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Insect Management on Organic Farms

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Insect management presents a challenge to organic farmers. Insects are highly mobile and well adapted to farm production systems and pest control tactics. On organic farms, where the focus is on managing insects rather than eliminating them, success depends on learning about three kinds of information:

- *Biological information.*What the insect needs to survive can be used to determine if pest insects can be deprived of some vital resource.
- *Ecological information*. How the insect interacts with the environment and other species can be used to shape a pest-resistant environment.
- *Behavioral information* about both pest and beneficial insects. How the insect goes about collecting the necessities of life can be manipulated to protect crops.

This knowledge can be used to craft a management plan that incorporates many different elements to suppress pest insects. No single tactic, employed alone, is likely to give satisfactory control of chronic pest species. Certified organic farmers can use a wide range of practices to create an integrated pest management approach that complies with the standards of the USDA's National Organic Program (NOP): www.ams.usda. gov/nop/, (202) 720-3252. The standard states that a farmer must use management practices to prevent crop pests, weeds, and diseases,

Figure 1. Striped cucumber beetle *(Acalymma vittatum)* (Photo courtesy of USDA.)

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including but not limited to these: crop rotation and soil and crop nutrient management practices; sanitation measures to remove disease vectors, weed seeds, and habitat for pest organisms; and cultural practices that enhance crop health, including selection of plant species and varieties that are suitable to site-specific conditions and resistant to prevalent pests, weeds, and diseases.

According to the organic standard, insect pest problems may be controlled through cultural, mechanical or physical methods; augmentation or introduction of predators or parasites of the pest species; development of habitat for natural enemies of pests; and nonsynthetic controls, such as lures, traps, and repellents. When these practices are insufficient to prevent or control crop pests, a biological, botanical, or chemical material or substance included on the National List of nonsynthetic and synthetic substances allowed for use in organic crop production may be applied to prevent, suppress, or control pests. However, the conditions for using the material **must** be documented in the organic system plan.

Pest management plans are site-specific. Farmers should develop their own strategies based on their knowledge, available time, and capital—the resources they can devote to pest management. This chapter provides basic information on pest insects and the management tactics that organic farmers can use to keep pest insect populations at levels that do not pose an economic threat to crops. It is not a how-to guide that can be followed step by step. We will focus on the following topics:

- **Cultural practices.** The first key step toward managing pest insects is using cultural practices that suppress pest species and encourage their natural enemies, also referred to in this chapter as *beneficials*.
- **Pheromones and other attractants.** Organic farmers can use chemical attractants to trap pest insects, disrupt their reproduction cycle, and monitor their population levels.
  Biological control using insect pathogens. Organisms that cause disease in insects can be exploited to help control pest populations by managing the environment to favor insect disease or by applying allowable purchased products. The use of insect pathogens to manage pests is called *microbial control*.
- **Biological control using insect natural enemies.** Farmers can manage their fields to provide habitats for species that eat and live on pest insects. This can be accomplished through conserving and augmenting beneficial populations.
- **Insecticides.** Allowable organic and inorganic chemicals, insecticidal oils and soaps, microbial insecticides, particle films, and botanicals, when used in combination with the above pest management strategies, can help to suppress pest insect populations.

All of these practices used together comprise an integrated pest management (IPM) approach.

CULTURAL PRACTICES: THE PLACE TO START

Pest insect problems are influenced by three components of a farming system. Farmers can manipulate all of these components to suppress pest species.

- The *crop species and cultivar* present a set of resources, growth habits, and structure.

- *Production practices*, such as rotation, timeliness of planting and harvesting, spacing of plants, fertility and water management, tillage, mulching, sanitation, and companion planting.
- *Agroecosystem structure* includes field borders, natural vegetation, and other crop production areas that resupply fields with pest insects and beneficial species when crops are replanted.

Insects require a basic set of resources to live and reproduce. Production practices that deprive a pest species of at least one needed element of life may maintain pest populations below economically damaging levels for extended periods. It is unlikely, however, that cultural practices will provide permanent control because the most troublesome insect species are those that are well-adapted to the production systems used on a farm. Populations of these pest insects will tend to increase under a particular production system, while populations of less well-adapted species will decrease.

Pest insects must be very adaptive to succeed because their physical environment changes as production systems change. Insects must deal with many environmental changes, including different tillage practices, fertility regimes, and planting dates. Each individual practice can change pest insect population dynamics. In organic systems, farmers use many different cultural practices and cultivate a wide array of crops. The interactive effect of this array of interacting elements on pests is difficult to predict and usually can be determined only through research and experience.

Farmers can use cultural control measures to modify the crop environment enough to increase environmental resistance to pest insects. This can involve one or all of the following strategies:

- Reducing initial pest levels by making the crop environment unattractive, unfavorable for pest reproduction and growth, or both.
- Producing favorable conditions for natural enemies.
- Increasing the plants' ability to withstand pest damage.

When used together, the cultural practices described on the following pages provide useful tools for reducing or preventing pest problems.

Monitoring

Monitoring insects is fundamental to good management. Determining when a pest insect first colonizes a crop and measuring its abundance on a regular schedule provides the information needed to make control decisions.

Monitoring does not have to be a rigorous procedure, but it needs to be done on a regular basis using the right procedure.

In some cases (as for mites and aphids) simply checking crops by direct observation is all that is needed. For other pests, it is easier and quicker to use a device, such as a sweep net, to sample crops. Many devices—from plastic lunch trays to ground cloths—are used to sample pests. Some pests, like thrips, require a different procedure.

Local Extension offices have information on how and when to monitor many crops for pests. This procedure is essentially the same for organic or conventional crops.

Crop Cultivar

Plant breeders traditionally have placed more focus on creating disease-resistant varieties than on creating insect-resistant varieties. Where they are available, however, insect-resistant varieties can be an effective defense. It is important to find out about the mechanism of insect resistance in a crop variety because genetically modified crops (GMOs, transgenic crops) are not allowed in organic production systems. Even when insect-resistant cultivars are not available, some varieties may be less attractive to pest species or tolerate more damage than others. Plant size, shape, coloration, leaf hairs, and natural chemicals—both attractants and repellents—all affect the outcome of insect crop colonization. Note that changing cultivars to reduce pests can also reduce beneficial insects either directly (characteristics that affect pest abundance may also influence beneficial insects) or indirectly (through providing less prey).

Although resistant varieties and natural controls generally work together to suppress pests, some exceptions have been documented. If difficult, persistent pest problems occur, selection of a resistant or more tolerant cultivar is an option that should be tested. Most land-grant universities have official variety tests that may include observations or screening on insect resistance. Often, however, farmers must depend upon observation, experience, and exchanging information with other farmers.

Crop Rotation

Crop rotation or sequence is designed to present a nonhost crop to pest insects. Realistically, rotations are likely to have little effect on highly mobile foliar insects. Less mobile foliar pests—such as the Colorado potato beetle (CPB), subterranean pests, or pests with one generation a year—may be substantially suppressed with proper rotation. The distances required, however, may exceed the space available on small-scale operations. For example, to reduce insecticide applications for CPB by 50 percent, potatoes have to be moved 1/4- to 1/2-mile away from previous potato crops (Weisz et al. 1994). To be most effective, rotations between susceptible crops should be three to seven years.

Planting Date and Method

The stage of crop development can have a profound effect on a crop's attractiveness to pest insects. For some pests and crops, stage of development dictates whether or not a pest is a problem. If very few crops are available when insects emerge in the spring, pest insects may concentrate on a few early planted fields. Conversely, if many crop and noncrop host plants are available in early spring, then pests may disperse widely and not concentrate in any one crop. Thrips, for example, often infest early planted crops in high numbers. But they cause fewer problems on later planted crops. For some pest insects, planting a crop early so that it reaches a less susceptible physiological stage can be a practical solution to a pest problem. For example, corn earworm causes fewer problems in early planted sweet corn. Additionally, aphid-transmitted plant viruses may be minimized in early planted crops.

Vigorous crop growth is also important. Seeds should be sown when temperatures will allow them to emerge and grow quickly. Using seedlings or transplants instead of seeds can also speed crop development. Plants struggling to survive or plants under stress will be more attractive to pest insects and more affected by damage.

Most of the time, planting date and method are dictated by markets, weather, labor availability, and other factors. But if a pest insect presents an especially difficult problem, manipulating the planting date and method may be one option to explore.

Harvest Date

The shorter the time a crop is in the field, the less time pest insects have to damage it. Combining early planting with early maturing varieties may allow a crop to mature before pest insects reach damaging levels.

This can also be effective for minimizing insect-transmitted plant diseases. For example, curcubit crops may have fewer virus problems with early harvest. Other factors, however, such as markets and weather, may dictate longer seasons. This must be weighed against insect pest losses.

Crop Population Density —Row Spacing & Seeding Rate

Decisions about crop population densities are dictated more by the growing characteristics of the crop, weed management, and harvest requirements than by pest insect management. In general, if increasing the population density of a crop increases beneficial insects, it can lead to a decrease in pest insects. In some crops, close row spacing increases control by beneficial insects. More ground shading will usually increase ground-dwelling predators, such as ground beetles. Some species of ground beetles also consume weed seeds on the soil surface.

Fertility Management—Nutrition, Vigor, and Soil pH

Proper nutrient management is an important component of IPM in organic systems. Organic production does not allow synthetic fertilizers or sewage sludge. Check with your certifier if you are in doubt about your fertility management materials.

Although crop plants must grow vigorously to withstand pest damage, overly lush plants often attract more pest insects and experience more damage than other plants. Overfertilized plants may give visual clues to insects and become targets of attack. Survival of immature insects may also be better on overfertilized plants. Nutrient stress from insufficient plant nutrients can also cause plants to be more attractive to insect pests or more susceptible to damage by insect pests. Consequently, the careful planning and execution of soil fertility programs (including pH) is an important component of pest insect management.

Increasing Soil Organic Matter

Studies have shown that as organic matter in the soil increases, microscopic life increases, which can lead to an increase in generalist insect predators.

Additions of organic matter must be handled carefully because some soil-dwelling pests, such as the seed corn maggot, can present significant problems. Only throughly composted materials, well incorporated, should be used to minimize soil pest insect problems.

Water Management

Irrigation has both direct and indirect effects on pest insects. Insect populations can decrease if overhead sprinklers knock insects off plants or raise microenvironment humidity enough to encourage insect disease caused by bacteria or fungi. Because irrigation methods vary considerably (whether drip, overhead sprinkler, or flood irrigation), the impact of irrigation on insects also varies. Pest insect populations can increase if irrigated plants are lusher and more attractive than surrounding plants. Likewise, plants stressed by drought can be more attractive to insect pests or less tolerant to their feeding. The need for irrigation is dictated by crop growth and weather rather than the need for insect control. But when there is some flexibility in irrigation scheduling, a farmer should think about irrigation as a tool for suppressing pest insects. Several naturally occurring insect pathogens, especially insect-pathogenic fungi, provide effective pest suppression when high humidity microenvironments are created.

Tillage

Tillage practices affect both subterranean and foliar insect pests. Infrequent disturbance of soils in natural systems preserves food webs and diversity of organisms and habitats. The regular disturbance of agricultural soils disrupts ecological linkages and allows adapted pest species to increase without the dampening effects of natural controls. Nevertheless, tillage can also destroy insects overwintering in the soil as eggs, pupae, or adults, and reduce pest problems.

Organic producers usually rely on tillage to control weeds and to prepare the soil for planting. Research is being conducted on methods and equipment that may allow for the reduction of tillage in organic systems. Some practices to reduce tillage in organic systems include zone tillage, ridge tillage, and including a perennial or sod-producing crop in the rotation. Reduction of tillage alters pest insect dynamics considerably. Thrips cause fewer problems in reduced-till systems. Ground-dwelling predators, such as ground beetles that prey on pest insects, can increase. However, cutworm and slug problems can also increase where tillage is reduced. The degree of pest population shifts between a tilled and reduced-tillage system cannot be reliably predicted. Species shifts will occur and should be carefully monitored. Tillage is not likely to have a significant effect on most common foliar-feeding insect pests.

Mulches

Mulching systems fall into various categories, including plastic (woven or nonwoven) and natural materials. Although allowable, the use of plastic mulch is frequently discouraged by organic certification agencies because it relies on a nonrenewable resource. Biodegradeable plastic mulches are being developed and may affect pests in a similar way to that of conventional, nonbiodegradeable muclhes. Organic farmers often use a straw mulch because it is readily available and provides good weed suppression. Planting into a living or killed mulch is growing in popularity as more information on this practice is provided and as specialized equipment becomes available. (See the discussion of cover crops in this chapter, under “Conserving Natural Enemies,” page 15) New systems, such as hydromulch (which consists of wood fibers sprayed on with an adhesive to keep them together) may one day supplant plastic and straw if they are developed with organically allowable components. For now, plastic and straw mulches remain high in popularity.

All mulches suppress insects in comparison to bare soil. Different colors of plastic have been tested; and clear, white, yellow, or aluminum (reflective) colors may provide some additional suppression of aphids and whiteflies. Blue and yellow may bring in more pests. Plastic can be painted the desired color. Before painting mulch, farmers should check with their certifiers to see if the practice is allowable.

Straw mulches can affect insect pests. Crops that are traditionally mulched with plastic may benefit from straw mulches. For example, suppression of the Colorado potato beetle has been demonstrated with straw mulch in potatoes. Not enough information is available to make definite recommendations about the advantages of one mulch over another. Testing in a restricted area is recommended when using mulches for the first time or changing mulching materials. Mulching alone will probably not prevent pest problems. Nevertheless, if used in combination with other tactics, mulching may help reduce populations of difficult insect pests.

Sanitation

Good farm sanitation can help to prevent introductions of pest insects from outside sources, slow their movement within the farm, and eliminate them when they are discarded with crop materials that may harbor them.

If transplants are purchased off-farm, buy from a reputable dealer and check very carefully before bringing transplants to the farm. A simple screening process can save time and money later. Quarantine any purchased transplants for at least a week, and examine them carefully for pests daily.

Some pests (such as spider mites and whiteflies) are not very mobile but can spread when people and equipment move from an infested area to uninfested areas. After working in an infested area, clean equipment and clothes before going to another area of the farm.

Culled plants and produce are often piled near the field or processing area for later disposal. This can provide a suitable feeding and breeding site for insect pests. These piles should be composted, buried, or otherwise destroyed as soon as possible.

Companion Planting

The companion planting approach is based on the theory that various plants grown in close proximity to the crop plant will repel or kill pest insects. Studies to date have not shown this approach to be effective. Note that companion planting is not the same as intercropping, which may be a valuable tool in attracting beneficial insects.

Trap Crops

Trap crops attract pest species away from the cash crop to be protected and into a specific area where they can be destroyed. Depending on the target pest and the cash crop, trap crops can be planted with or around the perimeter of the cash crop field. This approach is an appealing idea, and it has proven useful in some situations. Implementation of trap cropping takes careful management. Knowledge of the biology and ecology of the target pest species is critical when considering trap cropping. Species that are weak fliers or pests that are blown into a crop (such as aphids) or are dispersed in the wind (such as spider mites) are not good candidates. Good target pests show a strong preference for a particular type, variety, or physiological stage of the crop.

The size and configuration of the trap-crop area usually is not based on the size of the cash-crop area but on the number of pests expected. A small trap-crop area that is quickly destroyed will not give satisfactory results. If enough land is available, it is better to have a trap-crop area that is too large rather than one that is too small. Some trap crops are planted within the field of the cash crop. Another approach, called *perimeter trap cropping*, involves planting at least two rows of the trap crop around the entire perimeter of the cash crop. An approach to trap cropping that improves efficacy is to combine it with other tactics. For example, with a *push-pull approach,* a trap crop is used to pull the pest species away while the protected cash crop is intercropped with a plant that repels pests. This approach has been used successfully to protect maize in Kenya.

Trap cropping was originally designed to be used in conjunction with a highly effective insecticide to kill pest species in the trap crop. In organic systems, however, there are few allowable insecticides, so it is important to know if there are allowable insecticides that are effective and economical to use against the expected target pest, or that the trap crop is destroyed before the target insect moves onto the cash crop. Correct timing of crop destruction is important: Destroying the trap crop either too early or too late can have negative consequences. In addition, any beneficial insects colonizing the trap crop will also be destroyed.

Knowledge and record-keeping can help improve the performance of trap cropping. For example, one approach may be to plant a small area of the cash crop very early so it can reach an attractive physiological stage *before* the primary planting. Variations in growing conditions (for example, if conditions are too dry or too cold) can change the timing of physiological stages so that it is possible to end up with both crops in the same physiological stage. Keeping good records of weather conditions and performance of the trap crop and the cash crop will help in developing pest management systems.

PHEROMONES AND OTHER ATTRACTANTS

Insects are very small creatures in a very large world. They have evolved many different ways of finding each other to mate. Some insects can make a sound as loud as a chainsaw; others have striking colors. Many insects find each other over long distances by emitting chemical signals or *pheromones* to attract individuals of the same species into an area so they can find each other to mate. Once the individuals get close together, visual cues—such as color, shape, and behavior—become more important. Entomologists have determined the chemical structure of pheromones for many pest species and duplicated them synthetically.

Insects also use other chemical messages. Chemical cues to the location of food can draw insects into a particular area where, once they get close enough, visual and tactile cues lead them to food sources.

Pheromones and other chemical attractants can be used in several different ways: to monitor pests, disrupt mating, capture a large number of adults (called *mass trapping*), distribute an insect pathogen or or lure pests to consume poisoned bait. Any trap baited with an attractant must be used carefully. Some research has demonstrated that a trap can bring more pests into an agroecosystem than it kills.

Figure 2. Pheromone traps often have a characteristic triangular shape. (Photo courtesy of www.insectimages.org.)

Chemicals that trick pest insects to expect food or mates can be very effective at attracting insects from long distances. The primary use of these chemicals has been to monitor pest activity. New traps and baits, however, are showing the potential to reduce pest abundance directly.

Using Pheromones to Monitor Insect Populations

Monitoring insect pests is one of the most effectives uses for pheromones. They can be used to detect the first arrival of a pest insect species or an increase or decrease in populations. Attractants are used in several different types of traps (including sticky, wire, mesh, pan, and water traps) that all work on the same basic principle: Attract insects to the trap where they can be captured and counted. Because each trapping location is unique and the patchwork of crops and noncropland shifts yearly, interpreting the importance of the arrival time or the number of insects trapped comes with experience.

Often the peak number of insects counted is less important than the length of time they are present. Most pheromone traps attract males, which are indirect indicators of potential pest problems. Also, when females are in the area, they can be more successful than traps at attracting the males. For the right species, however, and with experience, pheromone traps can be effective and inexpensive monitoring tools.

Using Pheromones to Disrupt Mating

Mating disruption works by permeating the crop environment with a chemical message that prevents pest insect adults from locating each other to mate. The logic of using pheromones to disrupt mating is simple: If enough males can be confused so they cannot find mates, then almost all females are unmated and fewer immature insects will result. Because there are fewer immature insects, crop damage is minimized or eliminated. In some cases this approach has worked well.

Like most control measures based upon insect behavior, however, successful disruption of insect mating requires an understanding of some basic concepts. For example, pheromones emit a plume of chemical carried on the prevailing wind. During the course of the mating season, wind shifts and eddies will distribute the pheromone over a wide area. Males detect this plume and follow it into the area where the pheromone is located. This plume can be carried a long distance and may actually attract males that otherwise would not be in the immediate area. If the number of males in the vicinity is increased, then the net effect may be to increase the number of mating males.

Concentrated applications of pheromone are generally used for this method. The probability of success increases if more pheromone is used and the release rate (frequency) is stepped up. This approach can give results equal to or better than conventional insecticides. Instructions from the supplier should be followed carefully.

Mating disruption is not foolproof, and it is important to understand when it may not be useful. Pheromones are specific to each pest species and are only effective for insects that find mates over long distances. Insects that use visual cues to find mates will not be good candidates for mating disruption.

Also, the use of pheromones is usually an expensive option. Another concern is that previously mated females can fly into the protected area and cause economic damage. For high value crops, the offspring of a few mated females can cause a large amount of crop damage. So it is wise to consider the area surrounding the crop of interest to determine if it is hospitable to the pest species.

Very high populations of pest insects may not respond to mating disruption with pheromones if they are able to respond to visual cues from their close proximity to each other. If no other control choice is available, then it may be necessary to try mating disruption. For a complete discussion of pheromones, see this Web site: http://ipmworld.umn.edu/chapters/flint.htm

Using Pheromones for Mass Trapping

Pheromones can be so powerful that many or most of the adults insects in an area can be trapped and killed. It is easy to conclude that so many are caught that the number remaining cannot cause substantial crop loss. Insects, however, can mate repeatedly. So the remaining males will usually be sufficient to keep pest populations at economically damaging levels. Studies have demonstrated that more than 95 percent of the males must be destroyed before populations decline. Achieving this level of destruction is not practical for most farmers.

BIOLOGICAL CONTROL USING INSECT PATHOGENS

Insects have many types of natural enemies. As with other organisms, insects can become infected with disease-causing organisms called *pathogens*. Soil serves as a natural home and reservoir for many kinds of insect pathogens, including viruses, bacteria, protozoa, fungi, and nematodes. Pest control products based on insect pathogens are available commercially, and some products are allowed in organic production. As with all pest control products, it is critical to determine if the specific insect-pathogen-based product that you want to use is allowed by your certifier.

Insect-Parastic Nematodes

Traditionally, soil-inhabiting insect pests have been managed by the application of pesticides to the soil. Interest in biological control to manage crop pests has increased because of concerns about the economic, environmental, and health costs of chemical crop protection and because of the need to develop production systems that are environmentally and economically sustainable.

Insect-parasitic nematodes show promise as biological control agents for soil pests. Nematodes are microscopic, whitish to transparent, unsegmented round worms. Nematodes in the families Steinernematidae and Heterorhabditdae have been studied extensively as biological control agents for soil-dwelling insects. These nematodes occur naturally in soil and possess a durable and motile infective stage that can actively seek out and infect a broad range of insects. They do not infect birds or mammals. Because of these attributes, as well as their ease of mass production and exemption from EPA registration, a number of commercial enterprises produce insect-parasitic nematodes as biological "insecticides."

Figure 3. Tiny worm-like *Heterorhabditis* nematodes have killed this wax moth caterpillar. (Photo courtesy of www.insectimages.org.)

Life Cycle. The infective third-stage (sometimes referred to as the *dauer* or *IJ stage*) is the only life stage wherein the nematode exists outside of the host insect. This is the stage that is available as a commercial product.

Upon locating a suitable insect host, the infective juvenile enters the insect through natural openings (the anus, spiracles, and mouth) and penetrates the insect body cavity. The nematodes develop and reproduce in the infected insect. Two to three generations occur in the insect cadaver.

As resources are depleted and crowding occurs, infective juveniles (IJ) are produced. The IJ emerge from the cadaver to search for new hosts. The reproductive potential of insect-parasitic nematodes is very high: Thousands of nematodes can be produced from a single mated pair. The time from infective juvenile to infective juvenile takes about two weeks in the laboratory. Under natural conditions, the recycling time will vary depending on environmental conditions and the susceptibility of the host insect.

Application. Some nematodes that are commercially available are *Steinernema carpocapsae, S. feltiae, S. riobrave, Heterorhabditis bacteriophora,* and *H. megidis*. Treatment with these nematodes can be expensive, and they are most commonly used for managing soil insect pests in high-value crops, such as turf, nurseries, citrus, cranberries, and mushrooms, as well as in home lawns and gardens. As production technologies improve, however, the cost of using nematodes is falling, and it may be economical to use them in lower value crops.

The efficacy of nematodes in the field can be variable. Their successful use probably depends on favorable environmental conditions — adequate moisture, temperatures within the tolerance levels for the nematode, and protection from ultraviolet radiation during application.

Nematodes are very sensitive to destruction by bright sunlight and to desiccation if they are applied to plant foliage. This limits their use mainly to soil, although there are some instances where they have been successfully applied above-ground to insect tunnels or mines in plant tissue.

Nematodes are formulated as suspensions in liquid, on sponge, in gels, or as semi-dry granules. The main application approach is as suspension in water at a typical rate of 1 billion per acre, but this rate varies depending on the crop. They can be applied with conventional chemical application equipment, but screens in nozzles should be removed when applying nematodes with a back-pack sprayer or spray rig. Nematodes tend to settle in the tank, so agitation must be provided for uniform application. Nematodes can also be applied with irrigation. However, some irrigation systems, especially low-volume trickle systems, may not move water fast enough to keep nematodes suspended. When in doubt, check periodically by taking a sample at the emitters to determine if live nematodes are being moved through the system.

Conserving Nematodes. Insect-parasitic nematodes occur worldwide, and they have been found throughout the U.S. in many different soil types and habitats, both natural and managed. We do not yet know what level of natural insect control these nematodes exert, or how to predictably increase the levels of natural control to an economic level of control. Native nematodes may play an important role in regulating insect populations in some farm systems, but the level of disturbance in agricultural systems may require the use of non-native nematodes that are tolerant to the farming practices being used.

Some studies suggest that insect-parastic nematodes are more abundant in less disturbed systems, such as orchards or pastures, and in minimum- or no-till plots than in conventionally tilled plots. Different nematode species are differentially tolerant to soil disturbance. Survival of insect-parasitic nematodes is higher in mulched soil than in bare soil, probably because of differences in soil physical structure, temperature, and moisture.

Research to determine the effects of pesticides on insect-parasitic nematodes has shown that some pesticides and fertilizers are less harmful to nematodes than others. Compatibility with pest and fertility management materials is usually provided on the product labels or packaging information that accompanies purchased nematodes.

Efficacy of Treatment with Nematodes.

To date, the level of control achieved by applying nematodes has varied, with some failures and some successes. The successes have occurred mostly in simplified, controlled systems such as nursery containers. The efficacy of nematodes is affected by environmental conditions: They need adequate but not excessive moisture, temperatures within the tolerance levels for the particular nematode, and protection from UV radiation during application (apply early in the morning or in the evening). Some research has indicated that the type of plant an insect eats can affect its susceptibility to infection by insect-parasitic nematodes and other types of pathogens.

Nematode species and target insect. Most failures in the effectiveness of field applications are related to a poor match between the nematode species and target insect. Species of nematodes vary in their host range and in their host-finding behavior. Some nematodes—*Heterorhabditis bacteriophora,* for example—are very active in the soil and search a relatively large area for a host insect, whereas others—*Steinernema carpocapsae,* for example—are relatively sedentary and tend to wait for a host insect to pass by in close proximity. A nematode that is an active searcher will be more effective than a sedentary nematode at finding a sedentary insect host, such as a white grub. The relatively sedentary nematodes are effective at infecting active insect hosts, such as cutworms or mole crickets. Some appropriate nematode host targets are known:

- *S. scapterisci* against mole crickets;
- *S. carpocapsae* against cutworms and other mobile caterpillar pests;
- *S. riobrave* against cutworms and other noctuid larvae and pupae and citrus weevils;
- *S. feltiae* against sawfly larvae and fungus gnat maggots; and
- *H. bacteriophora* against white grubs and other sedentary soil-dwelling beetle larvae.

Product viability. As with any purchased natural enemy, product quality can affect efficacy. The viability of the product can vary by batch and can be affected by shipping, storage, and application conditions. Nematodes are living organisms that are subject to destruction by excessive cold or heat and lack of moisture or oxygen. A small sample of the mixed product should be checked with a magnifying lens to observe viable, moving nematodes.

For additional information about using nematodes as pest management tools, see www2.oardc.ohio-state.edu/nematodes — *Insect Parasitic Nematodes: Tools for Pest Management*. This SARE-funded Web site has information on the biology and ecology of insect-parasitic nematodes, instructions on application, a publications database, an "Ask the Expert" advice service, a list of retail suppliers, and links to other sites with information about insect-parasitic nematodes.

Insect-Parasitic Fungi

Fungi are a diverse group of organisms with close ties to agriculture. Some fungi are used successfully to protect crops from a variety of insect pests. Most fungi can cause natural outbreaks when environmental conditions are favorable. Several species have been developed as commercial products because of their ability to be mass-produced. Specific fungal strains in commercial products target thrips, whiteflies, aphids, caterpillars, weevils, grasshoppers, ants, Colorado potato beetles, and mealybugs. Currently (2008), allowable products containing the fungus *Beauveria bassiana* that are commercially available include Mycotrol O (Emerald BioAgriculture), Naturalis H&G, and Naturalis L (Troy BioSciences Inc.). Before applying any pest control product, make sure that it is currently allowable by the NOP and your certifier.

Life-cycle. Fungi that infect insects are found in the environment as spores. Insects can become infected when they come into contact with spores on the surface of plants, in the soil, in the air as windborne particles, or on the bodies of already dead insects. Spores attach to the surface of the insect and infect by penetrating through the insect cuticle, often at joints or creases where the insect’s protective covering is thinner. Once inside, the fungus grows throughout the insect’s body. Many fungi also produce toxins in the host that increase the speed of kill or prevent competition from other microbes.

Usually after the insect has died, the fungus grows out through the outer covering (exoskeleton) of the insect, usually at thinner areas like joints or creases, and begins to produce spores. The spores of commercially developed fungi are spread passively by wind, rain, or contact with other hosts or animals in the environment. Insects killed by fungi often have a “fuzzy” appearance caused by the growth of the fungus out of the exoskeleton. Most commercial strains of fungi produce spores that are either white or green, although the color of the fungi can change over time as the fungus grows and ages.

Spores that do not encounter a host either die or persist in sheltered areas of crop plants or in the soil. Although some species of fungi produce spores that can persist for years in the soil, most spores are viable only for a growing season or at most a year.

Advantages. Fungi make good insect control agents for a variety of reasons. They generally do not affect people or other mammals, making them extremely safe to use. It is relatively easy to mass-produce spores of some insect-parasitic fungi, so they are comparably priced with other biological control agents, such as bacteria. Most commercial fungal products are formulated as spores, which are easily adapted to existing application technology, such as spray rigs. The relatively broad host range of many fungi means one can often achieve control of multiple pests with the same product. Finally, successful infections can spread to other hosts and lead to high rates of persistence within a growing season, even if between-season persistence tends to be low for most types of fungi.

Challenges. There are some challenges to the effective use of insect-parasitic fungi to control pests. High concentrations of spores are often needed to get adequate control of pests in a crop, which can cut down on the cost effectiveness of fungal products. The kill time is relatively long (more or less a week for most fungi), although strains used for commercial products are chosen to kill as fast as possible. Their broad host range can sometimes be a problem, especially if beneficial insects (for example, predators, parasitoids, and pollinators) are present in a crop. Nontarget mortality in these populations of beneficial insects can negatively impact the success of the overall biological control program.

Environmental factors can also play an important role in the success of fungi. Moist conditions or high relative humidity in the crop canopy are often necessary for control to be effective. Prolonged exposure to sunlight can also inactivate spores, reducing persistence in the crop. Owing to these environmental limitations, natural outbreaks of fungi tend to be sporadic and very patchy in the environment, which can limit their effectiveness in controlling pests.

Application. As with all biological control agents, fungi work best as one component of a multi-tactic IPM program. Farmers can use several tactics to increase fungi effectiveness, especially of commercial products:

- Scout consistently and often. Apply only when the target pest is present, not as a preventive application as residues are not long-lasting. The best time to apply fungi is before pest populations reach their peak, so early application can increase their effectiveness. Also, scouting can help determine the population levels of beneficial insects and pollinators so the timing of fungal applications will not impact them as strongly. Finally, scouting can help discover natural outbreaks of fungi (for example, aphid fungi) in time to influence control decisions.
- Time applications of fungi to coincide with a target pest's life stages so that pests are more likely to come in contact with the spores. In general, *B. bassiana* products are more effective against earlier than later stages of insects. For example, applying a fungal product for grasshoppers will be most effective when there are active nymphs present that have not grown into winged adults.
- Do not apply fungal products during droughts or dry spells because these environmental conditions will decrease their effectiveness.
- Be aware of fungicide applications in the area. Even if fungicides are not directly applied to the crop, drift from nearby fields could impact the success of a fungal biological control agent.
- Apply fungal inoculum carefully to get effective coverage. Cover all plants thoroughly. Also try to reduce spillover into refuge areas where natural enemies may be present.
- Do not apply fungal products during the heat of the day because this will diminish the potency of the spores. There have been some reports of phytotoxicity to young vegetable transplants with products formulated as an emulsifiable suspension. Also, do not apply on rainy days, when spores will be washed from plant surfaces and may not come into contact with the target pest.
- Use cropping practices that encourage a diverse understory and soil surface, such as cover cropping or conservation tillage. These practices will help maintain fungi in the field and could increase persistence within and between seasons.

Insect-Parasitic Viruses

Insect viruses are obligate disease-causing organisms that can only reproduce within a host insect. They can provide safe, effective, and sustainable control of a variety of insect pests, although they are most effective as part of a diverse IPM program. Some viruses are produced as commercial products, most notably for fruit pests, but many others are naturally occurring and can initiate outbreaks without additional inputs.

Commercially available insect viruses that are allowed in organic production can be found at the National Organic Program's Web site (see the list of online references on page x). All are highly specific in their host range, usually limited to a single type of insect. These currently (2008) include

- Gemstar LC (Certis USA), a nuclear polyhedrosis virus of *Heliothis and Helicoverpa* spp. (corn earworm, tobacco budworm);
- Spod-X LC (Certis USA), a nuclear polyhedrosis virus of *Spodoptera* spp. (beet armyworm);
- CYD-X (Certis USA) and Virosoft CP4 (BioTEPP, Inc.), granulosis virus of *Cydia pomonella*, the codling moth; and
- CLV LC (Certis USA), a nuclear polyhedrosis virus of *Anagrapha falcipera*, the celery looper.

Life Cycle. Insect virus particles are usually found on the surface of plants or in the soil. Insects become infected when they consume plant material with viral particles on the surface, although some pests of low-growing plants can be infected by contact with the soil.

Virus infection begins in the insect's digestive system but spreads throughout the whole body of the host in fatal infections. The body tissues of virus-killed insects are almost completely converted into virus particles. Infected insects often look normal until just prior to death, when they tend to darken in color and behave sluggishly. They often develop more slowly than uninfected individuals.

Most virus-infected insects die attached to the plant on which they feed. Virus-killed insects break open and spill virus particles into the environment. These particles can infect new insect hosts. Because their internal tissues are destroyed, dead insects often look "melted". The contents of a dead insect can range from milky-white to dark-brown or black.

While natural virus outbreaks tend to be localized, virus particles can spread via the movement of infected insects; the movement of predators, such as other insects or birds that come into contact with infected insects; or nonbiological factors, such as water runoff, rain-splash, or air-borne soil particles. Many virus-infected insects also climb to higher positions on their host plant before they die, which maximizes the spread of virus particles after the insect dies and disintegrates.

The number of virus infection cycles within a growing season depends heavily on the insect's life cycle. Insect pests with multiple generations per season or longer life cycles can be more heavily impacted by virus outbreaks because a greater opportunity exists for multiple virus infection cycles within a growing season.

Advantages. Using viruses to control insect pests has many advantages. Insect viruses are unable to infect mammals, including humans, which makes them very safe to handle. Most insect viruses are relatively specific, so the risk of nontarget effects on beneficial insects is very low. Many viruses occur naturally and may already be present in the environment. Even in cases where they are applied, successful infections can perpetuate the disease outbreak making repeat applications within a season unnecessary.

Challenges. A disadvantage of using viruses to control insects is their relatively slow kill time. Most insect viruses take several days to kill their host insect, during which the pest is still causing damage. Insect death is also dose-dependent, and very high doses are often necessary for adequate control. As insects age, they can become less susceptible to virus infection, so viruses are usually only effective against early larval life stages.

Although viruses can persist in the environment for months or years, exposed virus particles, such as those on plant surfaces, are quickly inactivated by direct sunlight or high temperatures, which can limit their persistence within a given season. Also, some agricultural practices can reduce persistence between seasons, such as tillage, which buries virus particles in the soil.

Application. Viruses are usually not "stand-alone" solutions to an insect pest problem, but are most effective in conjunction with other management strategies. Although there are not many commercial products available for organic growers in the United States now, several are being developed and may become available in the near future.

If there is a viral product available, the grower can do several things to increase effectiveness:

- Insect viruses are fairly specific, be sure that the target pest is correctly identified.
- Carefully scout fields before application and apply a virus when the target pests are young but actively feeding. Scouting can also help you discover natural viral or other disease outbreaks developing in your crop, which, depending on their extent, could influence other control decisions.
- Apply the virus to maximize the longevity and effectiveness of its particles:
    1. Thoroughly coat plants to maximize coverage. Young plants can even be dipped in a solution of virus particles to completely cover the leaf area.
    2. Apply in the morning or evening or on cloudy days when degradation from sunlight is reduced.
    3. Avoid applying on rainy days, as rain will wash virus particles off the leaf surfaces.
    4. Use formulations with ultraviolet (UV) light blockers and sticking agents to increase longevity. Check carefully to make sure these formulations comply with organic standards.
- Use mixed cropping, and reduce soil disturbance after application. These help increase the persistence of virus particles in the system and may lead to better control within and between growing seasons.

Insect-Pathogenic Bacteria

Many insect diseases are caused by bacteria. The most commonly used bacterial product available to organic growers is *Bacillus thuringiensis* (Bt). This bacterium produces an insecticidal protein that provides effective control for many pest insects and has very little effect on nontarget insects and natural enemies. Because Bt products are applied like insecticides, it will be discussed in the section on insecticides in this publication. Not all formulations of Bt are allowable in organic production, so it is important to check with your certifier before purchasing or using Bt.

BIOLOGICAL CONTROL USING INSECT NATURAL ENEMIES

The frequency and severity of insect pest problems depends on the biological and physical characteristics of the agroecosystem, which is composed of both managed crop areas and unmanaged areas, such as hedgerows. An important component of the biological environment is natural enemies or beneficials—the predators and parasitoids that dampen pest insect populations. Organic farmers often assume that withholding conventional pesticides will have a beneficial effect on population levels of species that weaken and kill pest insects. The absence of conventional pesticides will likely encourage the natural enemies of pest insects. But that encouragement may not be enough to provide substantive control of chronic pests without additional changes in the agroecosystem, which provide habitat for the pests *and* their natural enemies.

Entomologists have different theories about the complexity of agroecosystems and whether diverse or simple agroecosystems are better at enhancing pest insect biological control (Bugg and Pickett 1998). Generally, however, they agree that simplified environments, such as *monocultures* that consist of a single crop, foster more pest problems. In contrast, a diversified plant environment buffers pest problems by re-allocating insect populations to larger areas and encouraging natural control. This means that the plants growing both inside and outside of cultivated areas must be considered when designing a system to suppress pests.

Recent research on organic farms shows that predation and parasitism of pest insect eggs, without any augmentation by the farmer, could be as high as 85 percent. It appears that plant diversity on the farm and the absence of conventional pesticides contribute to the provision of a suitable habitat for beneficial insects. That is the good news. The bad news is this: Even high levels of natural control may not be enough to prevent economic damage from insects that directly attack fruiting plants. Simple concepts about biological control should be re-examined in the light of new information. For example, predator species (such as ladybird beetles) are often credited with a great deal of biological control. There is little doubt that they do contribute significantly. Research has indicated, however, that in many cases, much of the natural control is actually provided by tiny parasitoids that work in relative obscurity.

Figure 4. Parasitoids such as this braconid wasp laying its eggs into a caterpillar are important contributors to insect pest management. (Photo courtesy of USDA.)

Natural systems behave in unpredictable ways, and biological control using predators and parasitoids is a complex undertaking. The complicated interactions are not easily understood, and directing them in a particular way is even more difficult.

Natural Enemies: Their Survival Needs

As a first step, it is necessary to understand that beneficials need year-round habitat and certain resources for survival.

Nectar from Flowers or Extra-floral Nectaries. Adult parasitoids feed on and often depend upon nectar to help them mature. Studies have shown that longevity and *fecundity* (the number of eggs laid per female) increase when suitable nectar sources are available. This can have a profound effect on parasitism rates and control of pest species. Not many plant species have extra-floral nectaries. Cotton and bachelor buttons are examples of species that do. Flowering plants have a limited time during which nectar is available, which can make it difficult or impossible for a beneficial insect to use the nectar. So careful planning is needed to provide this resource. Pest species, especially moths and butterflies, will also make use of nectar sources, which will extend their life, improve their fecundity, and perhaps make pest problems worse.

Pollen. Adult beneficial insects often use pollen as a food source. For example, adult hoverflies use pollen and may need it to mature eggs and produce their young, which are aphid predators. Some predatory insects are able to complete their life cycle entirely on supplementary food.

Alternate (Nonhost) Prey. Providing a constant source of food will slow emigration of beneficial insects and keep them at high population levels.

Refugia. This is a noncrop area where beneficial insects are provided with micro-habitats that contribute to their survival and persistence. Beneficial insects have enemies, too. They need a place to hide when they are not searching for prey. This area should also provide overwintering habitat.

Diversity. In general, the more plant-rich an area is, the more likely natural control will work. But some insect natural enemies are more effective in grass or legume monocultures than in a grass-and-legume mixture, so plant diversity does not universally encourage natural control.

No one can provide a blueprint for building a workable system of natural insect control on a specific farm. Many different ways of conserving beneficial insects have been tested: managing soil, water, and crop residue; varying cropping patterns and noncrop areas; and growing plants that attract beneficial species. All of these approaches may have benefits and drawbacks, and making changes can be a challenging endeavor because other activities within the agroecosystem can conflict with efforts to conserve beneficial insects. For example, cover crops are grown for many reasons — to add organic matter to soil, provide supplemental nutrients, and prevent soil erosion. The timing of planting, species selection, and many other decisions that would be best for these purposes may *not* be best for providing beneficial insect habitat. Some compromises may have to be made.

When considering strategies to enhance biological control, it may be helpful to look at them in two categories:

- Conservation. These techniques *conserve* naturally occurring beneficial species.
- Augmentation. These techniques *augment* or supplement the actions of naturally occurring beneficial species.

For more information about biological control using insect predators and parasitoids, see Pickett and Bugg, 1998; Barbosa, 1998; or Landis et al. 2000 in the "Recommended Reading" list at the end of this chapter. An extensive discussion can be found at these Web sites:

- Michigan State University site: http://ipm.msu.edu/natural-enemies.htm.
- Cornell University site: www.nysaes.cornell.edu/ent/biocontrol

Conserving Natural Enemies

Conservation biological control involves managing crops and surrounding vegetation in a manner that encourages natural enemies and their negative impacts on pest species. This involves identifying anything that suppresses the natural enemies and modifying agricultural fields and surrounding vegetation to provide habitats for them. Manipulation of habitats extends to both crop and noncrop areas. In the crop area, *intercropping* can enhance biological control.

Intercropping. Keeping beneficial insects in and around annual crops may be achieved by intercropping, which involves placing a crop plant and another plant within close proximity to promote insect interaction. It is one part of a comprehensive conservation plan to manipulate habitats in ways that enhance natural control. The resources provided to natural enemies include pollen, nectar, alternate prey or hosts. These resources can considerably enhance biological control. Because annual crops are interrupted seasonally, they are not a *continuous* habitat. Therefore, survival of a pest insect's natural enemies depends on their success in finding the other habitat and prey they need to survive. When annual crops are planted, beneficial insects must discover and invade the new crop. Unfortunately, beneficials are usually slower to recolonize than pest species. Intercropping provides a way to keep the beneficials close to crops and to provide them with consistent sources of food and shelter.

Many organic farms are already intercropped to maximize land use and to suppress weeds. *Polycultures*—diversely planted crop areas—are common in tropical countries, but they are used very little in conventional agriculture in the United States because they do not fit well with mechanization. Some research information is available on how a polyculture affects insect pests and their natural enemies. Proponents of polyculture cite the concept of *diverse stability* as the basic ecological theory for this approach: Diverse habitats are considered more stable, so pest outbreaks are dampened. The thinking that underlies this concept is this: If an agricultural system can mimic a natural system with many different plants (and many *trophic levels* or levels of food web relationships among organisms), it will be better able to resist pests.

Why Use Intercropping?

The intercropping system should relay or transport predators and parasitoids from crop to crop. The purpose is to present a continuous, attractive habitat for beneficial insects.

Intercropping challenges. Several problems exist with the intercropping scenario. First, pest population levels in a polyculture may stabilize, but at a level above the economic threshold for the crop. Second, the evolution of insect interactions cannot be oversimplified in this manner. For example, many natural systems are functionally monocultures. So the dampening mechanisms that evolved under these conditions should operate best in monocultures. It is more realistic to assume that some natural control agents are more effective in monocultures and that some are more effective in polycultures. These reservations are not presented as arguments against polycultures but as a warning: Diverse agroecosystems must be carefully planned if the farmer's objective is to maximize natural control of insects.

Few guidelines have been developed to aid in the process of designing an intercropped system. Research on the effect of intercropping on insect natural enemies is very difficult due to the complexity of the work. For example, fewer pest species in a polyculture could mean there are more predators and parasitoids, or that the crop is less attractive or less nutritious due to plant competition, or a combination of all of these. Uncoupling the impact of intercropping from the effects of surrounding vegetation (such as woods and field margins) and unraveling the operating mechanisms are difficult tasks. Nevertheless, some studies indicate that polycultures may be an effective way to diversify agroecosystems.

As a general rule, polycultures are a positive step toward pest control *if* carefully planned. For example, certain plants can serve as reservoirs for pest insects, such as thrips or stink bugs. Observations from organic farms, however, indicate that this tactic is successful enough that intercropping should be tried to determine possible benefits. The benefits and problems associated with this strategy are very sitespecific. The pest situation, plant combinations, weather, and other factors make the final outcome of this approach unpredictable.

Intercropping design considerations. Polycultures are often thought of as a crop-to-crop combination (for example, beans and corn). But they can also include natural-vegetation-crop and living-mulch-crop mixtures. Some common objectives should be considered when designing a polyculture:

- The intercropping system should *rela*y or move predators and parasitoids from crop to crop.
- Its purpose is to present a continuous, attractive habitat for beneficial insects. This habitat rotation includes the crop needing protection. It will likely involve planting the relay crops very early, growing cover crops in the winter to maintain beneficial insects, or both. As one crop begins to *senesce* or age, predators and parasitoids can exploit new crop habitats.
- Crop relaying should continue throughout the year.
- The plant combinations are important. Different plants will support different sizes of insect populations. So a weed-corn intercrop will not have the same insect populations as a bean-corn system.

Often, all of the requirements for intercropping can be met simply by incorporating native vegetation strips within cropping systems. Keeping the plants mowed at specific times can encourage beneficial insects to migrate to crop plants. This is an easy and inexpensive way to try intercropping to attract and conserve beneficials. Weedy species, however, are likely to dominate for three to four years. And many growers are not enthusiastic about encouraging weeds because another function of intercropping is to suppress weeds. In this case, *relay cropping* will have to be used. Using this approach, an intercrop is planted in strips among the crop of interest so that when it senesces or is mowed, the crop of interest will be able to support natural control agents. This relaying continues throughout the year. Relay cropping can also include planting into living mulches that naturally die in time (such as cereal rye or vetch).

The questions to ask when considering intercropping are, "What plants?" and "When should they be planted?" Because there are many possible answers, the most prudent plan is to introduce different species one at a time and judge the impact before moving to more complex plant communities.

Cover Crops. Cover crops are usually planted to sequester soil nutrients, add organic matter to the soil, prevent erosion, and add nutrients. Cover crops can also provide food and habitat for beneficial insects. Insect natural enemies need food and shelter during the winter, and keeping them close to current or planned crops may help protect newly planted crops. Cover crops can increase the overall number of beneficial insects, and beneficials can move from dying winter cover crops to spring-planted crops to provide some pest suppression. However, the kind of cover crop (whether it is crimson clover, cereal rye, vetch, or some other cover) appears to be important. Moreover, an increase in beneficial insects does not always translate into a general decrease in pest species or an increase in yield. Each cover crop provides different resources and habitats that may encourage some species and not others. Most often, cover crops are selected for agronomic characteristics and their ability to suppress weeds. Their influence on insect natural enemies should be a part of the evaluation process when deciding on specific crops.

The success of cover crops in preserving or encouraging beneficial insects depends in large part on how the cover crop is going to be destroyed or suppressed so that crops can be planted. The frequency and intensity of disturbance is important to the stability of populations of pests and their natural enemies. A cover crop that can be allowed to die naturally so that beneficials have time to find other habitat is preferable to a cover crop that must be managed all at once. Mowing a cover crop will have less effect on pest and beneficial populations than disking or plowing. Whether the cover is destroyed all at once or in stages is another factor that influences the preservation of beneficials. Mowing a cover crop to encourage beneficials to change habitat before disking will lessen mortality.

Field Borders and Hedgerows. Field borders and hedgerows represent an important component of the whole *mosaic* or combination of habitats occupied by beneficial insects. It is unlikely that all the survival needs of beneficials will be met within field borders. Many beneficials will spend part of their time in field borders or hedgerows. These areas also serve as corridors that beneficials use to move from one field to another. Some consideration of all these areas is needed to develop a complete plan for encouraging natural control.

Plants in hedgerows usually consist of natural vegetation that, as much as practical, should be preserved. Field borders, depending on how they are managed, usually consist of annual plants. The natural complex of annual plants may provide the habitat and resources needed by beneficial insects. Certain practices can help to maintain a desired mix of plants. For example, mowing at a particular time interval or height will stop the natural process of succession to woody perennial vegetation. Some plans for maintaining plant mixtures should be made. Too often, borders are left unattended until there is time to mow them. Some pest problems, such as mites, can be spread by waiting until midsummer to mow. Gather all the information that is available about maintaining field borders before deciding on a maintenance schedule.

Arranging Crops. The physical arrangement of crops in an area may affect biological control. Beneficial insects often occupy the ground under plants and the foliage. Tall-growing plants may afford little cover or moisture for ground-dwelling beneficials. Similarly, foliage-dwelling beneficials spend little time on the ground. Short crops intercropped with taller crops may encourage more interaction between these two groups and result in more robust natural control.

Augmenting Natural Enemies

Some insects that are natural enemies of pests are produced and sold as pest treatments. For organic pest management, this may be an important way to suppress damaging insects. Obtaining the best possible outcome depends on understanding how to develop a successful biological control program.

Augmentation involves adding something to an agroecosystem to regulate pest population densities. It usually involves either mass production of beneficials or genetic enhancement to improve their ability to survive negative influences. The most common example of augmentation is purchasing commercially available predators or parasitoids for release into greenhouses or commercial crop fields. If the natural enemy is released in large numbers (tens of thousands to hundreds of thousands), it is called an *inundative release*. If a few are released (hundreds to thousands) with the expectation they will reproduce and increase in number, then it is called an *inoculative* release.

Augmentation of natural enemies is probably the most widely recognized form of biological control. Commercial use of natural enemies is most developed in Europe, where farmers commonly release natural enemies in orchards, vineyards, and vegetable crops to manage pest species. Many farmers recognize that lady beetles are "good bugs" that eat "bad bugs" and purchase them for natural control of aphids. Many suppliers of beneficial arthropods in the U.S. market predatory mites, greenhouse parasitoids and predators, and general predators. For example, the trichogramma wasp, a parasitoid of insect eggs, is the most widely produced and released arthropod used for augmentative biological control in commercial settings. These parasitoids are easy to rear, and they kill pest eggs before the hatched insects can cause injury. Trichogramma are commonly used in inundative releases.

Careful planning is critical to the success of a natural enemies release program. There are three important considerations when using natural enemies:

- The natural enemy selected should be correct for the specific situation and specific pest.
- The quality or viability of the product purchased should be adequate.
- The timing and rate of application should be correct.

Figure 5. Releasing predators and parasitoids into greenhouse vegetable crops for pest management is a common practice. (Photo by Matt Miller, Department of Entomology, N.C. State University.)

Purchasing Natural Enemies. *Buyer beware* is a good warning to remember when purchasing natural enemies. Dozens of suppliers market insect natural enemies. Some may want to sell products that are not wanted or needed. Some may not be able to provide the technical help that successful use of a biological control requires. Suppliers of biological controls should maintain professional standards, and a thorough scientific analysis should be required for any product.

When selecting a supplier, asking the kinds of questions suggested here may help identify those that are reputable and reliable:

- Does the company provide professional consulting services to set up an IPM program prior to selling natural enemies? This should include a thorough understanding of the pest situation and current crop management practices.
- Does the company provide detailed instructions on how to handle and apply the natural enemies before they arrive?
- Does the product arrive by overnight delivery in an insulated container that may contain a cold pack? This will protect natural enemies from temperature extremes, and prevent some natural enemies from emerging prior to arrival.

One important question to ask is this: Does the company provide any measure of the quality of the natural enemies received? This question involves several quality considerations:

- Does the company tell exactly what species will be shipped and who made the species determination? This determination should have been made by a recognized taxonomic expert, not necessarily someone at the company. The species name should be a double Latin name, for example: *Encarsia formosa*. If the name appeared as *Encarsia* sp., then the species may be unknown, and no one can be sure the product would work for a specific pest problem.
- How many natural enemeies are received? This should be presented as an average, plus or minus a range. With some natural enemies, only the female actually attacks the target pest. Find out if this is the case for any control agents being purchased and, if appropriate, be sure to find out the number of females being shipped.
- How vigorous is the material? For the batch of natural enemies from which a shipment is being made, it is fair to ask for measures of the average fecundity (number of eggs laid), life span, and sex ratio (percentage of females). In some cases, it may be important to have specific information. For example, some parasitic wasps, such as trichogramma wasps, can lose the ability to fly when reared for many generations in insectary cultures. When purchasing this beneficial, ask the supplier to provide the percentage of natural enemies with wings in the batch. Or, in the case of ladybeetles, ask the supplier to indicate the percentage in the batch that are parasitized. Some ladybeetles are simply scooped from overwintering sites, and a substantial portion may be parasitized and die before they do any good in the field. The supplier also should provide standard values taken from an independent article in a scientific journal so that a buyer can determine if the count or ratio provided is adequate and make informed comparisons.
- How many natural enemies will actually emerge alive once they are introduced into the crop? The supplier should provide a method for determining how many natural enemies actually emerge in the field. This can be very important because it is the only way to determine the actual rate of product applied.

- Does the company offer reasonable solutions for any difficulties encountered? Does it follow up to determine success or failure?

Names, addresses, and telephone numbers of suppliers can be obtained from these sources:

Bio Integral Resource Center
P.O. Box 7414
Berkeley, CA 94707
www.birc.org

Association of Natural Biocontrol Producers
www.anbp.org

Handling and Releasing Natural Enemies. A supplier should provide specific handling instructions prior to or at the time the natural enemy shipment arrives, and the instructions should be followed carefully. Many natural enemies are tiny insects and mites. They should be kept under relatively cool conditions (at room temperature) and out of direct sunlight. If the beneficials arrived in an insulated container, they should probably be kept there until time for release. Usually, the sooner the beneficials can be released after arrival, the better. For example, some predatory mites are shipped with a small food supply. Once that food is exhausted, they feed on one another or starve.

How many to release. Suppliers should provide detailed instructions regarding the application "rate" for the natural enemies supplied. Usually this is expressed as a number of natural enemies per given "unit," such as a number of natural enemies per infested leaf, plant, square-foot, or acre. The recommended rate should be followed very closely. Any questions that may arise regarding application numbers can be directed to the supplier.

Timing of releases or applications. The timing of natural enemy releases is critical to the success of biological control. Because natural enemies work better as preventives rather than as pest management cures, it is important to release them when pest infestations are just beginning. Sampling methods and materials for specific pests are often readily available from suppliers.

Some natural enemies are affected by the season, and they can be less effective as a result. The time of day of release can also be important. When the temperature is high during the middle of the day, natural enemies tend to be more active and may disperse or leave the area where released. Higher temperatures during the release can cause increased mortality of the beneficials, reducing the number available to attack pests. Other weather conditions, especially rain, may also have an impact on natural enemy survival during release. As a general rule, releases should be made in a cool part of the day (early or late), under favorable weather conditions, and at a time of year that the specific natural enemy finds favorable. Suppliers can and should provide this information.

If a reliable and knowledgeable supplier of natural enemies has been selected, then the quality of material received should be consistently high. However, some factors, such as shipping conditions, are out of a supplier's control. It may be helpful to work with suppliers to develop a quality-assurance protocol. The condition of the natural enemies when they are received can have a dramatic effect on the results.

Environmental conditions in the release area. Like all living organisms, natural enemies have specific requirements and limits for survival. The conditions present in the area where the natural enemies will be released should be considered before making a release. For example, some species of predatory mites will perform better under hot, dry conditions, whereas others will perform better under cool, humid conditions.

Light can also have a dramatic impact on natural enemies. For example, the mealy-bug destroyer beetle will slow or stop its reproduction, feeding, and growth if supplemental lighting is not sufficient in winter months. If releasing a mobile stage of a natural enemy (for example, adults that can fly) it may sometimes be advisable to cage the natural enemies on infested plants for a day or two to allow them to become accustomed to their new surroundings. The presence of pest insects will also encourage reproduction and reduce the likelihood that the beneficials will leave the area. In some cases, the presence of nectar-bearing plants or other food sources (such as aphid honeydew) may also encourage natural enemy populations.

Insecticide use may be the most important consideration when including natural enemies in a pest management program. Spraying for pests other than those being targeted by natural enemy releases may interfere with or eliminate the natural enemies. Care should be taken to avoid spraying materials harmful to natural enemies directly before, during, and after release. If spraying must be conducted, it is important to find out which pesticides have the least effect on natural enemies.

Encouraging natural enemies after their release. Following a release of natural enemies, it is extremely important to make sure that sufficient numbers have been established to control a pest problem. Scouting procedures used to monitor for pest populations can be modified to monitor natural enemy populations as well.

Evaluating Control Efforts with Natural Enemies

To determine the success of a biological control program, develop a strict set of conditions in the planning stage before the program starts. Program success will be easier to determine if there is at least one pair of treated versus untreated areas. Use natural enemies only in the treated plot(s). The untreated plot(s) should not receive natural enemies. The treated and untreated plots should be far enough apart to avoid dispersion of natural enemies from a treated to an untreated plot. The supplier can help determine how to do this.

Define what measurements to take in the plots. These are some examples of useful information:

- The density (number per plant or feet of row) of the damaging stage of the pest before and after treatment. Remember that natural enemies usually require time to be effective.
- The percentage of natural enemies that actually were released.
- The percentage of the target pest population that is parasitized (if the beneficial released was a parasitoid).
- The level of pest damage.
- The final yield.

Developing a Biological Control Plan: When Are Natural Enemy Releases Appropriate?

As with other pest management methods, the success or failure of biological control will be determined by the population levels of pests when natural enemies are applied. For example, if a pest population level is too high, the natural enemies released may not be able to act quickly enough to protect crops. In this case, an insecticide application may be needed prior to the introduction of natural enemies.

If, on the other hand, the pest population is very small, then naturally occurring enemies may already be present. Another approach to take in this case might be to treat only infested areas with insecticide, rather than spending the time and money to treat the entire crop.

Usually, natural enemies work best as a preventive pest management method. That is, they should be introduced into a crop before an economically damaging pest infestation begins.

If pests reach economically damaging levels before the release of natural enemies, successful control is not likely. This means that pest problems must be anticipated by carefully monitoring pest populations so that the response can be planned and timed correctly. Well-established monitoring or sampling and record-keeping methods have been developed for a wide variety of pest and crop situations.

INSECTICIDES

When nonchemical practices documented in the Organic System Plan are not sufficient to prevent or control populations of insect pests from rising above a level that is economically damaging, a biological or botanical material or a substance included on the national list of synthetic substances allowed for use in organic crop production may be applied to prevent, suppress, or control pests. *The National List of Allowed and Prohibited Substances* provides information on allowed and prohibited synthetic and nonsynthetic substances for organic crop and livestock production: http://www.ams.usda.gov/nop/NationalList/ListHome.html

A producer must know which organic pesticides are allowable, what materials are labeled for their crops, and the efficacy of those materials against the intended target pests. Pest control materials are classified as allowable, restricted, or prohibited for use in organic systems. To avoid the risk of losing organic certification, make certain you know if and under what circumstances the material that you are planning to use is allowed. Examples of types of materials that are currently allowed in organic production include allowable formulations of insecticidal soap, diatomaceous earth, potassium or sodium bicarbonate, spinosad, various microbials, bentonite and kaolinite particle films, plant extracts and oils, and pheromones. Some products with allowable active ingredients may contain unacceptable adjuvants, so it is important to check the label with your certifying agency before using a material.

Some types of materials that are restricted in organic production include dormant and summer oils (narrow-range petroleum, fish, and plant oils), sulfur compounds, copper compounds, and botanical pesticides. Examples of materials that are NOT allowed in organic production include: transgenic crops; synthetic insecticides and miticides, unless specifically allowed on the National List; heavy-metal-based pesticides, such as arsenates and lead; synthetic wetting agents; nicotine sulfate and other tobacco products; strychnine; and some botanicals.

The conditions for using the allowable material or substance must be documented in the Organic System Plan. The producer should have a plan for how and when they will react to an insect pest outbreak with an allowable substance. In all cases, if you have any questions as to whether a material is allowable or not, you should check with your organic certification agency to determine if specific materials are allowed, restricted, or prohibited in your organic system. Use of a nonallowed substance can result in the loss of certification and the need to re-transition the affected land for 36 months.

The decision to employ an insecticide in organic systems, even if it is an allowed material, is difficult for several reasons:

- Insecticides may disrupt a balance between beneficial and pest species, making the original problem worse or causing secondary pest outbreaks.
- Most organic insecticides are expensive to use.
- Insecticides represent a temporary solution. This is the most important consideration: Without more permanent interventions, the same species is likely to cause problems regularly.

Insecticides approved for use in organic systems can be less efficacious than insecticides available for use in nonorganic systems, so trying to determine if the control delivered is worth the cost can be a difficult decision. In many cases, the degree of success will be site specific. Usually only after an insecticide has been used several times under various conditions is it possible to reach a full appreciation of what a particular product will deliver. Before using any insecticide, a farmer should consider the following issues:

- Determine if the insecticide that you intend to use is allowable in organic systems. The use of some insecticides, even if allowed, is restricted. Check with your certifier to determine under what conditions the insecticide may be used.
- Consider the level of insect damage that is acceptable to your market. What is an unacceptable level of damage may differ in direct, wholesale, and retail markets.
- Total control may not be necessary. Just slowing the rate of pest population increase may be sufficient to allow natural control to provide suppression.
- Repeat applications may be necessary if total control is needed.
- Unusual pests may become more of a problem. Wide-spectrum insecticides often keep species other than the target pests under control. Narrow-spectrum biological insecticides may allow these other pests to flourish.
- Beneficial species can be negatively affected by organic insecticides.

In view of these issues, these use guidelines should be followed:

- Use insecticides selectively, as unintended effects can lead to using more insecticides.
- Use insecticides with the least negative consequences. For example, *Bacillus thuringiensis* insecticides, which are toxic to a relatively narrow range of pests, will have the potential to cause far fewer problems than products that are toxic to a broader range of pests.
- Use rates and application methods that correspond to the size of the crop plant. Small plants can be more easily covered than large plants. A large, dense plant may require an increase in insecticide rate, application volume and pressure, or all of these.
- Consider environmental conditions that can affect the efficacy of an insecticide. Conditions such as temperature, humidity, sunlight, and rainfall or irrigation can all affect how long organic insecticides are able to protect plant surfaces. Usually, the greater the environmental extremes, the shorter the period of protection. Never spray during the hottest part of the day (in the

afternoon). Apply dusts only when plants are dry.

- Observe recommended harvest intervals for organic insecticides. Read and follow all label instructions.
- Follow mixing and application instructions exactly.
- Use all pesticides carefully. They can be toxic or irritating to humans and animals. Follow label guidelines on safe application, including necessary protective clothing or gear. Some are very toxic and can have negative nontarget or off-site effects.

Organic Insecticides

Historically, conventional insecticides have not been approved for use in certified organic systems. Recently, however, some companies that manufacture and sell agricultural chemicals have been using active ingredients from natural sources. An example is the insecticide spinosad. Spinosad is a fermentation product of the soil-dwelling actinomycete *Saccharopolyspora spinosa*.

There are commercially available formulations of spinosad insecticides allowable for use in organic systems. Allowable formulations of spinosad will provide excellent control of many caterpillar species, but they are less efficacious on piercing-sucking insects (such as stinkbugs and plant bugs). Formulations of spinosad are labeled for a wide array of vegetables—for example, potatoes, eggplant, tomatoes, cucurbits (melons, cucumbers, pumpkins, squash), cole crops, and sweet corn, as well as some field crops (such as peanuts). Spinosad controls Colorado potato beetle larvae. Farmers should consult local Extension specialists for specific applications and follow label instructions.

Inorganic Insecticides

Diatomaceous Earth. This is a restricted material that can be used as a pest lure, repellent, or as part of a trap, or as a disease control. It may be used for other pesticidal purposes only if nonchemical practices documented in the Organic System Plan are insufficient to prevent or control insect pests. This product, which is silicon dioxide, is the finely milled fossilized remains of single-celled organisms (diatoms). The milling process produces a glass-like product that can scratch an insect's exoskeleton or puncture gut linings. When used as a desiccant, it is dusted or placed around plants to be protected. The dust scratches away the thin, waxy, waterproof layer on the exterior of insects, making them less tolerant of environmental conditions. Care should be taken to protect workers from the dust generated during mixing and application.

Kaolin. This is a naturally occurring clay resulting from the weathering of aluminous minerals with kaolinite as their prinipcal incredient, such as feldsspar. Kaolin is ground to a uniform particle size for application as a plant protectant applied as a water suspension to plant parts. This material has demonstrated efficacy for both insect and disease control. Kaolin controls insects by making the protected plant unattractive because it leaves a white film on leaves. The white film may interfere with the insect's host finding. It also acts as a physical barrier preventing insects from reaching vulnerable parts, and acts as a repellent by crerating an unsuitable surface for feeding or egg-laying. The particles also cling to insects and make their normal activities more difficult. It has proven highly effective for some pest species and less for others. In regions with high light and temperature levels, kaolin also acts as an antitranspirant, reducing plant stress and sunburn. Care should be taken to protect workers from the dust generated during mixing and application. Local recommendations should be followed.

Sulfur. Elemental sulfur is a restricted use material that may be used for pesticidal purposes only if nonchemical practices documented in the Organic System Plan are insufficient to prevent or control insect pests. This product is applied as a finely ground powder or spray for control of spider mites. It must be used carefully or it can burn foliage.

Insecticidal Oils

Oils kill insects and mites by smothering eggs or adults. Oil products can control a wide range of soft-bodied insects, such as aphids, mites, thrips, and whiteflies.

Narrow-range (median boiling points 415 – 440º F) insecticidal oils are highly refined petroleum oils and are restricted use materials. Narrow-range oils may be used for pesticidal purposes only if nonchemical practices documented in the Organic System Plan are insufficient to prevent or control insect pests. Petroleum derivatives outside the narrow range are prohibited in organic production. Oils have become more widely used in crop production as new refining methods have made it possible to make oils less phytotoxic to plants. They still must be used carefully to avoid foliage burn. Allowed oils also can be derived from vegetable and fish sources. Approved products must not contain any prohibited inert ingredients.

Oils are classified as *summer oils* and *dormant oils*. Summer oil is usually used as a 0.5 to 3 percent finished solution. Because this material is used during the growing season, farmers can prevent phytotoxicity by paying careful attention to rate, method, and timing of application. It is a good idea to test a small sample of a summer oil for both phytotoxicity and efficacy before applying it to an entire crop area. Dormant oils are restricted-use materials. As the name implies, dormant oils are used in the winter when plants are not growing. The timing of application can be critical as some insect life stages are unaffected by dormant oils.

Plant and fish oils are long-chain hydrocarbon lipids that include fatty acids, some alcohols, glycerides, and sterols. Plant oils are derived from seeds, whereas fish oils are byproducts of the fish processing industry. Essential plant oils, including mixtures of wintergreen, clove, and rosemary, are generally derived from stems and leaves rather than seeds. Plant and fish-derived oils are also used as spreader-stickers, surfactants, emulsifiers, and carriers. Such oils may not contain synthetic pesticides. Plant and fish oils are becoming more available than in the past, and they show promise for mite control. Recent tests have demonstrated that these oils are effective on plant-eating mites and less harmful to predaceous mites.

Follow label recommendations to reduce the risk of phytotoxicity of insecticidal oils. Conditions that slow evaporation increase the risk of phytotoxicity. Crops vary in their sensitivity, and oils are incompatible with sulfur and copper on some crops.

Insecticidal Soaps

Insecticidal soaps are restricted-use materials that may be used for pesticidal purposes only if nonchemical practices documented in the Organic System Plan are insufficient to prevent or control insect pests. Soaps or fatty acid salts are manmade fatty acids that are used to control soft-bodied pests like aphids and mites.

Insecticidal soaps work by smothering soft-bodied insects and disrupting their cuticle layer. Soaps do not have residual activity and do not provide lasting control. They are effective only on contact, so thorough coverage of the infested area is critical to success. Soap products are most effective when they dry slowly. Once dry on the plant surface, they are not effective againsts insects and mites. Soaps are not effective against insect eggs.

Phytotoxicity can be a concern with soap products, and crops vary in their sensitivity. Test effectiveness and phytotoxicity before spraying a large area.

Microbial Insecticides

Bacillus thuringiensis (Bt). This product contains a bacteroa; toxin that kills insects. It is derived from a naturally occurring soil bacterium and is harmless to other animals, including man. Bt must be ingested to work. After the bacterium is eaten, the toxin causes midgut paralysis in insects, which stops their feeding, usually within 24 hours. Next, the midgut lining is perforated, allowing leakage between the gut and the insect body cavity. The insect dies in two to four days. Bt will not kill other pests, such as aphids, mites, or thrips. Not all formulations of Bt are allowed in organic production. Check with your certifier to determine which formulations are currently allowed.

Thousands of Bt strains have been discovered and usually have more activity on specific groups of insects—beetles, caterpillars and worms, or flies and mosquitoes. This varying toxicity is apparently due to different toxins and different midgut environments within species. Bt toxins have a third name associated with them to differentiate the various strains. For example, Bt *kurstaki* and Bt *aizawai* are more active on caterpillars and worms, whereas Bt *tenebrionis* and Bt *san diego* work better on beetle pests. For this reason, it is very important to match the product with the target pest.

Even within strains that demonstrate activity on similar insect groups, there can be differences in control among species. For example, Bt *aizawai* is more active than Bt *kurstaki* on army worms. Some weaknesses of these products must be considered before use:

- Bt products have a short residual period because the ultraviolet radiation in sunlight breaks down the toxin. Farmers traditionally have extended residual effectiveness by spraying just before dark.
- Timing of application should be matched to the pest's feeding habits. Bt must be consumed to work. An insect that hatches, feeds for a short time, and then bores into the plant or fruit will probably not ingest enough toxin to be affected. For boring insects, applications must be made at or just before egg laying and thoroughly cover the plant.

In recent years, Bt products and plant varieties genetically modified to express Bt toxins have been relied upon to control pest species that are resistant to conventional insecticides, and some pests have developed resistance to Bt. The diamondback moth is an example of a pest with Bt resistance. Farmers should be very watchful when using Bt on vegetable pests to be sure that they are achieving the desired control, especially if their farms are surrounded by land where conventional vegetable production occurs. Even if a farmer has used Bt very little in the past, highly mobile resistant adults can immigrate into their crops from nearby farms, leading to control failures.

Beauveria bassiana. This common insect-pathogenic soil fungus has been formulated into an insecticidal product. Fungal insecticides have two advantages. First, they are contact insecticides. The insect does not have to ingest them to become infected. Spores land on an insect, germinate, and penetrate the exoskeleton. Once inside, the fungus proliferates, adsorbs nutrients, and emits toxic compounds. After the insect is dead, the fungus grows out to the surface of the exoskeleton and forms millions of spores. Second, fungi can initiate an *epizootic* (a widespread, self-sustaining disease of insects) which can be very effective at controlling insects at high population levels. Beauveria has been formulated into several commerically available products to control insects, such as aphids, whiteflys, thrips, mealybugs, mites, and various caterpillars. These products are sold under different tradenames, such as BotaniGard, Naturalis, and Mycotrol.

Botanical Insecticides

Botanical insecticides are made from plants that have insecticidal properties. Botanical insecticides are restricted-use materials. They may be used for pesticidal purposals only if nonchemical practices documented in the Organic System Plan are insufficient to prevent or control pests. These materials have several common characteristics:

- They are broad spectrum insecticides.
- They break down rapidly in the environment and so provide little, if any, residual control.
- They are less toxic to mammals than synthetic insecticides in most, but not all, cases.

Some botanicals, however, are very toxic to fish, other wildlife, and humans. Some have potential user and off-site problems that require careful safety precautions. The botanical insecticide rotetone is prohbited for use in organic systems. Petitions have been made to the National Organic Program to prohibit the use of other botanicals. Always check with your certifier to determine if the botanical pesticide that you plan to use is allowed.

Contact Botanicals. All of the contact insecticides are nerve poisons that cause insects to stop feeding and die quickly.

Pyrethrum. This is the generic name of a plant-based insecticide derived from the powdered flowers of a chrysanthemum species. Synthetic pyrethroids are not allowed in organic production. Most pyrethrum is imported from Africa. It is a contact poison that acts quickly as a "knockdown." Pyrethrum is a broad-spectrum insecticide that used against true bugs, caterpilars, beetles, aphids, flies, whiteflies, thrips, leafhoppers, and mites. Some insects may be able to recover after the initial knockdown if the dose is too low. Pyrethrum is highly toxic to honeybees, other beneficial insects, and fish, and moderately toxic to birds. Pyrethrin degrades rapidly and offers little residual control.

Synergists, such as piperonyl butoxide (PBO), are often added to pyrethrum products. PBO is not allowed in organic production. Care should be taken to avoid products that contain synergists and additives not allowed in organic production. Check with your certifier to determine if the product that you plan to use is allowed

Citrus oils (d-limonene, l-limonene) are extracts from citrus peels and are usually combined with soaps as contact poisons against soft-bodied insects and mites. This material works only on contact and will provide no residual control.

Other Botanical Insecticides. These botanicals act to poison insects through their digestive systems or to repel insects with strong odors and tastes. Some interrupt life cycle stages with hormone-like substances. Always check with your certifier to determine if the botanical pesticide that you plan to use is allowed.

Neem (nonsynthetic extracts and derivatives) is a restricted material that can be used as a pest lure, repellent, or as part of a trap, or as a disease control. It may be used for other pesticidal purposes only if nonchemical practices documented in the Organic System Plan are insufficient to prevent or control insect pests. Neem products are derived from the seeds of the neem tree, *Azadiracta indica*, grown from India to Africa.

Neem products have been used extensively for insect control in tropical countries in field crops and in stored products. Chemically, neem mimics certain insect hormones used to control metamorphosis. Neem interrupts this process and the insect dies. It is also effective as a repellent and stomach poison. Some residual activity can be expected. Neem products are generally formulated as emulsifiable concentrates. Follow label directions for specific application guidelines and re-entry and pre-harvest intervals. Neem extracts have been shown to affect a broad range of insects, but efficacy varies among species. Used alone or in combination with *Bacillus thuringiensis* or pyrethrum it has provided satisfactory control of resistant pests, such as cabbage loopers and diamondback moths. Thrips and whiteflies may also be controlled.

Ryania comes from the stems of a tropical plant. It does not kill quickly, but it can cause pests to stop feeding relatively quickly. Ryania can be effective at controlling caterpillars and some thrips. It should be tested on a small scale before use because it is ineffective on some species. It is considered slightly toxic to mammals.

Sabadilla comes from a South American lily. It is not acutely toxic to mammals but must be carefully used because it is a powerful irritant and, if inhaled, may result in circulatory and respiratory problems. It may be used in a spray or dust and acts as a contact material, but it has some activity as a stomach poison. Sabadilla has some activity on the group of insects known as the *true bugs*. True bugs are insects in the order Heteroptera that have two pairs of wings and needle-like mouthparts for sucking fluids from plants (squash bugs, for example). This material deteriorates rapidly when exposed to light, so it offers little or no residual control. Always check with your certifier to detemine if the botanical pesticide that you plan to use is allowed.

Garlic barrier is an oil extracted from garlic. It is intended as a repellent for a wide variety of insects. Efficacy tests have resulted in highly variable control. This product should be extensively tested before depending on it for control.

Other Control Approaches

Chitin. Chitin is a material that makes up the exoskeleton of arthropods (insects and crustaceans) and nematodes. Chitin is a restricted use pesticide, and may be used as a pest lure, repellant, or as part of a trap or for other pesticideal purposes, such as nematicidal purposes only if non-chemical practices documented in the Organic System

Plan are insufficient to prevent or control insect pests. Only products derived from nonsynthetic sources may be used. Use of chitosan, a polysaccharide obtained by deacetylation of chitin, is prohibited. When chitin is added to the soil, microbes produce toxins (forms of ammonia), digestive enzymes that destroy the cuticles of insect and nematode pests, or both. Field tests of efficacy have not been consistent.

Home Remedies. Bug juices made from insects blended into a liquid and sprayed on crops have been the subjects of much anecdotal information. Very few of these materials have been scientifically tested. Any of these approaches should be tested on a small area until they have been thoroughly examined. Consult with your certifier to determine if your proposed method is allowable.

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Enhancing Beneficial Insects with Native Plants. http://www.nativeplants.msu.edu/

Identifying Natural Enemies. http://ipm.msu.edu/natural-enemies.htm

Manage Insects on Your Farm: A Guide to Ecological Strategies. http://www.sare.org/publications/insect/index.htm

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Resource Guide for Organic Insect and Disease Management. http://www.nysaes.cornell.edu/pp/resourceguide/

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