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Biointensive Pest Management

Pest management is an ecological matter. The size of a pest population and the damage it inflicts is, to a great extent, a reflection of the design and management of a particular agricultural ecosystem. We humans compete with other organisms for food and fiber from our crops. We wish to secure a maximum amount of the food resource from a given area with minimum input of resources and energy.

However, if the agricultural system design and/or management is faulty—making it easy for pests to develop and expand their populations or, conversely, making it difficult for predators and parasites of pests to exist—then we will be expending unnecessary resources for pest management.

Therefore, the first step in sustainable and effective pest management is looking at the design of the agricultural ecosystem and considering what ecological concepts can be applied to the design and management of the system to better manage pests and their parasites and predators. The design and management of our agricultural systems need re-examining. We've come to accept routine use of biological poisons in our food systems as normal.

But routine use of synthetic chemicals represents significant energy inputs into the agricultural system, and carries both obvious and hidden costs to the farmer and society. Attempting to implement an ecology-based discipline like Integrated Pest Management (IPM) in large monocultures, which substitute chemical inputs for ecological design, can be an exercise in futility and inefficiency.

However, IPM has strayed from its ecological roots. Critics of what might be termed "conventional" IPM note that it has been implemented as Integrated Pesticide Management with an emphasis on using pesticides as a tool of first resort. What has been missing from this approach, which is essentially reactive, is an understanding of the ecological basis of pest infestations.

AIMS OF BIOINTENSIVE IPM

Biointensive IPM incorporates ecological and economic factors into agricultural system design and decision making, and addresses public concerns about environmental quality and food safety. The benefits of implementing biointensive IPM can include reduced chemical input costs, reduced on-farm and off-farm environmental impacts, and more effective and sustainable pest management.

An ecology-based IPM has the potential of decreasing inputs of fuel, machinery, and synthetic chemicals—all of which are energy intensive and increasingly costly in terms of financial and environmental impact. Such reductions will benefit the grower and society. Over-reliance on the use of synthetic pesticides in crop protection programs around the world has resulted in disturbances to the environment, pest resurgence, pest resistance to pesticides, and lethal and sub-lethal effects on non-target organisms, including humans.

These side effects have raised public concern about the routine use and safety of pesticides. At the same time, population increases are placing ever-greater demands upon the "ecological services"—that is, provision of clean air, water and wildlife habitat—of a landscape dominated by farms. Although some pending legislation has recognised the costs to farmers of providing these ecological services, it's clear that farmers and ranchers will be required to manage their land with greater attention to direct and indirect off-farm impacts of various farming practices on water, soil, and wildlife resources. With this likely future in mind, reducing dependence on chemical pesticides in favor of ecosystem manipulations is a good strategy for farmers.

Consumers Union, a group that has carried out research and advocacy on various pesticide problems for many years, defines biointensive IPM as the highest level of IPM:

— A systems approach to pest management based on an understanding of pest ecology. It begins with steps to accurately diagnose the nature and source of pest problems, and then relies on a range of preventive tactics and biological controls to keep pest populations within acceptable limits. Reduced-risk pesticides are used if other tactics have not been adequately effective, as a last resort, and with care to minimise risks.

This "biointensive" approach sounds remarkably like the original concept of IPM. Such a "systems" approach makes sense both intuitively and in practice.

The primary goal of biointensive IPM is to provide guidelines and options for the effective management of pests and beneficial organisms in an ecological context. The flexibility and environmental compatibility of a biointensive IPM strategy make it useful in all types of cropping systems.

Even conventional IPM strategies help to prevent pest problems from developing, and reduce or eliminate the use of chemicals in managing problems that do arise. Results of 18 economic evaluations of conventional IPM on cotton showed a decrease in production costs of 7 percent and an average decrease in pesticide use of 15 percent. Biointensive IPM would likely decrease chemical use and costs even further. Prior to the mid-1970s, lygus bugs were considered to be the key pest in California cotton. Yet in large-scale studies on insecticidal control of lygus bugs, yields in untreated plots were not significantly different from those on treated plots. This was because the insecticides often induced outbreaks of secondary lepidopterous larvae and mite pests which caused additional damage as well as pest resurgence of the lygus bug itself.

These results, from an economic point of view, seem paradoxical, as the lygus bug treatments were costly, yet the treated plots consistently had lower yields. This paradox was first pointed out by R. van den Bosch, V. Stern, and L. A. Falcon, who forced a reevaluation of the economic basis of Lygus control in California cotton.

COMPONENTS OF BIOINTENSIVE IPM

An important difference between conventional and biointensive IPM is that the emphasis of the latter is on proactive measures to redesign the agricultural ecosystem to the disadvantage of a pest and to the advantage of its parasite and predator complex. At the same time, biointensive IPM shares many of the same components as conventional IPM, including monitoring, use of economic thresholds, record keeping, and planning.

Good planning must precede implementation of any IPM program, but is particularly important in a biointensive program. Planning should be done before planting because many pest strategies require steps or inputs, such as beneficial organism habitat management, that must be considered well in advance. Attempting to jump-start an IPM program in the beginning or middle of a cropping season generally does not work.

When planning a biointensive IPM program, some considerations include:

- Options for design changes in the agricultural system (beneficial organism habitat, crop rotations).
- Choice of pest-resistant cultivars.
- Technical information needs.
- Monitoring options, record keeping, equipment, etc.

The Pest Manager/Ecosystem Manager

The pest manager is the most important link in a successful IPM program. The manager must know the biology of the pest and the beneficial organisms associated with the pest, and understand their interactions within the farm environment. As a detailed knowledge of the pest is developed, weak links in its life cycle become apparent. These weak links are phases of the life cycle when the pest is most susceptible to control measures. The manager must integrate this knowledge with tools and techniques of biointensive IPM to manage not one, but several pests.

A more accurate title for the pest manager is "ecosystem doctor," for he or she must pay close attention to the pulse of the managed ecosystem and stay abreast of developments in IPM and crop/pest biology and ecology. In this way, the ecosystem manager can take a proactive approach to managing pests, developing ideas about system manipulations, testing them, and observing the results. IPM options may be considered proactive or reactive. Proactive options, such as crop rotations and creation of habitat for beneficial organisms, permanently lower the carrying capacity of the farm for the pest.

The carrying capacity is determined by factors like food, shelter, natural enemies complex, and weather, which affect the reproduction and survival of a species. Cultural controls are generally considered to be proactive strategies. The second set of options is more reactive. This simply means that the grower responds to a situation, such as an economically damaging population of pests, with some type of short-term suppressive action. Reactive methods generally include inundative releases of biological controls, mechanical and physical controls, and chemical controls.

Proactive Strategies

- Healthy, biologically active soils (increasing belowground diversity)
- Habitat for beneficial organisms (increasing aboveground diversity)
- Appropriate plant cultivars

Cultural controls are manipulations of the agroecosystem that make the cropping system less friendly to the establishment and proliferation of pest populations. Although they are designed to have positive effects on farm ecology and pest management, negative impacts may also result, due to variations in weather or changes in crop management.

Maintaining and increasing biological diversity of the farm system is a primary strategy of cultural control. Decreased biodiversity tends to result in agroecosystems that are unstable and prone to recurrent pest outbreaks and many other problems. Systems high in biodiversity tend to be more "dynamically stable"—that is, the variety of organisms provide more checks and balances on each other, which helps prevent one species (i.e., pest species) from overwhelming the system.

There are many ways to manage and increase biodiversity on a farm, both above ground and in the soil. In fact, diversity above ground influences diversity below ground. Research has shown that up to half of a plant's photosynthetic production (carbohydrates) is sent to the roots, and half of that (along with various amino acids and other plant products) leaks out the roots into the surrounding soil, providing a food source for microorganisms. These root exudates vary from plant species to plant species and this variation influences the type of organisms associated with the root exudates.

Factors influencing the health and biodiversity of soils include the amount of soil organic matter; soil pH; nutrient balance; moisture; and parent material of the soil. Healthy soils with a diverse community of organisms support plant health and nutrition better than soils deficient in organic matter and low in species diversity. Research has shown that excess nutrients as well as relative nutrient balance (i.e., ratios of nutrients—for example, twice as much calcium as magnesium, compared to equal amounts of both) in soils affect insect pest response to plants.

Imbalances in the soil can make a plant more attractive to insect pests, less able to recover from pest damage, or more susceptible to secondary infections by plant pathogens. Soils rich in organic matter tend to suppress plant pathogens. In addition, it is estimated that 75% of all insect pests spend part of their life cycle in the soil, and many of their natural enemies occur there as well. For example, larvae of one species of blister beetle consume about 43 grasshopper eggs before maturing. Both are found in the soil. Overall, a healthy soil with a diversity of beneficial organisms and high organic matter content helps maintain pest populations below their economic thresholds.

Genetic diversity of a particular crop may be increased by planting more than one cultivar. For example, a recent experiment in China demonstrated that disease-susceptible rice varieties planted in mixtures with resistant varieties had 89% greater yield and a 94% lower incidence of rice blast (a fungus) compared to when they were grown in monoculture. The experiment, which involved five townships in 1998 and ten townships in 1999, was so successful that fungicidal sprays were no longer applied by the end of the two-year program.

Species diversity of the associated plant and animal community can be increased by allowing trees and other native plants to grow in fence rows or along water ways, and by integrating livestock into the farm system. Use of the following cropping schemes offers additional ways to increase species diversity.

Crop rotations radically alter the environment both above and below ground, usually to the disadvantage of pests of the previous crop. The same crop grown year after year on the same field will inevitably build up populations of organisms that feed on that plant, or, in the case of weeds, have a life cycle similar to that of the crop. Add to this the disruptive effect of pesticides on species diversity, both above and below ground, and the result is an unstable system in which slight stresses (e.g., new pest variety or drought) can devastate the crop.

An enforced rotation program in the Imperial Valley of California has effectively controlled the sugar beet cyst nematode. Under this program, sugar beets may not be grown more than two years in a row or more than four years out of ten in clean fields (i.e., non-infested fields). In infested fields, every year of a sugar beet crop must be followed by three years of a non-host crop. Other nematode pests commonly controlled with crop rotation methods include the golden nematode of potato, many root-knot nematodes, and the soybean cyst nematode.

When making a decision about crop rotation, consider the following questions: Is there an economically sustainable crop that can be rotated into the cropping system? Is it compatible? Important considerations when developing a crop rotation are:

- What two crops can provide an economic return when considered together as a biological and economic system that includes considerations of sustainable soil management?
- What are the impacts of this season's cropping practices on subsequent crops?
- What specialised equipment is necessary for the crops?
- What markets are available for the rotation crops?

A corn/soybean rotation is one example of rotating compatible economic crops. Corn is a grass; soybean is a leguminous broadleaf. The pest complex of each, including soil organisms, is quite different. Corn rootworm, one of the major pests of corn, is virtually eliminated by using this rotation. Both crops generally provide a reasonable return. Even rotations, however, create selection pressures that will ultimately alter pest genetics. A good example is again the corn rootworm: the corn/bean rotation has apparently selected for a small population that can survive a year of non-corn (i.e., soybean) cropping.

Management factors should also be considered. For example, one crop may provide a lower direct return per acre than the alternate crop, but may also lower management costs for the alternate crop, with a net increase in profit.

Other Cropping Structure Options

Multiple cropping is the sequential production of more than one crop on the same land in one year. Depending on the type of cropping sequence used, multiple cropping can be useful as a weed control measure, particularly when the second crop is interplanted into the first.

Interplanting is seeding or planting a crop into a growing stand, for example overseeding a cover crop into a grain stand.

There may be microclimate advantages (e.g., timing, wind protection, and less radical temperature and humidity changes) as well as disadvantages (competition for light, water, nutrients) to this strategy. By keeping the soil covered, interplanting may also help protect soil against erosion from wind and rain. Intercropping is the practice of growing two or more crops in the same, alternate, or paired rows in the same area. This technique is particularly appropriate in vegetable production.

The advantage of intercropping is that the increased diversity helps "disguise" crops from insect pests, and if done well, may allow for more efficient utilisation of limited soil and water resources. Disadvantages may relate to ease of managing two different crop species— with potentially different nutrient, water, and light needs, and differences in harvesting time and method—in close proximity to each other. Strip cropping is the practice of growing two or more crops in different strips across a field wide enough for independent cultivation.

It is commonly practiced to help reduce soil erosion in hilly areas. Like intercropping, strip cropping increases the diversity of a cropping area, which in turn may help "disguise" the crops from pests. Another advantage to this system is that one of the crops may act as a reservoir and/or food source for beneficial organisms. However, much more research is needed on the complex interactions between various paired crops and their pest/predator complexes. The options described above can be integrated with no-till cultivation schemes and all its variations as well as with hedgerows and intercrops designed for beneficial organism habitat. With all the cropping and tillage options available, it is possible, with creative and informed management, to evolve a biologically diverse, pest-suppressive farming system appropriate to the unique environment of each farm.

Other Cultural Management Options

Disease-free seed and plants are available from most commercial sources, and are certified as such. Use of disease-free seed and nursery stock is important in preventing the introduction of disease.

Resistant varieties are continually being bred by researchers. Growers can also do their own plant breeding simply by collecting non-hybrid seed from healthy plants in the field. The plants from these seeds will have a good chance of being better suited to the local environment and of being more resistant to insects and diseases. Since natural systems are dynamic rather than static, breeding for resistance must be an ongoing process, especially in the case of plant disease, as the pathogens themselves continue to evolve and become resistant to control measures. Sanitation involves removing and destroying the overwintering or breeding sites of the pest as well as preventing a new pest from establishing on the farm. This strategy has been particularly useful in horticultural and tree-fruit crop situations involving twig and branch pests.

If, however, sanitation involves removal of crop residues from the soil surface, the soil is left exposed to erosion by wind and water. As with so many decisions in farming, both the short- and long-term benefits of each action should be considered when tradeoffs like this are involved.

Spacing of plants heavily influences the development of plant diseases and weed problems. The distance between plants and rows, the shape of beds, and the height of plants influence air flow across the crop, which in turn determines how long the leaves remain damp from rain and morning dew. Generally speaking, better air flow will decrease the incidence of plant disease. However, increased air flow through wider spacing will also allow more sunlight to the ground, which may increase weed problems. This is another instance in which detailed knowledge of the crop ecology is necessary to determine the best pest management strategies. How will the crop react to increased spacing between rows and between plants? Will yields drop because of reduced crop density? Can this be offset by reduced pest management costs or fewer losses from disease?

Altered planting dates can at times be used to avoid specific insects, weeds, or diseases. For example, squash bug infestations on cucurbits can be decreased by the delayed planting strategy, i.e., waiting to establish the cucurbit crop until overwintering adult squash bugs have died. To assist with disease management decisions, the Cooperative Extension Service (CES) will often issue warnings of "infection periods" for certain diseases, based upon the weather.

In some cases, the CES also keeps track of "degree days" needed for certain important insect pests to develop. Insects, being cold-blooded, will not develop below or above certain threshold temperatures. Calculating accumulated degree days, that is, the number of days above the threshold development temperature for an insect pest, makes the prediction of certain events, such as egg hatch, possible. University of California has an excellent Web site that uses weather station data from around the state to help California growers predict pest emergence.

Some growers gauge the emergence of insect pests by the flowering of certain non-crop plant species native to the farm. This method uses the "natural degree days" accumulated by plants. For example, a grower might time cabbage planting for three weeks after the *Amelanchier* species on their farm are in bloom. This will enable the grower to avoid peak egg-laying time of the cabbage maggot fly, as the egg hatch occurs about the time *Amelanchier* species are flowering. Using this information, cabbage maggot management efforts could be concentrated during a known time frame when the early instars are active.

Optimum growing conditions are always important. Plants that grow quickly and are healthy can compete with and resist pests better than slow-growing, weak plants. Too often, plants grown outside their natural ecosystem range must rely on pesticides to overcome conditions and pests to which they are not adapted.

Mulches, living or non-living, are useful for suppression of weeds, insect pests, and some plant diseases. Hay and straw, for example, provide habitat for spiders. Research in Tennessee showed a 70% reduction in damage to vegetables by insect pests when hay or straw was used as mulch.

The difference was due to spiders, which find mulch more habitable than bare ground. Other researchers have found that living mulches of various clovers reduce insect pest damage to vegetables and orchard crops. Again, this reduction is due to natural predators and parasites provided habitat by the clovers. Vetch has been used as both a nitrogen source and as a weed suppressive mulch in tomatoes in Maryland. Growers must be aware that mulching may also provide a more friendly environment for slugs and snails, which can be particularly damaging at the seedling stage.

Mulching helps to minimise the spread of soil-borne plant pathogens by preventing their transmission through soil splash. Mulch, if heavy enough, prevents the germination of many annual weed seeds. Winged aphids are repelled by silver- or aluminum-colored mulches. Recent springtime field tests at the Agricultural Research Service in Florence, South Carolina, have indicated that red plastic mulch suppresses root-knot nematode damage in tomatoes by diverting resources away from the roots (and nematodes) and into foliage and fruit.

Biotech Crops. Gene transfer technology is being used by several companies to develop cultivars resistant to insects, diseases, and herbicides. An example is the incorporation of genetic material from *Bacillus thuringiensis* (Bt), a naturally occurring bacterium, into cotton, corn, and potatoes, to make the plant tissues toxic to bollworm, earworm, and potato beetle larvae, respectively.

Whether or not this technology should be adopted is the subject of much debate. Opponents are concerned that by introducing Bt genes into plants, selection pressure for resistance to the Bt toxin will intensify and a valuable biological control tool will be lost. There are also concerns about possible impacts of genetically-modified plant products (i.e., root exudates) on non-target organisms as well as fears of altered genes being transferred to weed relatives of crop plants. Whether there is a market for gene-altered crops is also a consideration for farmers and processors. Proponents of this technology argue that use of such crops decreases the need to use toxic chemical pesticides.

BIOLOGICAL CONTROLS

Biological control is the use of living organisms—parasites, predators, or pathogens—to maintain pest populations below economically damaging levels, and may be either natural or applied. A first step in setting up a biointensive IPM program is to assess the populations of beneficials and their interactions within the local ecosystem. This will help to determine the potential role of natural enemies in the managed agricultural ecosystem. It should be noted that some groups of beneficials may be absent or scarce on some farms because of lack of habitat. These organisms might make significant contributions to pest management if provided with adequate habitat.

Natural biological control results when naturally occurring enemies maintain pests at a lower level than would occur without them, and is generally characteristic of biodiverse systems. Mammals, birds, bats, insects, fungi, bacteria, and viruses all have a role to play as predators and parasites in an agricultural system. By their very nature, pesticides decrease the biodiversity of a system, creating the potential for instability and future problems. Pesticides, whether synthetically or botanically derived, are powerful tools and should be used with caution.

Creation of habitat to enhance the chances for survival and reproduction of beneficial organisms is a concept included in the definition of natural biocontrol. Farmscaping is a term coined to describe such efforts on farms. Habitat enhancement for beneficial insects, for example, focuses on the establishment of flowering annual or perennial plants that provide pollen and nectar needed during certain parts of the insect life cycle.

Other habitat features provided by farmscaping include water, alternative prey, perching sites, overwintering sites, and wind protection. Beneficial insects and other beneficial organisms should be viewed as mini-livestock, with specific habitat and food needs to be included in farm planning. The success of such efforts depends on knowledge of the pests and beneficial organisms within the cropping system. Where do the pests and beneficials overwinter? What plants are hosts and non-hosts? When this kind of knowledge informs planning, the ecological balance can be manipulated in favor of beneficials and against the pests.

It should be kept in mind that ecosystem manipulation is a two-edged sword. Some plant pests are attracted to the same plants that attract beneficials. The development of beneficial habitats with a mix of plants that flower throughout the year can help prevent such pests from migrating *en masse* from farmscaped plants to crop plants.

Applied biological control, also known as augmentative biocontrol, involves supplementation of beneficial organism populations, for example through periodic releases of parasites, predators, or pathogens. This can be effective in many situations—well-timed inundative releases of *Trichogramma* egg wasps for codling moth control, for instance.

Most of the beneficial organisms used in applied biological control today are insect parasites and predators. They control a wide range of pests from caterpillars to mites. Some species of biocontrol organisms, such as *Eretmocerus californicus*, a parasitic wasp, are specific to one host—in this case the sweetpotato whitefly. Others, such as green lacewings, are generalists and will attack many species of aphids and whiteflies.

Information about rates and timing of release is available from suppliers of beneficial organisms. It is important to remember that released insects are mobile; they are likely to leave a site if the habitat is not conducive to their survival. Food, nectar, and pollen sources can be "farmscaped" to provide suitable habitat.

The quality of commercially available applied biocontrols is another important consideration. For example, if the organisms are not properly labeled on the outside packaging, they may be mishandled during transport, resulting in the death of the organisms. A recent study by Rutgers University noted that only two of six suppliers of beneficial nematodes sent the expected numbers of organisms, and only one supplier out of the six provided information on how to assess product viability.

While augmentative biocontrols can be applied with relative ease on small farms and in gardens, applying some types of biocontrols evenly over large farms has been problematic. New mechanised methods that may improve the economics and practicality of large-scale augmentative biocontrol include ground application with "biosprayers" and aerial delivery using small-scale (radio-controlled) or conventional aircraft. Inundative releases of beneficials into greenhouses can be particularly effective. In the controlled environment of a greenhouse, pest infestations can be devastating; there are no natural controls in place to suppress pest populations once an infestation begins.

For this reason, monitoring is very important. If an infestation occurs, it can spread quickly if not detected early and managed. Once introduced, biological control agents cannot escape from a greenhouse and are forced to concentrate predation/parasitism on the pest(s) at hand. An increasing number of commercially available biocontrol products are made up of microorganisms, including fungi, bacteria, nematodes, and viruses.

MECHANICAL AND PHYSICAL CONTROLS

Methods included in this category utilise some physical component of the environment, such as temperature, humidity, or light, to the detriment of the pest. Common examples are tillage, flaming, flooding, soil solarisation, and plastic mulches to kill weeds or to prevent weed seed germination.

Heat or steam sterilisation of soil is commonly used in greenhouse operations for control of soil-borne pests. Floating row covers over vegetable crops exclude flea beetles, cucumber beetles, and adults of the onion, carrot, cabbage, and seed corn root maggots. Insect screens are used in greenhouses to prevent aphids, thrips, mites, and other pests from entering ventilation ducts. Large, multi-row vacuum machines have been used for pest management in strawberries and vegetable crops.

Pest Identification

A crucial step in any IPM program is to identify the pest. The effectiveness of both proactive and reactive pest management measures depend on correct identification. Misidentification of the pest may be worse than useless; it may actually be harmful and cost time and money. After a pest is identified, appropriate and effective management depends on knowing answers to a number — What plants are hosts and non-hosts of this pest?

- When does the pest emerge or first appear?
- Where does it lay its eggs? In the case of weeds, where is the seed source? For plant pathogens, where is the source(s) of inoculum?
- Where, how, and in what form does the pest overwinter?
- How might the cropping system be altered to make life more difficult for the pest and easier for its natural controls?

Monitoring (field scouting) and economic injury and action levels are used to help answer these and additional questions.

Monitoring

Monitoring involves systematically checking crop fields for pests and beneficials, at regular intervals and at critical times, to gather information about the crop, pests, and natural enemies. Sweep nets, sticky traps, and pheromone traps can be used to collect insects for both identification and population-density information. Leaf counts are one method for recording plant growth stages. Square-foot or larger grids laid out in a field can provide a basis for comparative weed counts. Records of rainfall and temperature are sometimes used to predict the likelihood of disease infections.

Specific scouting methods have been developed for many crops. The Cooperative Extension Service can provide a list of IPM manuals available in each state. Many resources are now available via Internet. The more often a crop is monitored, the more information the grower has about what is happening in the fields. Monitoring activity should be balanced against its costs. Frequency may vary with temperature, crop, growth phase of the crop, and pest populations. If a pest population is approaching economically damaging levels, the grower will want to monitor more frequently.

Economic Injury and Action Levels

The economic injury level (EIL) is the pest population that inflicts crop damage greater than the cost of control measures. Because growers will generally want to act before a population reaches EIL, IPM programs use the concept of an economic threshold level (ETL or ET), also known as an action threshold. The ETL is closely related to the EIL, and is the point at which suppression tactics should be applied in order to prevent pest populations from increasing to injurious levels.

In practice, many crops have no established EILs or ETLs, or the EILs that have been developed may be static over the course of a season and thus not reflect the changing nature of the agricultural ecosystem. For example, a single cutworm can do more damage to an emerging cotton plant than to a plant that is six weeks old. Clearly, this pest's EIL will change as the cotton crop develops. ETLs are intimately related to the value of the crop and the part of the crop being attacked. For example, a pest that attacks the fruit or vegetable will have a much lower ETL than a pest that attacks a non-saleable part of the plant.

The exception to this rule is an insect or nematode pest that is also a disease vector. Depending on the severity of the disease, the grower may face a situation where the ETL for a particular pest is zero, i.e., the crop cannot tolerate the presence of a single pest of that particular species because the disease it transmits is so destructive.