing the population by each stepwise seasonal reduction (ϕ_k) is equal to the value of the primary crop at the population level at time k , less the value of the alternate crop. Thus,

$$\phi_k = C_1Z^{(P_k-T)} - C_2 - A_1 + A_2 \quad [5]$$

where $P_k = N(1 - b)^k$.

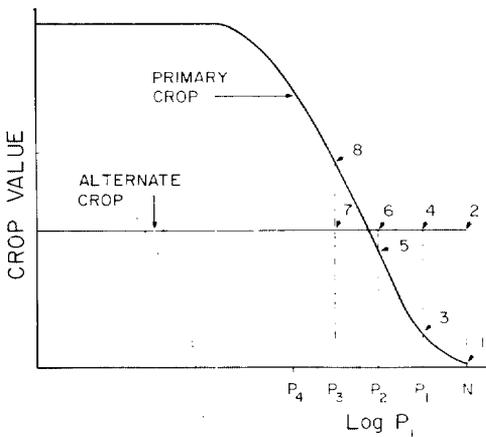


FIG. 3. Determination of the economic threshold with a discontinuous-control cost model as exemplified by rotation to a nonhost crop. The threshold is passed during the season in which the cost of the step-reduction in the nematode population passes from negative to positive.

If this value is initially positive, the field population N is already below the optimizing economic threshold for the management alternative under consideration. If yields of the primary crop are not acceptable at this population level, alternative approaches should be considered. When the function is initially negative, the population is above the economic threshold and subsequent years should be tested. The threshold is bridged during the season that the step-reduction cost function becomes positive and the rotation should revert to the primary crop after this season to maximize profits. Then, it is possible to estimate the economic threshold by determining the population level at which the cost of population reduction becomes zero, i.e., $\phi_k = 0$ so that $C_1 Z^{(P_k - T)} - C_2 - A_1 + A_2 = 0$

$$\begin{aligned} \therefore C_1 Z^{(P_k - T)} &= A_1 - A_2 + C_2 \\ (P_k - T) \ln Z &= \ln \left[\frac{A_1 - A_2 + C_2}{C_1} \right] \\ P_k &= T + \frac{1}{\ln Z} \left[\ln \left[\frac{A_1 - A_2 + C_2}{C_1} \right] \right] \end{aligned} \quad [6]$$

The number of years (k) to reduce the population to P_k is derived from: $P_k = N(1 - b)^k$,

$$\begin{aligned} \therefore \ln N + k \ln(1 - b) &= \ln P_k \\ k &= \text{INTEGER} \left[\frac{(\ln P_k - \ln N)}{\ln(1 - b)} \right] \end{aligned} \quad [7]$$

Note that since it is not desirable to stop the population reduction in the middle of a crop, k takes the value of the next integer. Equations 6 and 7 can be combined to give a value for the expected length of rotation:

$$\begin{aligned} k &= \text{INTEGER} \left[\left[\ln \left[T + \frac{1}{\ln Z} \right. \right. \right. \\ &\quad \left. \left. \left[\ln \left[\frac{A_1 - A_2 + C_2}{C_1} \right] \right] - \ln N \right] \right. \\ &\quad \left. \left. \left. \right] / \ln(1 - b) \right] \end{aligned} \quad [8]$$

This approach gives initial indications of rotation length when there is only one alternate crop, or when average crop values

are used for a series of alternate crops. With multicrop rotations, the approach would be to determine whether the threshold had been bridged by predicting the cost of nematode reduction in one-season steps using equation 5 and substituting appropriate crop values. The same approach can be used for monitoring the progress of a single-alternate rotation scheme at the end of each season by substituting actual crop prices.

The concepts involved in both the continuous and discontinuous models can be exemplified and tested using data for *Heterodera schachtii* from Cooke and Thomason (3). The damage function determined for sugar beets in the Imperial Valley of California, using five-year average prices (3, 4) is: $y = 858.42 (.99886)^{(P - 100)}$, where population levels are expressed as eggs plus larvae per 100 g soil. Assuming that the nematode can be controlled to the 10% level by an in-row treatment of 10 g/A of 1,3-D nematicide at recent commercial application costs of \$52.50 for material and \$7.25/acre for application, the parameters for the hypothetical continuous control cost function (eqn. 2) are available. If the field population (N), measured by sampling, is 2,000 propagules/100 g soil, the appropriate substitutions can be made in the derivative equations (eqns. 3 and 4):

$$\frac{dy}{dP} = 858.42 \ln .99886 (.99886)^{(P - 100)}$$

$$\frac{dy}{dP} = -(52.5 \times 0.1 \times 2000)/P^2$$

The optimizing threshold population for the chemical control approach can be determined by finding the value of P at the point of equality of the derivatives:

$$\begin{aligned} 858.42 \ln .99886 (.99886)^{(P - 100)} &= \\ -(52.5 \times 0.1 \times 2000)/P^2 & \\ -.97916 (.99886)^{(P - 100)} &= -10500/P^2 \end{aligned}$$

$$2 \ln P + (P - 100) (-.00114) = 9.2802$$

$$2 \ln P - .00114P = 9.3942$$

This transcendental equation can be solved by iteration to yield: $P = 109.6$ eggs and larvae/100 g soil. Alternatively, the value of P can be determined graphically as the point of intersection of the derivatives. Note that under a standard definition of the economic threshold as the number of nematodes at which the loss in crop value

is equal to the cost of control, the estimate would be at a crop value of $$(858.42 - 52.5 - 7.25) = 798.67 . Substituting in the damage function yields an economic threshold of 163.3 propagules/100 g soil, so that the optimizing technique yields a lower threshold in this case. However, the control cost function was based on a hypothetical model. The optimizing approach (excluding production overheads) as determined by substitution in the damage function and equation 2 would yield a crop value of \$849.07 and control cost of \$103.05, resulting in a net return of \$746.02. Assuming 90% effectiveness of the control treatment, the standard approach would result in reduction of the population to 200 propagules/100 g soil at a cost of \$59.75. The crop value would be \$765.88 and the net return \$706.13.

A variation on the control efficiency assumptions would be provided by assuming that the 10 g/A in-bed treatment resulted in 80% control of the nematode population, while 90% control could be achieved at 15 g/A broadcast. This would result in optimizing threshold estimates of 138.3 and 119.8 propagules/100 g soil and optimized profits (excluding production overheads) of \$662.64 and \$700.53, respectively. In this case, the broadcast treatment might be a preferable selection.

The University of California recommends crop rotation to nonhosts such as alfalfa for *H. schachtii* control (10, 19). Examining the economics of the discontinuous control model, current yields and prices of alfalfa in the Imperial Valley (4) produce crop values of \$589.30 with production overheads of \$169.30 for stand establishment and annual production costs of \$480.56. The establishment cost represents an extra production overhead which will be prorated over an average of three years of the crop, i.e., \$56.43 is the cost per year. Sugar beet production currently costs \$719.13 per acre, resulting in 28.5 tons valued at \$30.12 (based on a five-year average), a total crop value of \$858.42. Substituting in the discontinuous model (eqn. 6):

$$P_k = 100 + \frac{1}{(-.00114)}$$

$$\ln \left[\frac{589.30 - 536.99 + 719.13}{858.42} \right] = 193.7$$

The annual rate of population decline in the Imperial Valley is about 50% (I. J. Thomason, personal communication), so that the required length of rotation from eqn. 7 is:

$$k = \text{INTEGER} \left[\frac{(\ln 193.7 - \ln 2000)}{\ln .5} \right] = 4 \text{ years}$$

Thus, a four-year alfalfa rotation is initially indicated, but annual up-dating of the economic situation based on actual crop prices may result in modification of this estimate as time progresses.

NONMATHEMATICAL SUMMARY

The concepts explored are based on the premises that the value of a crop can be related to the initial population density of the nematodes damaging it, and that the cost of controlling a nematode population by a specific method varies with the level of control desired. The difference between the crop value and the cost of control represents the benefit to the grower. There is an optimum level (point F, Fig. 1) to which the nematode population can be reduced at a cost (point G, Fig. 1) determined by the shape and position of the control cost curve (curve B, Fig. 1), at which the benefits of the treatment are maximized (point H minus point G, Fig. 1). Curve E (Fig. 1) represents the difference between the crop value and control cost lines for various nematode population densities, indicating the population density at which benefits are maximum. This density is the optimizing threshold, different from the standard definition of economic threshold as the point at which returns equal control costs (7). In the case of crop rotation (Fig. 3), where the population is reduced in a stepwise manner, the optimum number of years for rotation to reduce the nematode population can be determined if the seasonal reduction under a nonhost and the relationship between nematode densities and expected growth of the primary crop are known. The economic threshold is reached when returns from the

primary crop at that population level would be equal to or greater than those of the alternate crop.

DISCUSSION

A prerequisite for determination and application of economic thresholds is a knowledge of the relationship between pest density and expected damage. Currently, there is intense interest in developing these damage functions because of: 1) environmental and health pressures restricting pesticide use, and pending legislation requiring documented justification before pesticide application (22); 2) the desirability of regulating the pesticide load in the environment; 3) the legal requirement to demonstrate documented evidence of the benefit of pesticides during the RPAR process (24); 4) increasing cost and lack of availability of pesticides relative to declining fossil fuel supplies; and 5) lower efficiency of many alternative pest control measures. These factors require consideration of the economics and cost/benefit analysis of pest management programs. Data which are currently largely unavailable are needed for such analyses. Besides damage functions, data on costs of control measures, and estimated yields and crop value for a particular field are required. Operational costs are largely calculable, although an element of estimation and forecasting is involved in determining expected yields and crop value. Farmer experience and agricultural statistics are useful.

The models developed in this paper have informational requirements which indicate needed research emphasis in quantitative aspects of nematology. It is useful to examine these requirements.

The damage function: Prediction of yield losses in annual crops is, at least in concept, simpler for nematodes than for many other pests. Nematodes are relatively less motile, and crop yields can be related to preplant population densities (16, 20), so that considerations of crop age or status at the time of pest invasion are not necessary. However, edaphic, environmental, cultural and varietal conditions do need to be considered in determining or applying the density/damage relationship. The situation is more complex in perennial crops,

where the response of the host to the pathogen, and the effect of this response on the pathogen, is a reflection of crop history (6).

The general nematode damage function involves an essentially linear relationship between plant damage and log-transformed nematode densities, with several alternatives at its extremities (16). Equations for the relationship, based on theoretical damage considerations (20), are compatible with empirical observations, although the validity of underlying assumptions of the theoretical relationship has been questioned (25). The theory-based relationship allows consideration of a tolerance limit (T) below which damage is not seen. That concept has also been questioned (25), although it has practical validity when considered as the population below which yield loss is not measurable. The term "tolerance" is perhaps too limiting.

Scinhorst's (20) damage function relates yield (y), on a relative scale, to initial population density (P) by $y = CZ^{(P-T)}$ when $P > T$ and has the value $y = 1$ when $P \leq T$. If T (measurable damage/tolerance limit) is greater than zero, it is important in determining the position of the damage portion of the relationship and imparts greater sensitivity to this position since it is expressed at the low end of the logarithmic population scale where damage per individual is greatest. Unfortunately, most yield/population data are too variable to allow estimation of T with confidence. Square root transformations of population data have been suggested to facilitate determination of T (21).

Damage functions for applied use must be based on data from field and microplot trials. From a practical standpoint, the yield-loss portion of the relationship approximates linearity. Any error incurred by the assumption of linearity is minimal relative to the inherent variability of field data. The assumption allows the advantage of using standard linear regression techniques to enable nonsubjective line fitting. However, the existence of a tolerance/measurable damage limit may be overlooked, resulting in a linear damage function with a more gradual slope. Linear regression techniques have been used with microplot data (2).

The data base from which damage

functions are derived is a limitation to the confidence with which they can be used. The slope and position of the regression line may be influenced by seasonal variation, crop variety and predisposition, and soil factors. The influence of these factors can be determined by repetition of field experiments over several years and in different localities. The damage function on a heavy soil might be shifted to the right (line A, Fig. 4) and its slope altered from the situation on a sandy soil (line B, Fig. 4). Knowledge of this variability would allow estimation of the position and slope of the line in individual fields of intermediate soil texture (line C, Fig. 4). Similar considerations for other influences would allow useful estimates based on data from extreme situations rather than from every possibility.

Data from microplots are valuable and have been used extensively (2, 9, 17). Microplots have the disadvantage of being expensive and unadaptable to standard cultural practices, and lack the full interacting complement of soil flora and fauna. However, they reduce much of the extraneous variability inherent in field-plot data. Attempts were made to obtain crop-damage data from field conditions by exploiting the variability in horizontal distribution of nematodes through random location of individual plots (5). Crop yields in plots were related to the range of nematode densities encountered. Exact relocation of plots proved difficult, and data were variable because of textural and agronomic variations across the field. Another ap-

proach is to obtain data from crops grown in adjacent strips. Direction of the strips is rotated through 90° in different crop years to manipulate nematode densities in square plots, similar to cross-over rotation trials (15). Even in a small area of apparently uniform soil conditions, growth differences occur which cannot be ascribed to nematode effects. Precision of regression analyses is improved by expressing yield data (0-1 scale) relative to maximum and minimum yields in stratified areas of the block of plots. A variation of this approach is to use a paired plot technique where one plot of each pair is treated with a nematicide. Yield of an untreated plot is expressed relative to that of the treated plot of the pair, reducing the effects of site variability. In this approach it may be necessary to adjust for any stimulatory effects of the nematicide not associated with reduction of nematodes.

The control cost function: This area has received very little consideration. Control costs are based on specified control recommendations (19), and the costs of varying levels of control have not been investigated. Such control-cost relationships are necessary for optimizing approaches to nematode pest management. Some studies have examined levels of control achieved by varying nematicide dosages in closed chambers (13), but the amount of nematicide necessary to achieve these dosages under field conditions is not known. There is, however, some information on the amount of nematicide needed to achieve a specified level of control under different soil conditions (11, 12). Similar information is needed for other management practices to which a continuous model could be applied. These might include cost of biological control agents incorporated into the soil, lengths of fallowing or flooding of the soil, and the levels of control achieved.

Information for discontinuous control cost models might be available in the literature. It includes, for example, relative crop values of alternate crops and rate of nematode decline under these crops, or degree of control achieved by, and cost of, repeated soil tillage. However, there are many gaps to be filled in this knowledge.

Analysis of nematode populations: The derivation and practical use of damage functions involves determination of nem-

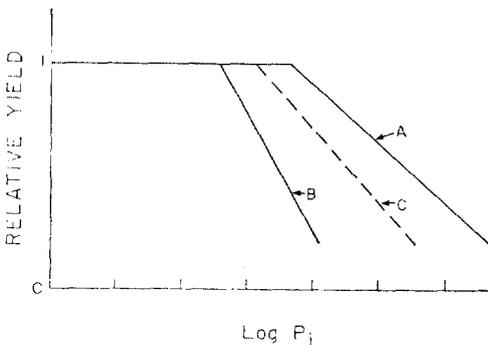


FIG. 4. Conceptual influence of environmental factors on the damage function. Damage functions measured at extremes (lines A and B) of climatic or edaphic factors and estimated (line C) for intermediate conditions.

atode population densities. Expected population densities on a regional basis for use in crop-loss estimates may be available from the records of advisory agencies (8). However, data for regressions and decisions on management approaches involve sampling, extraction, identification, and counting of nematodes. The reliability and cost of the sampling program may be the limiting factor in development and use of damage functions. Treatment of the field for insurance purposes rather than economic threshold considerations might be a reasonable approach if the cost of nematode assessment is too high. In the optimizing approach to economic thresholds (7), it is useful to include a population assessment-cost constant in the control cost function. This will not change the population level at which the difference between the derivatives of the control cost and damage functions is minimized, but it may result in a vertical shift in the control cost function to the point that the management approach is not profitable. It is important that damage functions and economic thresholds are corrected for extraction efficiency so that they can be adapted to other extraction systems.

CONCLUSIONS

Data needed for considerations of economic and optimizing thresholds include reliable damage functions relating expected crop yields to nematode densities and an understanding of the influence of geographic, climatic, and edaphic factors on them. Also required are data on costs of control or management practices, in absolute terms for standard threshold estimates, or as related to levels of control for optimizing approaches. In individual fields, estimates of potential yields and expected crop values are required. The forecasting involved will be based on market trends, farm, local, and state averages, and grower experience. Reliability of nematode population assessment is a prerequisite of these approaches.

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