PHOTOS ABOVE:
D.P. Groenendale
PHOTOS BELOW:
D.G. James

Principles of Integrated Pest Management

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Integrated pest management (IPM) is a pest management strategy formally developed in the 1950s by entomologists and other researchers in response to widespread development in agricultural settings of pesticide resistance in insects and mites, outbreaks of secondary and induced insect and mite pests resulting from pesticide use, and transfer and magnification of pesticides in the environment. Initially focusing on biological control of insects and mites in agricultural systems, IPM has assumed a broader role and meaning over the last 60 years, encompassing management of diseases and weeds as well as insects and mites (and other arthropods) in agricultural, horticultural, and urban settings. Broadly speaking, IPM emphasizes selecting, integrating, and implementing complimentary pest management tactics to maintain pests at economically acceptable levels while minimizing negative ecological and social impacts of pest management activities. Although the details of IPM programs vary to meet the needs of individual cropping situations, all are based on several related principles.

Systems-Level Management

Modern IPM emphasizes the management of agricultural systems, rather than individual pests, to prevent or reduce the number and severity of pest outbreaks. This is also referred to as agro-ecosystem planning or whole-farm planning. A focus on whole-farm planning is also a focus on prevention, which expands management efforts in time and space. In agricultural crops, this includes using cultural methods such as crop rotations and fallow periods, tillage, and variety selection (i.e., use of pest-resistant or tolerant varieties and pest-free rootstock), and legal methods such as quarantines. Included in prevention is the conscious selection of agronomic procedures such as irrigation and fertilizer management that optimize plant production and reduce plant susceptibility to pests. Prevention can be very effective and cost-efficient and presents little or no risk to people or the environment.

Pest and Natural Enemy Identification

The ability to accurately identify pests or pest damage is central to IPM, as is the ability to recognize and accurately identify a pest's important natural enemies. Many plants and other organisms live in agricultural fields, and most of these are innocuous or even beneficial. Accurate identification is needed to determine if pests are present and to obtain information on their biology and life history that may be critical to effective monitoring and control efforts. For example, damage to hop caused by the California prionus beetle, Verticillium wilt, and Fusarium canker can be superficially similar in appearance, but the first is a root-feeding insect and the other two are caused by pathogenic fungi. Management options for these pests are very different, therefore positive identification is required to select effective treatment options.

Pest and Natural Enemy Biology and Life History

An understanding of the biologies and life histories of pests and their natural enemies, as well as an understanding of the environmental conditions affecting their growth and reproduction, provide valuable information for pest management. Knowing which development stage of a particular pest causes damage; knowing when and where the damaging stage of a pest is located within or near the crop; knowing which pest stage is susceptible to particular management tactics; and knowing what host plant(s) and climatic conditions are favorable or unfavorable to pest development—all of these help determine when, where, and how to control the pests of interest. The continuing trend toward more biologically based pest management systems requires detailed information on the life cycles of pests, their natural enemies, unintended consequences of applying certain control measures, and the complex interaction of these factors with the environment.

Economic Injury Levels and Economic (Action) Thresholds

In most situations it is not necessary, desirable, or even possible to eradicate a pest from an area. The presence of an acceptable level of pests in a field can help to slow or prevent development of pesticide resistance and maintain populations of natural enemies that slow or prevent pest population buildup. In IPM, acceptable pest levels are defined in terms of economic injury levels (EILs): the pest density (per leaf, cone, or plant, for example) that causes yield loss equal to the cost of tactics used to manage the pest. The economic injury level provides an objective basis for making pest management decisions. At densities below this level, management costs exceed the cost of damage caused by the pest, and additional efforts to manage the pest do not make economic sense and are not recommended. At densities above the economic injury level, losses in yield exceed the cost of management and avoidable economic losses have already occurred; management tactics should have been used earlier.

Ideally, an EIL is a scientifically determined ratio based on results of replicated research trials over a range of environments. In practice, economic injury levels tend to be less rigorously defined, but instead are nominal or empirical thresholds based on grower experience or generalized pest-crop response data from research trials. Although not truly comprehensive, such informal EILs in combination with regular monitoring efforts and knowledge of pest biology and life history provide valuable tools for planning and implementing an effective IPM program. Economic injury levels are dynamic, changing with crop value (decreasing as crop value increases) and management costs (increasing as management costs increase). In theory, economic injury levels can vary from year to year or even from field to field within a year depending on crop variety, market conditions, and available management options.

The economic threshold (sometimes called an action threshold) is the pest density at which control efforts are triggered so as to prevent pest populations from reaching the economic injury level. Economic thresholds are probably more familiar to growers and field personnel than economic injury levels. The economic threshold may be close to or the same as the economic injury level for quick-acting management tactics, such as some pesticides, or much lower than the economic injury level for slower-acting tactics such as some biological control methods. Planning for any lag period between application of a management tactic and its impact on pest numbers is an important part of utilizing economic injury levels and economic (action) thresholds in an IPM program. The principle of EILs and economic (action) thresholds are illustrated graphically in Figure 1.

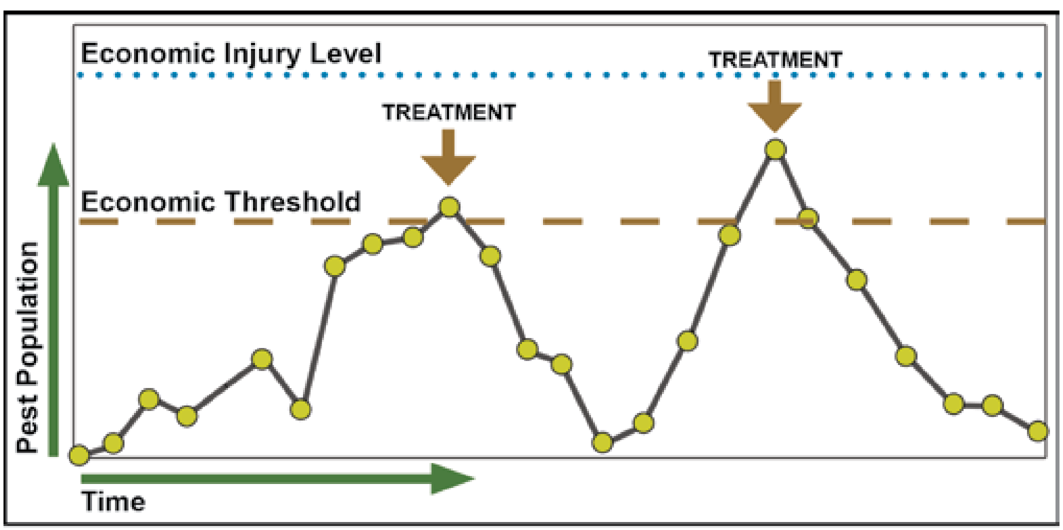

Figure 1. Graphic illustration of the use of an economic injury level and economic threshold for pest management decision making. The economic injury level is the break-even point where management costs equal the damage caused by a pest. The economic threshold is the pest density at which control efforts are triggered so as to prevent pest populations from reaching the economic injury level. The short brown arrows illustrate times when a treatment should be applied because the economic threshold was exceeded.

At a Glance:
Integrated Pest Management

IPM emphasizes selecting, integrating, and implementing complimentary pest management tactics to maintain pests at economically acceptable levels while minimizing negative ecological and social impacts of pest management activities.

Key concepts include:

- Systems-level management
- Pest biology
- Beneficial organism ID
- EILs and economic (action) thresholds
- Scouting
- Monitoring treatment success
- Forecasting
- Recordkeeping
- Multi-tactic management

Consult with local experts about the availability, potential uses, and limitations of pest forecast models to support hop IPM in your area.

PHOTOS ABOVE: A.J. Dreves, B. Price, A.J. Dreves
AT RIGHT: B. Price

Monitoring for Pests, Damage, and Treatment Success

The concepts of acceptable pest levels, economic injury levels, and economic thresholds imply a need to monitor for levels of pests or pest damage in relation to these levels. Monitoring is fundamental to IPM because it is used to objectively determine the need for control and also to assess the effectiveness of control after action has been taken. Sampling and monitoring requires the ability to identify pests, pest damage, and key natural enemies of pests, as well as knowledge of pest and natural enemy biology and life history. In monitoring, the grower or field scout takes representative samples to assess the growth status and general health of the crop, the presence and intensity of current pest infestations or infections, and the potential for development of future pest problems. Monitoring may take many forms, from simply noting the presence or absence of a particular pest to counting the number of pests present. Pest counts can take place through visual inspection of plants (with or without aid of a magnifying lens); dislodging pests through shaking them onto surfaces; gathering pests with a sweep net or other tool; or deploying traps (e.g., sticky traps, pheromone traps, spore traps) in or around a hop yard and counting the captured pests. Sampling should be conducted to provide a representative assessment of the pest population in all areas to be similarly treated, such as part of a field, a single field, or adjacent fields.

Monitoring an area for environmental conditions (especially temperature and relative humidity) that are favorable or unfavorable for pest development is also important. This includes the use of models (e.g., the powdery mildew risk index, degree-day for downy mildew spike emergence and spider mites) to forecast conditions conducive to disease or pest development, and surveying the area for the presence of alternate hosts of hop pests (e.g., agricultural or ornamental varieties of prune that might harbor overwintering hop aphids) and natural enemies (e.g., flowering weeds that provide habitat for natural enemies).

Monitoring, when conducted routinely—at least weekly during the growing season—and in combination with good record keeping and awareness of model forecasts, can help determine trends in pest and natural enemy population growth over time. This assists in planning for pest management decisions and assessing the effectiveness of control actions.

Multi-tactic Management Approaches

When prevention is not effective or possible and monitoring indicates that a pest population has reached or exceeded an action threshold, intervention is required to lower pest numbers to acceptable levels. For any given pest situation, pest/crop managers will need to choose one or more appropriate and compatible management tactics. The basic types of controls are mechanical, biological, and chemical.

Mechanical controls include simple handpicking, erecting barriers, using traps, vacuuming, and tillage to disrupt pest growth and reproduction. Tillage is commonly used to manage weeds in hop, and can be important in managing arthropod pests such as the garden symphylan.

Biological control agents are beneficial organisms that prey on or parasitize pests, or organisms that do not damage crops but compete with pests for habitat and displace pests (e.g., *Bacillus pumilus* for powdery mildew management). Some biological control agents are commercially available for release into cropping systems (i.e., fields, greenhouses) in numbers that can overwhelm pests or that supplement existing natural enemy populations. Adding biological control agents to the ecosystem is referred to as augmentative biocontrol; an example would be the purchase and release of predatory mites *Galendromus occidentalis* and/or *Neoseiulus fallacis* for management of twospotted spider mites. Natural enemy populations also can be augmented using commercially available chemical attractants, such as methyl salicylate. In addition, biological control can be implemented by managing crops to conserve existing natural enemies (conservation biological control) through preserving habitat (including alternative hosts and prey) necessary for normal natural enemy growth and reproduction, or by using management tactics (e.g., selective pesticides or pesticide uses) that have minimal negative impact on natural enemies. In hop, biological control is most widely practiced in the form of conservation biological control through the use of selective pesticides and modified cultural practices.

Chemical controls include synthetic and natural pesticides used to reduce pest populations. Many newer synthetic pesticides are much less disruptive to non-target organisms than older, broad-spectrum chemistries (e.g., organophosphate, carbamate, and pyrethroid insecticides). Insecticides derived from naturally occurring microorganisms such as *Bacillus thuringiensis,* entomopathogenic fungi and entomopathogenic nematodes, and natural insecticides such as pyrethrins and spinosyns are important tools in many organic farming operations, and are playing larger roles in non-organic crop production. Selective pesticides should be chosen over non-selective pesticides to preserve natural enemies and allow biological control to play a greater role in suppressing pest outbreaks. However, broad-spectrum pesticides remain useful and necessary components of IPM programs when other management tactics fail to maintain pests at acceptable levels.

PHOTOS ABOVE: D.H. Gent, D.G. James, D.P. Gronendale
AT LEFT: D.H. Gent