ECONOMIC INJURY LEVEL (EIL) AND ECONOMIC THRESHOLD (ET) CONCEPTS IN PEST MANAGEMENT

David G. Riley
University of Georgia
Tifton, Georgia, USA

One of the fundamental concepts of integrated pest management is that each pest species has a definable relationship in terms of damage to the plant or animal host that it attacks. This relationship is often referred to as the damage curve (Fig. 1), which is often determined relative to yield loss. This damage curve can take several forms, but was summarized by Higley and Peterson as having a tolerance or overcompensation phase ([1] no yield response, or [2] positive yield response to injury), a linearity phase ([3] e.g., yield loss = -a (unit injury) + b), and a desensitization and an inherent impunity phase ([4] decreasing and finally [5] no additional yield loss per unit injury). The curve can be used with various methods to determine whether or not any action or pest management tactic (e.g., pesticide, biological control, cultural control, etc.) is needed to reduce the damage associated with this pest. Also, this relationship is uniquely characterized by a critical point, the economic injury level (EIL), or the point in the agricultural production system where the costs associated with pest management equal the benefits from the pest management actions. In other words, below the pest population represented by the EIL there is no need to take pest control actions because they are not economically justified, but onomic damage can occur when the pest population densities are above the EIL.

A simple, robust model of the EIL relationship between pest control costs and benefits from control actions was developed by Pedigo et al. as:

$$EIL = C/VDIK$$

where C = management cost per production unit, V = market value per production unit, D = damage per unit injury, I = injury per pest equivalent, and K = proportional reduction in injury with management. They later combined D+I into a single variable, D' = percent yield loss per pest. A variation on this formula that is often used that assumes 100% control is: EIL = (C x N) / (V x I), where N = the number of pests causing injury, and I = the percent yield loss (similar to the D' value above). In an example using the EIL = C/VD'K formula, if a seasonal average of one insect/plant causes a 10% reduction in yield, the market value of the crop is \$0.4/lb fruit and you expect 5 lb fruit/plant yield, the cost of control is \$0.04/plant, and you can count on a 75% reduction in damage with the control tactic used, then:

EIL = \$0.04 cost per plant/(\$0.4/lb x 0.5 lb/insect x 0.75) = 0.27 insects/plant

Notice that if you halve the number of insects required to inflict 10% yield loss, you halve the EIL value. In contrast, if you double the cost of control you double the EIL value, again balancing the tradeoff between control costs and benefits. In reality, the EIL value can be difficult to calculate exactly because of the temporal and dynamic nature of pest damage and crop value. In the example above, an early season average of one insect might result in 15% yield while late season results in only 5% yield, so the estimate based on a seasonal mean would not be very precise for a given period during the season. One way to avoid large seasonal differences is to calculate an early-season and a late-season EIL, for example:

$$EIL_1 = C/VD_1'K \text{ and } EIL_2 = C/VD_2'K$$

or

$$EIL_1 = \$0.04 \text{ cost per plant}/(\$0.4/\text{lb} \times 0.75 \text{ lb/insect} \times 0.75) = 0.18 \text{ insects/plant}$$

$$EIL_2 = \$0.04 \text{ cost per plant}/(\$0.4/\text{lb} \times 0.25 \text{ lb/insect} \times 0.75) = 0.53 \text{ insects/plant}$$

The EIL can be based on a single, seasonal mean, based on periods during the season with similar responses (e.g., seedling, vegetative, fruit formation, or simply early versus late season), or be accurately calculated over time for the life span of the affected host. This latter determination of a dynamic EIL requires a great deal of data and is seldom accomplished for most crop or livestock systems. In addition, the EIL formulas often assume a linear response to injury at any given time during the season, which may not be entirely accurate. Even so, an assumption of linearity can be generally sufficient for the range of pest injury critical for an EIL determination.

Estimates based on the aforementioned EIL formulas are in use for many agricultural pests and have successfully provided pest management decision criteria for many production systems, mainly because of both their effectiveness and ease of use. It should be noted that in commercial production systems, economic injury levels are likely to be close to a maximum allowable pest management cost because these systems have traditionally focused on maximizing returns and reducing risks to production. What is often lacking in these estimates of EILs is an environmental cost factor. The environmental cost would adjust the pest management cost by taking into consideration not just what the farm spends on management tactics, but also an estimated average cost to the environment or agro-ecosystem where the farm exists. Using the environmental economic injury level:

$$EIL = (C + EC)/VDIK$$

proposed by Higley and Wintersteen and adding an environmental cost of $0.04/plant would increase the EIL to 0.53 or double its previous level in the aforementioned example. There will likely be a high degree subjectivity in this kind of environmental cost estimate. Even with its complications, the EIL is fundamental for understanding the interaction of pests with their host, but the calculation of economic thresholds from these data is quite a different problem, which will be discussed in the next section.

An economic threshold (ET) is typically the pest population density at which a pest control action (e.g., pesticide, biological control, cultural control, etc.) should be taken in order to prevent an increasing pest population from reaching economically damaging levels, which is the economic injury level (EIL). As shown in the diagram of the two-level fixed economic threshold (Fig. 2), two different fixed economic thresholds are estimated for a single pest in a given cropping season depending on if the time frame is early season (ET-1) or late season (ET-2) as:

$$ET_1 = 90\% \text{ x } EIL_1 = 0.16 \text{ insects/plant}$$

$$ET_2 = 90\% \text{ x } EIL_2 = 0.48 \text{ insects/plant}$$

Also as an example, the pest population levels of a treated field (control actions taken) versus an untreated field (no control action) are indicated by the narrow and solid lines, respectively (Fig. 2). What can be seen from this example is that, on several levels, time is as critical a component in the estimation of economic thresholds as pest numbers. Also, it is clear that frequent pest monitoring or scouting will be required to track pest population density through time with some accuracy. In this example, it is assumed that approximately twice as many insects are required to cause an equal amount of yield loss in late season (EIL-2) as early season (EIL-1). Another aspect of time is that there may be an increase in the pest population or damage over time, and will tend to increase at a determined rate, excluding massive emigration events, as the season progresses. Finally, there is a time component in the duration of delay from when a pest population reaches an economic threshold, when control actions are actually implemented, and when the reduction of the pest population begins to occur. This can directly affect the threshold value, because the purpose of the threshold is to prevent the pest population density from reaching the EIL. As Pedigo stated, “the ET actually represents the time for taking action against a pest; population density serves as a convenient index of that time”.

Economic thresholds for agricultural pests vary greatly in their accuracy (how close the estimate is to a true ET) and their precision (degree of variation around an estimated value) depending on the method used for its development. In the broadest sense, thresholds in the literature are either more subjective (based on an educated guess or ‘guesstimate’) or more objective (based on research data used to estimate an EIL and an effective method for relating the EIL to a threshold level for initiating pest management actions). In either case, the objective is to prevent the pest population from reaching an economically damaging level. However, a low level of accuracy, often associated with subjective estimates called ‘nominal thresholds,’ can lead to either underestimating or overestimating the pest population level where action should be taken. An underestimate will result in more control costs than is economically justified, whereas an overestimate will result in crop or livestock damage that could have been avoided economically with the appropriate timing of an effective control tactic. Even though an objective ET can be more accurate than a subjective ET, the objective ET’s precision can be greatly influenced by the method in which an EIL is calculated. An EIL based on seasonal population means relative to final yield loss can be very accurate, but not very precise for individual dates during the season. Using the previous example of 15% yield loss during early season and 5%

yield loss during late season for an equal number of pests, the calculated EIL values for early and late season are 0.18 and 0.53, respectively. If a single EIL = 0.27 is used for the entire season, then there will be an overestimated ET early in the season and an underestimated ET late in the season, causing the same problem as a lack of accuracy, even if it is likely to a lesser degree.

A subjective ET can be based on effective observational data as, for example, by adjusting the threshold higher or lower after each production season based on yield response, so that a reasonably accurate ET is developed through a long term process of iteration. Generally, a subjective ET is fixed at a value or named by consensus for a given use period and is thus referred to as a nominal threshold. In fact, a significant number of thresholds in use today are based on this method. The problem with this method is that it does not define the mechanism behind the EIL and ET, and can thus be affected by changes in production factors, e.g., crop variety, climate, market-driven planting dates, etc., to some unknown degree from year to year. At the very least, a subjective ET can be a starting point for threshold development, and potentially provide significant pest management benefits.

Although objective determinations of ET are research-based, they also can have a range of sophistication and complexity beginning with a simple fixed ET. The fixed ET is set at a specific percentage of the determined EIL, usually based on conservative estimates for preventing significant crop loss. In the example for a single seasonal EIL determination described in the previous section, the estimated EIL = 0.27 insects per plant would result in 2.7% yield loss that cannot be economically prevented within the conditions of the example. If there was a relatively high risk of loss, for example above 10%, a conservative threshold might be set at half, regardless of whether or not the additional control actions are economically justified. High levels of threats of injury can even lead to abandoning the ET altogether. In the other direction, if a new, highly effective (100% control) and inexpensive ($0.01/plant) control product is introduced into the system, not only does the EIL drop to 0.05, the expected yield loss at this level is so low at 0.5% that the tendency will be to leave the ET at or even above the EIL = 0.05. In this case, increasing the EIL could be justified by using other decision criteria, like environmental costs that have not been included in the initial EIL determination. Subjective judgments on the overall percentage crop loss that can be tolerated tend to vary more at the low injury levels than the high injury levels since high injury levels are not commercially tolerated. What is not considered in detail with the fixed ET is the actual time between control actions and the time it takes for the pest population to increase to the predicted EIL. In most cropping systems, weekly scouting reports are followed by weekly curative actions in the form of pesticide applications. If a cultural or biological control tactic is used that needs time to affect the overall pest population, the estimation of this time becomes critical. In this case, more descriptive thresholds based on the mechanisms of pest population dynamics are needed to accurately predict when the population level will reach the EIL.

Descriptive thresholds are of two general types, stochastic and deterministic. The deterministic model assumes a fixed and unique outcome, whereas a stochastic model incorporates probabilities based on demographics. Thus, the stochastic ET is based on an estimated pest population growth based on average population dynamics, with an associated probability of error. An economic threshold based on sequential sampling of a pest population is a good, fairly complex example of a stochastic ET. A simple example, based on highly predictable pest population dynamics, would be if a pest population prior to reaching an EIL is known to increase at a given exponential rate that doubles the population ($y = 2^x$ where y = pest numbers and x = generation time) after each generation time and the scouting interval (e.g., 7 days), is equal to one generation time. Then using the EIL = 0.27, the threshold would simply be:

$$ET = EIL - (EIL/2) = 0.27 - (0.135) = 0.135$$

This simplistic example only works if the control action and response can occur between scouting intervals, that you can accurately predict that the EIL will be reached by the next scouting event, and that there is no great need to modify the value to include an additional margin of error based on a probability analysis.

The deterministic ET relies on knowledge of age-specific parameters and life processes of the pest population. It can still require probability estimates for specific processes, such as the average mortality of a beneficial insect that would affect the estimate of ‘K’ in the calculation of an EIL, but the key mechanisms that determine pest population growth are defined. Biological control or long term cultural control tactics could benefit from the use of this type of threshold. A typical difference in the response time for a biological control tactic versus a chemical control tactic is illustrated in Figure 3. In this example, both tactics provide equally high levels of control, but the response to the pesticide is fast, so the ET could be set closer to the EIL value than it can with the biological control. To estimate the biological control response it might be necessary to calculate life table data for both the predator and prey species (crop pest) and relate this to temperature, time and spatial dynamics; a fairly complex proposition. As the time increases between the initiation date of an effective control action and the control response of the pest, these descriptive thresholds can become more crucial.

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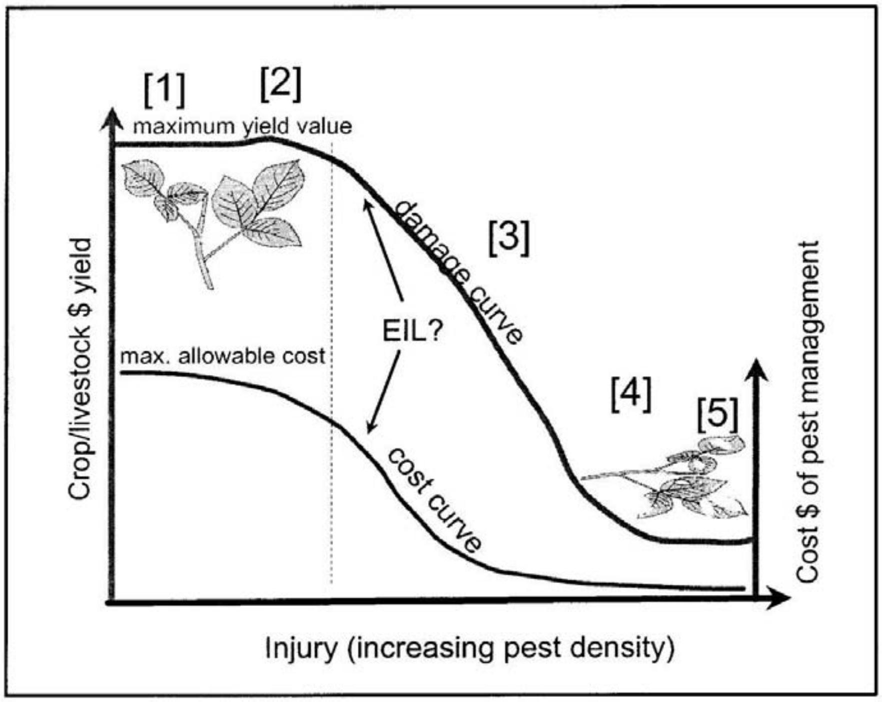

Figure 1. Example of a pest damage curve (thick line) and associated cost of pest control (thin line) used to estimate at economic injury level (EIL).

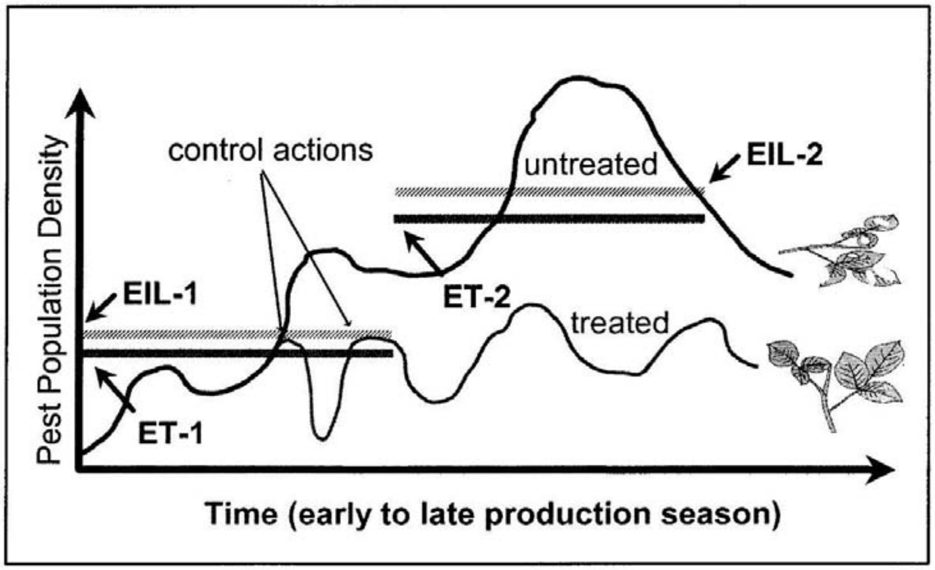

Figure 2. A two-level, fixed economic threshold with treated (narrow line), i.e., effectively controlled to stay below the EIL, and untreated (thick line) pest populations.

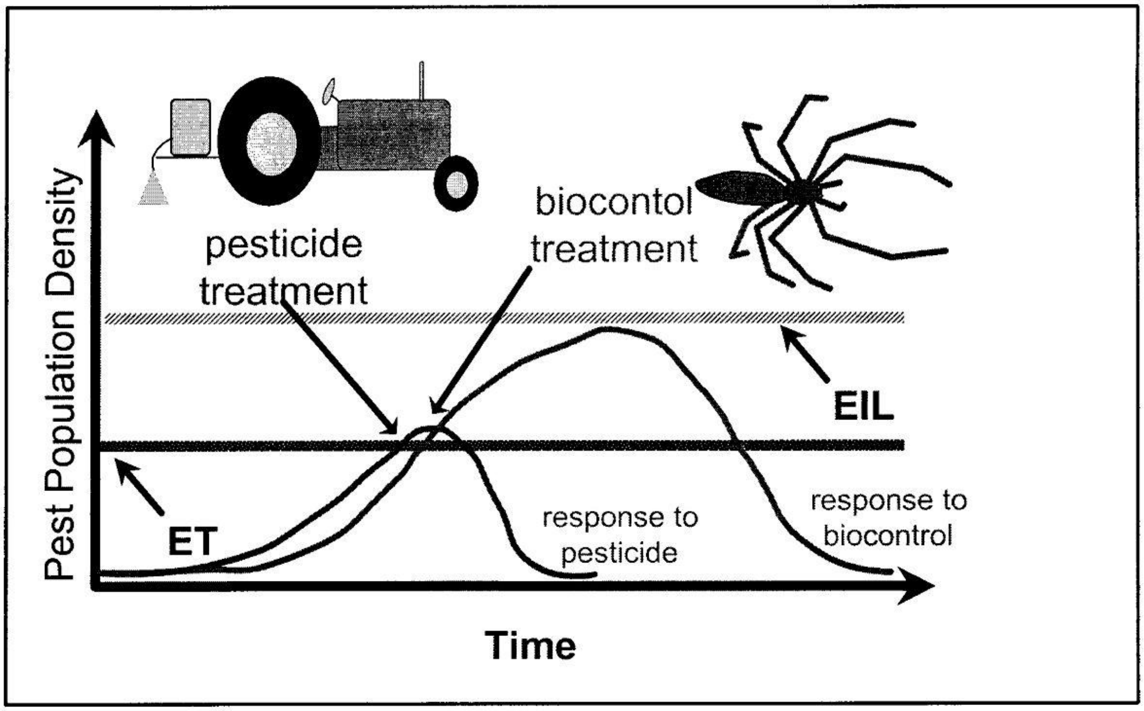

Figure 3. Delayed response to a biological control tactic.