Adaptation of Current Threshold Techniques for Different Farm Operations

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ABSTRACT

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A review of the literature points out the distinct need for more multidisciplinary work in developing economic thresholds for diseases, weeds, and insect pests in crops. Further work needs to be conducted to make current technological pest management information applicable and understandable at the farm level. Examples of successful uses of a variety of threshold models are presented.

The disciplines of crop protection and plant pest management have evolved in fairly recent times but have taken different turns (i.e., plant pathology, entomology, and weed science). From a teaching and research standpoint, it is frequently desirable to maintain a discipline distinction because of the complexities of each area. Field practitioners of crop protection (i.e., farmers, consultants, and extension agents) realize, however, that nature does not separate the disciplines. The various effects of disease, insects, and weeds are intertwined with those of water, fertility, and soil management.

Growers are sometimes confronted with conflicting recommendations by specialists from different disciplines (13). What may work best to manage a given pest or crop problem may well aggrevate another. This can confuse and even anger some growers. Thus, simple recommendations are needed that complement other aspects in the holistic system of crop protection.

Geir (5) states, "Pest control is an ancillary enterprise. It is practiced only as a means of furthering the purposes of production systems." He further cautions against "discipline-fixation" in favor of the "comprehensive dynamic model," which addresses all elements of the crop production cycle. Unfortunately, there are serious constraints to developing effective, real-world-systems models. Perhaps the greatest limiting factor is adequate biological information, followed closely by crop system component interactions. Thus, effective pest control may be likened to an art that is dependent on science and technology in much the same manner as medicine and architecture (5).

Practitioners of the art of crop protection frequently use the concept of thresholds to implement management strategies. A tremendous need exists to merge the use of thresholds between disciplines to effect optimal economic benefit at the farm level.

THRESHOLDS IN THEORY

To pursue a discussion on various threshold techniques, it is necessary to consider some of the terminology in current use.

Economic injury level (EIL). In 1959, Stern et al (14) defined EIL as "the lowest pest population density that will cause economic damage." Basing EIL on density alone does not reflect the dynamic interactions of crop and host population phenology, and it does not account for input from the marketplace. The concept of EIL becomes further complicated when multiple-pest situations are considered. It is common for crops to support pathogen, insect, and weed populations simultaneously. It also is common for multiple species of each category of pest to occur in crop fields. Management of any given pest or pest complex will change the effect other pests have on that field. Determination of EIL under more than single-factor situations is a necessary step for future growth in pest management disciplines.

It is useful for field practitioners to use single-factor EILs so long as they are used in the context of a broader crop ecosystem context. In that context, Headley's (6) definition of EIL as the "population that produces incremental

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damage" is a more suitable definition than earlier, population density-based definitions.

Economic threshold (ET). Stern et al (14) define the ET as "the density at which control measures should be applied to prevent an increasing pest population from reaching the economic injury level." As Luckman and Metcalf (8) point out, populations can become more damaging "as a result of density (number of individuals) or an increase in biomass (size of individuals)." Growth stage and expected value of the crop, interaction of other pests, physiological response of the crop to both pest damage and control practices, as well as cost of control significantly affect the ET.

The primary intent of the ET, however, is to focus a management decision at a discrete point in time, enabling the farmer to take action against a pest(s) so that the economic returns to that action are greater than the costs. This absolutely implies controlling pests before the EIL is reached.

Action threshold (AT). Because it is frequently necessary to actively control pest populations before they reach the EIL, AT describes the point at which the control action is taken. In theory, the AT will be at a lower population development stage than the ET. This is because the AT takes into account real-world aspects such as availability of chemical applicators, prospective weather, etc.

Multidimensional economic thresholds (MDET). Shoemaker (12) advocates the MDET because "it is clear that in many situations the advisability of implementing a pest control measure also depends upon plant vigor and maturity, the density of natural enemy populations, on the weather and/or the age structure of the pest population." This is a concept strongly supported by Ferris (4), although he calls it the dynamic action threshold (DAT). It is difficult to establish DETs or DATs, but they present more reliable references for sound management decisions because they are based on more determinant factors than pest population density.

Yield development thresholds (YDT). Hearn and Room (7) have developed the concept of YDT for cotton management in Australia. "The basis of the concept is to estimate the minimum number of squares and bolls required progressively through the season to enable a specified yield to be ultimately achieved." Because YDTs are a measure of anticipated crop yield based on crop physiology in response to abiotic and biotic factors, accurate pest thresholds need to be used in conjunction with YDTs. "Yield development thresholds constitute a statement of the pest manager's intent that is both biologically feasible and economically rational: the manager intends to keep the number of squares and bolls above the YDT just as he intends to keep number of pests below the pest threshold."

APPLICATION OF THRESHOLDS IN PRODUCTION SYSTEMS

Increased awareness within both the agricultural research and production communities regarding the importance of treating pest management as a systems science has led to significant progress in the application of thresholds to production agriculture. Pest managers are confronting increasingly complex systems as they study methods of managing agroecosystems. As scientists probe more deeply into the interactive aspects of these systems, the ratio of unknowns to knowns increases and can become a serious frustration. Thomas (15) notes, "The solidest piece of scientific truth that I know of . . . is that we are profoundly ignorant about nature. . . . It is this sudden confrontation with the depth and scope of ignorance that represents the most significant contribution of 20th century science to the human intellect."

Inroads are being made into the unknown as researchers and pest management practitioners continue to refine their knowledge of cropping systems and the thresholds that operate within them.

In this discussion, we will consider examples of thresholds used in pest management. The cases studied here are selected to reflect a variety of accomplishments to date and to cause reflection on crop protection needs now and in the future.

TECHNIQUES IN ASSESSING PEST NUMBERS

There are two obvious methods to determine whether pest populations are approaching threshold levels, actual population counts and crop damage assessments. A more indirect method of use when dealing with vectorborne pathogens is to count the vector itself (i.e., aphid, nematode, leafhopper, etc.)

When pest populations are counted, a variety of methods are used. The number of pests per unit area (number of weeds per square meter, number of nematodes per 100 g of soil, or number of insects per five sweeps) is frequently used in monitoring pests in field scouting programs. Also, the number of pests per plant or number of plants infested (usually expressed as a percentage on a whole-field basis) are used.

Insect population counts on aboveground surfaces can be obtained using sweepnets, suction devices, or absolute counts. Pheromone traps placed by or in a field can provide excellent population development data for insect pests. Weeds are usually counted in terms of population per unit area or length of row. Pathogen populations are much more challenging to assess than insect or weed populations. The choice of technique for sampling any pest population is determined by its efficiency and precision as well as cost.

The method of sampling selected for any given pest population needs to be studied empirically so that direct correlations between pest counts and associated crop loss are accurate and reflect a verifiable interaction within a broad geographic area.

Direct counts. In Idaho, Byrne and Bishop (1) have developed a model for using thresholds to control populations of green peach aphid (*Myzus persicae* (Sulzer)) on potatoes. This aphid is a serious pest of potatoes because it is the principal vector of potato leafroll virus (PLRV). In this model, the thresholds for green peach aphid are significantly different in southwestern and south central Idaho, with the first being 40 aphids per 50 leaf samples and the latter being 10 aphids per 50 leaf samples, both taken on two consecutive weeks before 1 August.

In Minnesota, Cancelado and Radcliffe (2) have determined the threshold for green peach aphid on potato as 30 apterae per 105 leaf samples and for seed potato production, 10 apterae per 105 leaf samples.

Clearly, the effects of green peach aphid on potato vary geographically. Attempts to apply one threshold to all production areas would cause both economic loss and unnecessary control measures. Regression models were used in Idaho to predict the percentage of PLRV infestations based on aphid numbers in the field. After verification, word models were constructed so that growers could use the predictive models for management decisions.

Damage ratings. Damage rating studies conducted in Ohio and Florida agree that for cabbage, monitoring larval insect feeding damage is more efficient than counting larvae. Chalfant et al (3) found that a visual threshold of one or two holes per plant used throughout the growing season reduced total sprayings from four to 12 per season compared with the standard once or twice weekly spray program. Visual thresholds for spray decisions were easy for growers to use, used less pesticides, and gave equal quality and yield when tested against once or twice weekly spray programs.

Similar results were obtained by Morisak et al (9), who observed reductions of spray applications for larval insect control by three to seven sprays per season when basing thresholds on cabbage leaf damage rather than on a weekly spray program. They also reported significant savings in time by sampling for damage rather than by counting individual larvae on the cabbage plants.

One problem with using visual damage assessment methods for management decisions is determining exactly what caused the damage. Checking for damage is easily done by growers who can use visual damage methods to determine if and when to spray. The assessment of plant disease damage requires identification of the causal agent to initiate management actions.

Stand counts. In Wyoming, two diseases are common in alfalfa production areas, Phytophthora root rot (*Phytophthora megasperma* Drechs.) and alfalfa stem nematode (*Ditylenchus dipsaci* Kühn). No economic thresholds exist for these diseases in Wyoming, yet they are implicated in larger crop losses (attributable to stand decline) than alfalfa insect pests. Because different farm operations have variable economic tolerances to loss of alfalfa production, a simple method for quantifying loss of stand has been developed. First, a positive disease identification is obtained in a given field. Because stand counts are taken each spring, a decline in stand and subsequent loss of productivity can be monitored. Rather than counting infected plants (many of which die during winter and are not present during the production season), live, healthy plants are counted and their number per square meter compared each season. The farmer can use these counts to decide when a stand is too thin to maintain in any given production cycle. Management of these diseases uses improved irrigation practices, resistant cultivars, crop rotation, and harvesting practices.

Although monitoring the number of healthy plants in a stand through successive production seasons is a simplistic method, it does provide an estimate of anticipated yield. As Ferris (4) notes, "The plant is the central feature of the system from an agricultural and production standpoint, and will always be present in this system even though individual pests may be absent."

Pheromone traps. The use of pheromone traps to monitor certain adult lepidoptera, coleoptera, and diptera pests has become more common. These traps use artificial chemical lures that attract adults of a specific species. Data from pheromone traps help growers predict accurately when field pest problems will occur. In some cases, such as with pink bollworm on cotton, trap counts are used to detect threshold-level populations that require treatment. Considerable research is required to make the necessary correlations between trap counts and subsequent yield losses. Frequently, weather and climate affect trap counts as well as subsequent population development. Especially in high-value crops, pheromone traps are useful because they provide early warning of pest population development before any actual injury to the crop.

INTERACTIONS

Norris et al (11) conducted a series of tests that "indicate that threshold densities for *Hypera brunneipenis* Boheman vary in relation to the presence or absence of weeds, and that the relative importance of weeds and *H. brunneipenis* is very site dependent." *H. brunneipenis* is the Egyptian alfalfa weevil, a pest of alfalfa. This study showed that combined weed competition and uncontrolled weevil feeding caused the greatest amount of yield loss. When the two effects were isolated, however, some fields with weed competition caused greater losses than weevil feeding, whereas the reverse was true in other fields. This study verifies the dilemma of the field practitioner of pest management regarding the use of static thresholds. Because many insects and pathogens are harbored in noncrop hosts, weed densities and population composition may be of great importance to the establishment of some insect and disease thresholds.

Ferris (4) notes that, in cases of multiple-pest populations in crop systems, additivity of estimates of individual pest losses is not valid. Field practitioners (farmer, consultant, or extension agent) often integrate to their best ability the missing factors. What must be considered in situations where interactive pest populations occur is the economic effect of multiple control strategies.

Crops generally experience a sequence of different pest problems separated by time, each pest affecting the crop in a different manner and leaving a residual effect on the crop. If multiple pests occur within the same time frame, growers will often respond to the most obvious problem first. It is common for secondary pests to obtain primary status resulting from control efforts aimed at initial primary pests. A serious consequence of the single-pest, static threshold is often the development of a new primary pest.

A tremendous diversity in alfalfa production systems occurs in Wyoming. One, two, or three harvests per year are taken in different locations. Elevations where alfalfa is produced range from 1,067 to 2,377 m above sea level. Hay is raised for on-farm feeding of cattle, sheep, and horses, for sale to dairies and beef cattle ranches, and for feeding U.S. National Park Service elk herds. Each market has different quality demands and brings a different price per ton. Annual yields range from less than 2 to more than 6 tons/acre, and the hay is put up in cubes, small square bales, 1-ton square bales, and 5,443-kg round bales.

Seeding rates to establish stands range from 1.81 to 9.07 kg/acre. In some cases, fields are planted to pure alfalfa, often using a preplant-incorporated herbicide. In roughly three-fourths of newly seeded acres, the stand is established under a companion crop of oats or barley. Reported alfalfa prices in 1984 ranged from $45 to $82/ton in Wyoming. In short, the use of static thresholds would be inappropriate if applied uniformly across the state. In reality, no economic thresholds have been developed for any pest of alfalfa in Wyoming. For insect management, guidelines developed in other states have some merit; for diseases and weeds, there are no economic thresholds.

In spite of this, significant yield improvement and cost benefits have been realized by applying the concepts of thresholds to pest infestations which, for this discussion, will be referred to as action thresholds.

As the production season starts, scouts count alfalfa stands (healthy plants) and weed populations in fields. When compared over time, the grower can measure stand decline and percentage of harvest that is undesirable weeds. As the first-cutting crop matures, the early problems are mainly insects. Alfalfa weevil (*H. postica* Gyllenhal) and alfalfa webworm (*Loxostege commixtalis* Walker) are frequent problems in first-cutting alfalfa in Wyoming. Alfalfa webworms are monitored by visual damage to plants. The action threshold used for seedling fields is 5% of plants damaged and for mature stands, 10–20% of the plants damaged.

Alfalfa weevils are not generally present until the crop is 20.3–30.5 cm high. An action threshold between 0.5 and 1.0 larva per stem is used for making control recommendations. The action threshold is applied with consideration to the growth stage of the crop. Fortunately, most fields will either be relatively uninfested or heavily infested (more than 1.0 larva per stem) making management of this pest straightforward. Emphasis is placed on controlling known infestations only and before any bloom occurs to avoid deleterious effects on predator/parasite species and bees.

Pea aphids are the primary insect pest problem of hay after first cutting. Because this species reproduces asexually, populations of pea aphid in infested fields can outstrip beneficial populations that feed on them. Scouts take 0.093-m^2 counts of aphids and beneficials by beating plants against a 0.093-m^2 board. After counts of 100 aphids per 0.093 m^2 are recorded, different fields have significantly different responses. In some fields where water stress may exist because of disease or improper irrigation, as few as 100 aphids per 0.093 m^2 may affect yield. Other fields, disease-free and properly irrigated, may show no yield effects with aphid populations as high as 500–600/0.093 m^2. Therefore, an action threshold must be based on apparent stress in the field as well as actual counts of aphids.

Disease symptoms are generally more apparent after first and second cuttings, especially for *P. megasperma, D. dipsaci*, and *Verticillium albo-atrum* Reinke & Berth. Scouts diagnose diseases (submitting samples for verification if in doubt) and assess the percentage of living plants showing symptoms at the time the survey is conducted. Infested sites are located on maps of each field so that growers can visualize where infestations occur. Some fields have shown as much as 25% stand loss each year over a 3-yr period and have been taken out of production in their third or fourth year. This phenomenon had been previously termed "winterkill" in Wyoming.

In the fall, a second weed survey and stand count is taken. If a producer knows that hay from an infested field will be marketed to dairies, dormant treatment to control the winter annuals will often be recommended.

Fields with disease problems generally lose alfalfa plants, which are replaced by weeds, further lowering quality and yield. Moisture-stressed fields are more susceptible to insect damage and disease invasion. In short, the complexity of the alfalfa production system makes the use of thresholds a difficult task and demands a multidisciplinary approach.

CONCLUSION

The preceding examples of the use of thresholds and quasithresholds in different cropping situations are extremely limited samples of the references currently available. They were selected to make three points.

First, the dynamic and interactive nature of agroecosystems creates an absolute necessity for multidiscipline, interactive research. Newsom (10) noted, "One of the most disappointing and disturbing results of research on the NSF/EPA soybean subproject is the failure to make any significant progress toward solving the problem of economic injury thresholds for pest complexes.... The importance of a healthy root system to plant growth is well recognized. Yet, very little research has been devoted to the insect pests that attack soybean roots and nodules.... That additional research is required for understanding the interrelationships between root-knot nematodes and *Rhizoctonia* on soybean applies even more strongly to interactions involving insects, nematodes, and fungi."

Second, significantly closer attention needs to be paid by researchers to the application of practical threshold techniques. Solid, scientifically developed methods are sometimes too complicated, abstract, or expensive for general use by producers. Once methods have been developed, the research community needs to translate the jargon into usable methods for the producers. The example of converting regression models for green peach aphid on potatoes in Idaho to word models for grower use in predicting PLRV infestations is an excellent example of how this needs to be done.

Geir (5) notes, "Pest control, which by nature is an ancillary pursuit, can progress only in incremental steps—not by quantam or paradigmatic leaps. Innovations represent genuine advances only when the managers of production systems can make an effective use of them. Research and development done in ignorance of this pre-condition is fundamentally inadequate."

Last, from a practitioner's point of view, use of today's knowledge, as inadequate as it sometimes is, is far superior to not using it. Especially in today's poor agricultural economy, inputs that can be of economic benefit need to be used. An action threshold with a 20% error margin is better than guessing, especially when applied to a specific system by a graduate from the school of experience. Certainly, a 20% error is not acceptable in the long run, but if the method can be improved, improve it. In the meantime, use it.

One of the greatest challenges facing us as we approach the next century is going to be our ability to produce food and fiber for the growing world population. We must increase our cooperative work across disciplines and improve the communication of needs and results between basic and applied science groups.

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