Economic Aspects of Integrated Pest Management Threshold Determination

GERALD A. CARLSON, Department of Economics and Business, North Carolina State University, Raleigh 27650, and J. C. HEADLEY, Department of Agricultural Economics, University of Missouri, Columbia 65211

ABSTRACT

Carlson, G. A., and Headley, J. C. 1987. Economic aspects of integrated pest management threshold determination. Plant Disease 71:459-462.

An economic threshold is defined, and steps in compiling information necessary for computing it are described. An example of the determination of a simple economic threshold is given for soybean cyst nematode, using field experiments and best available cost data. More complex economic thresholds with uncertainty and dynamics are described briefly, and possibilities of practical pest disease thresholds are assessed.

The economic threshold is a concept that has become accepted as a principle of plant protection and pest management. Beginning in entomology (14), it has spread to weed science and to plant pathology. In a practical way, the idea has to be very old, because it is difficult to envision any farmer applying controls against a pest without the expectation that the value of the damage prevented by so doing would outweigh the cost of the control measures. So, what Stern (13) and others after him have done is to formalize and articulate a concept that is rooted in common sense.

ECONOMIC THRESHOLD DEFINED

As presented by Stern (13), the economic threshold was defined as the density at which control measures should be determined to prevent an increasing pest population from reaching the economic injury level. The economic injury level is the lowest population density that will cause economic damage, and economic damage is defined as the amount of injury that will justify the cost of pest control measures (8,14). All of this is to say that the added cost of pest control should be equal to or less than the added benefits (value of damage prevented) of that control (7).

Presented August 12, 1985, at the symposium entitled "Components and Techniques of Economic Threshold Determinations for Programs in Integrated Pest Management (IPM)" at the 1985 Annual Meeting of The American Phytopathological Society, Reno, NV.

Accepted for publication 3 February 1987 (submitted for electronic processing).

The publication costs of this article were defrayed in part by page charge payment. This article must therefore be hereby marked *"advertisement"* in accordance with 18 U.S.C. § 1734 solely to indicate this fact.

It is useful to examine the concept to see how a threshold may be expressed and what variables influence it. First, an economic threshold for a particular pest organism on a given crop site represents a point on a pest population function that occurs at a time before the time of the expected economic damage. Second, the economic threshold will depend on the expected damage to the crop if the pest is not controlled at the time of decision. Third, the economic threshold will depend on the commodity price per unit of output of the crop. Fourth, the economic threshold will depend on the efficacy and cost of the control methods to reduce the population below the economic injury level. It is safe to say that the economic threshold will not be any single-pest density level that holds for all time because control costs, crop prices, pest damage, and control efficacy change. Rather, the pest density level known as the economic threshold will vary from season to season and between points within a season as any of the above factors change. Finally, the economic threshold can vary with the life stage of the pest, the susceptibility stage of the host, and the specific objectives of individual farmers so that even adjacent fields can have different economic thresholds.

Most discussions of practical threshold determination assume that although individual farmers may have different pest control objectives, it will be too expensive for a public research agency to develop a threshold for each farmer. Rather, regional thresholds for groups of farms with similar pest damage relationships and equal costs are determined. Farmers can then monitor their fields and implement actions when threshold pest populations are exceeded on individual fields. The justification for public provision of the basic research to establish the threshold is that this general information will be made available to all farmers, whereas information on an individual field will primarily benefit only that owner.

The discussion above indicates that the economic threshold for a pest on a given site or host crop is not necessarily a number with properties such as the constants of physics. This being the case, the determination of an economic threshold is not an easy task. Careful biological research is needed to provide the data necessary to determine an economic threshold (3–5). First and most obvious is the need to understand the population dynamics of the pest, because control action needs to be taken when the pest population or, in the case of a disease, the level of infection is still below the economic injury threshold. Therefore, it is necessary for researchers to be able to find relationships between observed pest level at the decision time and final crop value. Second, there is a need to understand the pest-host crop interaction. If certain growth stages of the host are more or less vulnerable than others, these need to be identified and the damage associated with different levels of pest incidence quantified. In addition, the time frame for the damage needs to be known. Certain pests cause immediate damage by either reducing yield within the season as do, for example, cutworms in corn or boll weevils in cotton. Other pests may alter crop quality as well as quantity by attacking the crop, such as occurs with brown rot in peaches. Still other pests, especially those on a perennial crop, such as spider mites on almonds, may not affect yield or quality immediately but may weaken the tree and reduce the lifetime yield of the tree. Accurate economic thresholds for this last group are more difficult and expensive to determine because, as the time periods are extended, the accuracy of pest density and control efficacy relationships are reduced. The example illustrated here will be limited to a simple case without unceraintty or delay (dynamic) effects. General approaches for dynamic thresholds and inclusion of risk are discussed below.

AN ECONOMIC THRESHOLD FOR SOYBEAN CYST NEMATODE

The establishment of an economic threshold is illustrated by an example in controlling the soybean cyst nematode (SCN) (*Heterodera glycines*). The SCN was first discovered in the United States in 1954 in North Carolina. At present, the SCN is found in 22 of the 30 soybean-producing states, and this pest is estimated to be one of the largest of all diseases in the United States, resulting in soybean losses of about 680 million metric tons (1). Control of the SCN has come primarily from the adoption of cyst-resistant crop cultivars; however, with new SCN races evolving and the continued high level of losses, more farmers have turned to nematicides. This example shows how a regional economic threshold for a nematicide treatment at planting could be determined. More information on combining resistant cultivars and pesticides for economical control is also available (15).

G. Noel at the University of Illinois is one of the individuals who has produced field data suitable for computing economic thresholds. His description of the data collection is as follows:

"The technique that is used in Illinois for determining the relationship of nematode numbers to crop yield is a systematic arrangement of plots in a grower's field. A field infested with SCN is selected and divided into grids. The grids are sampled to determine the number of SCN eggs, juveniles, and cysts total within each grid at planting. Levels of the nematode are randomly selected and range from 0–100,000 eggs and juveniles per 250 cm^3 of soil. The field is

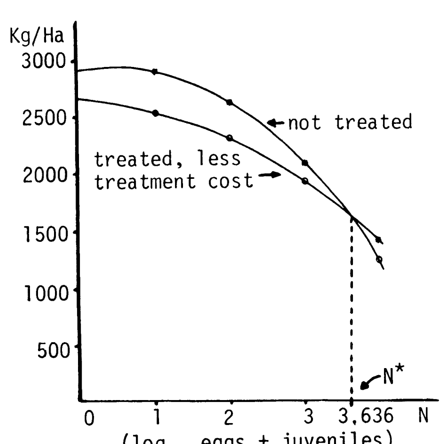

Fig. 1. Soybean cyst nematode economic threshold determination.

marked and plots are planted. Aldicarb treated plots serve as standards. Regression analysis was conducted using numbers of nematodes, aldicarb treatment and (soybean) yields (10)."

The aldicarb-treated plots and the plots not treated by Noel gave the following estimated relationships between soybean yield (Y = kg/ha) and the cyst density expressed as the $\log_{10}$ of total eggs and juveniles (N) measured at planting and treatment time: untreated—$Y = 3{,}013.68 + 95.5N^2$, $R^2 = 0.87$; aldicarb-treated—$Y = 3{,}375 - 47.73N - 69.552N^2$, $R^2 = 0.61$.

For these treated and untreated plots, there is a difference in soybean yields in plots that did not have any nematodes. This difference is 361.32 kg more (3,375–3,013.68, or about 10%) for aldicarb treatment. Noel thought this yield enhancement in the absence of cysts might be from control or other organisms that were known to be present, such as *Pratylenchus scribneri*, undetected SCN, or other pest species. Also, the difference might have been due to direct crop growth enhancement from the systemic nematicide, which affects plant processes (11).

Consider the case where there are no other pest types being controlled and no phytotoxic effects or direct effects of the nematicide on the plant, so that the yield is the same in the treated and untreated plots at the zero-nematode level (Y = 3,013.68 for $N = 0$). The treatment cost for the aldicarb treatment is known to be about $65/ha for material, labor, and equipment. Also, soybeans are assumed to sell for $0.24/kg at harvesttime. (For example, suppose a forward sale or futures contract is available for $0.24, net, to the grower.) This means that the control cost is equivalent in value to about 271 kg of soybeans. Therefore, treated fields must have a population of nematodes such that they result in 271 kg or more per hectare being saved to pay the cost of the treatment. For the above yield-cyst density equations, the economic or nematode treatment threshold is N, such that the yield in the untreated yields equals the yield of treated fields less enough yield with value to pay for treatment cost: $3{,}013.68 + 95.5N - 129.55N^2 = 3{,}013.68 - 47.73N - 69.55N^2 - 271$ or $271 + 143.23N - 60N^2 = 0$. Solving this quadradic equation for N yields a break-even or economic threshold of $N^* = 3.636$ or about 4,325 eggs and juveniles. The economic threshold is shown as the level N^*, where the lines cross in Figure 1. It reveals that only severely infested fields should be treated. At population levels lower than this, income will be higher by not treating. The threshold N^* gives a predicted yield of about 1,650 kg.

The procedure for finding the simple action threshold can be summarized as follows:

1. Compile disease or pest level and crop yield information (with the pest level pertaining to a time when a pesticide treatment would be made) for both treated and untreated plots under conditions approximating those for commercial production.

2. Estimate the yield-pest density relationships for typical (as to dosage and type) pesticide (or other disease control) treatments and the no-treatment case.

3. Compute the cost of treatment and obtain an estimate of crop value or price at harvesttime expected at treatment time. Divide treatment cost by crop price to find the crop yield that needs to be saved to equate income in the treated and untreated cases, and subtract this yield from the yield equation representing the pesticide treatment case.

4. Find the pest level where the yield equations are equal either by plotting the equations or by algebra.

REFINEMENTS IN DETERMINING ECONOMIC THRESHOLDS

Several quality aspects of the data used to develop economic thresholds should be emphasized. First, the pest level (N) must be measured and related to yield from measurements taken at the time the pest control is to be taken. In the example above, the aldicarb application decision must be made at planting time, so the only pest density information a farmer may have is the preplant pest density sample. For some diseases and crops, it may be better to take pest samples in the previous crop year. Second, threshold determination will be limited by the accuracy of the pest-sampling method. This is particularly important for organisms such as nematodes that are not randomly distributed across fields (3). Notice that the spatial unit of interest is either an entire farm, a field, or parts of fields for which separate pest control decisions are to be made. That is, if part of a field can be treated separately, then that field part is the sampling domain, whereas if an entire field or farm is to be uniformly treated, then the mean pest density for the field or farm is used. Finally, information for estimating the pest density-yield relationship should be taken from density levels near the economic threshold population level. It may be biologically interesting to know the pest density-yield relationship over wide ranges of pest levels, but analyzing this wide range of data can lead to fitted relationships that will not accurately estimate the shape of the yield curve near the threshold population level. For an illustration of the sensitivity of economic thresholds to range of data and functional forms, see the soybean-weed threshold analysis of Marra and Carlson (9).

Frequently, there may be several alternative treatment types (nematicides) and treatment dosages. The method above can be expanded to include comparisons of several treatments with their respective costs by repeating steps 1–4 for each or the optional treatments. Commercial pest control options with higher costs will often be more effective. This can result in economic thresholds for a pest that switch from no treatment to low-cost treatment and to a higher cost treatment as one moves from situations with low pest densities to higher and higher densities. For some pest situations, finding threshold densities for profitably shifting to higher dosages or alternative materials is an important application of the economic threshold concept. For other cases with relatively narrow ranges of efficacy with dosage, high application costs relative to material cost or low maximum dosages, there will be little gain from considering many different dosages.

Many disease control decisions involve multiple species or biotypes occurring simultaneously in a given field. Economic thresholds for multiple-pest species can be approximated by forming indices of pest densities where the crop damage effects of the individual species are assumed to be additive and separable. Such indices should be formed by weighting the pathogenic rating (relative yield damage potential) of each species by the density measure of that species. (See Ferris [4] for an application to crop nematodes.) Other similar adjustments can be made for different soil types or crop cultivars. When a pesticide has different control efficacies across the separate pest species (biotypes), then the control efficacy parameter (differences in slopes of the two damage curves in Fig. 1) should be an index of the control efficacies on the various species. Such refinements in economic thresholds would probably be justified where control efficacies or damage rates are sufficiently different across species. Many economic thresholds for annual protection decisions can be determined by the simple method illustrated above.

ECONOMIC THRESHOLDS AND UNCERTAINTY

The SCN threshold example above assumes certainty in critical variables. In reality, a grower never knows for sure whether the pest will reach damaging levels or what will be the exact extent of the damage. Carlson (2) developed a decision framework for control of diseases (brown rot in peaches) considering uncertainty. In the peach brown rot instance, the predicted crop loss was a function of 1) a fruit maturity index, 2) predicted rainfall during the decision period (2 days), and 3) the number of spores in the orchard. In this case, given a stage of fruit maturity and the predicted rainfall, when the quantity of spores produces a crop loss with value equal to or greater than the value of the peach crop saved from various fungicide treatments, this would be the economic threshold and would lead to a decision to treat. Alternatively, for a given fruit susceptibility and spore level, the predicted rainfall report that justifies treatment can be computed. The decision trigger can be defined in terms of weather events rather than pest density.

The fruit brown rot example illustrates a conditional decision rule. It assumes that the rainfall prediction will describe the rainfall for the next 2 days and that the loss function in general does a good job of estimating the crop loss. Actual crop cosses over different seasons and locations will follow some sort of probability distribution. If the grower treats and the rainfall does not develop, then the treatment has been wasted as viewed from the end of the season. Because most growers will recognize the risk attendant to such decisions, the individual grower's attitude toward risk and the subjective probabilities of the crop loss level faced could result in different treatment decisions by different growers with the same fruit maturity, rainfall predictions, and spore counts. This conclusion emphasizes that the economic threshold idea does not result in a general rule for pest control actions but rather is one piece of information in the decision process. It is possible to use formal Bayesian decision theory to develop strategies for growers with different risk attitudes, subjective probabilities, and disease density forecasts (2).

DYNAMIC ECONOMIC THRESHOLDS

Many pest management decisions involve multiple-treatment decisions and important growth relationships in host crops as well as pest levels (7). Likewise, pest control actions taken in one period can affect pest levels crop damage or control costs in other periods.

When there are known effects of current actions on future yield or cost, these can be reduced to current net return effects by finding the present values (discounting). Data for this type of analysis require that the longevity of a control action as well as its efficacy be known. Estimates of control efficacy in different time periods require data collection over several seasons for alternative control actions (12). Important examples might be for pests that spread relatively slowly and for which damage depends heavily on resident pest populations. Damage to the current-season crop as well as potential crop productivity such as from damage to a perennial crop is another area or application. Solutions to this type of problem frequently involve multiple-period-optimization procedures such as dynamic programming as well as time discounting (15).

ARE ECONOMIC THRESHOLDS OPERATIONALLY FEASIBLE?

It is appropriate to ask whether the economic threshold concept is practical. The answer must be qualified. How feasible it is depends on the value of the expected loss relative to the cost of the controls, how variable control efficacy is, and how effective and costly it is to gather information on the incidence of the pest. If efficacy of controls is variable but the frequency of the conditions leading to this variability can be estimated, it is possible to devise economic thresholds that maximize expected net returns. Marra and Carlson (9) provided an example for weed control with variable field conditions that create variable herbicide efficacy and costs. When economic injury level infestations can be predicted accurately with sufficient time to employ controls and when relatively accurate yield-pest density relationships are known, growers can be informed of economic threshold levels for their crops that they could use as a basis for treatment decisions. To implement such threshold decisions, farmers need pest density information for their yields and estimates of the cost for each control choice. If the costs of controls are high relative to crop price and if the intensity of damage or control efficacy is highly uncertain, then control decisions involve choices of risky prospects. Under these conditions, recommendations concerning economic thresholds need to be flexible and specified in enough detail so that growers can include their own subjective assessment of random variables such as pest level and control efficacy and use their individual attitudes toward risk. In this situation, extension pathologists need to operate more in an educational mode than in a service mode.

In an evaluation of economic thresholds in managing agricultural pests, Fohner et al (6) did a simulation experiment to describe the characteristics of pest problems that affect the numerical values computed for economic thresholds, to indicate the types of pest problems for which economic thresholds are most useful, and to determine the quality of information needed. They found that economic thresholds are most valuable when the most frequent pest densities are those that are clearly above or below the threshold. On the other hand, a small variance in crop losses is preferred because it is associated with low levels of unexplained crop damage.

To summarize, there is a need for various forms of biological research if economic thresholds are to become practical decision tools in pest management. The crop yield-pest density relationships for both the treated and untreated cases (shown in Fig. 1) are the key biological research outputs needed. This can be separated into disease-yield and control efficacy experiments for various combinations of IPM practices. The refinement of these relationships to include wider ranges of soil, weather, and initial infestation conditions can be accumulated by a combination of field experiments and basic host-pest theoretical models. Finally, the results of careful biological research must be merged with the practical needs of farm managers to provide economic thresholds that are easy to use, biologically sound, and economically efficient.

LITERATURE CITED

1. Bradley, E. B., and Duffy, H. 1982. The value of plant resistance to soybean cyst nematode: A case study of forest soybean. NRED Staff Rep. AGES820929, ERS, U.S. Dep. Agric. Washington, DC.
2. Carlson, G. A. 1970. A decision theoretic approach to crop disease prediction and control. Am. J. Agric. Econ. 52(2):216-223.
3. Ferris, H. 1980. Nematology—status and prospects; practical implementation of quantitative approaches to nematology. J. Nematol. 12(3):164-170.
4. Ferris, H. 1984. Nematode damage functions: The problems of experimental and sampling error. J. Nematol. 16(1):1-19.
5. Ferris, H. 1986. Components and techniques of integrated pest management threshold determinations for soilborne pathogens. Plant Dis. 71:452-455.
6. Fohner, G. R., White, G. B., and Schwager, S. J. 1982. The value of economic thresholds for managing agricultural pests. Cornell Univ. Dep. Agric. Econ. 82-46.
7. Headley, J. C. 1972. Defining the economic threshold. Pages 100-108 in: Pest Control Strategies for the Future. National Academy of Sciences, Washington, DC.
8. Hoyt, S. C., and Burts, E. C. 1974. Integrated control of fruit pests. Annu. Rev. Entomol. 18:259-280.
9. Marra, M. C., and Carlson, G. A. 1983. An economic threshold model for weeds in soybeans (*Glycine max*) Weed Sci. 31:604-609.
10. Noel, G. 1983. Relating numbers of soybean cyst nematode to crop damage. Pages 000-000 in: Proc. Cyst Nematode Workshop 5th. D. P. Schmitt, ed. N.C. State Univ. Raleigh.
11. Ragab, S. M. 1981. Cotton-growth and nutrient uptake following Temic, aldicarb application. J. Agric. Sci. Cambridge 97:731-737.
12. Reichelderfer, K. H., Carlson. G. A., and Norton, G. A. 1984. Economic guidelines for crop pest control. FAO Plant Prod. Prot. Pap. 58. Rome, Italy.
13. Stern, V. M. 1973. Economic thresholds. Annu. Rev. Entomol. 18:259-280.
14. Stern, V. M., Smith, R. F., van den Bosch, R., and Hagen, K. S. 1959. The integration of chemical and biological control of the spotted alfalfa aphid: The integrated concept. Hilgardia 29:81-101.
15. Zacharias, T. P., Liebman, J. S., and Noel, G. R. 1986. Management strategies for controlling soybean cyst nematode. N. Central J. Agric. Econ. 8(2):175-188.