Natural Enemies in Field Crops: A Guide to Biological Control
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Natural Enemies in Field Crops: A Guide to Biological Control




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Cover Photos

Front cover, clockwise from top left

Green lacewing adult (Karim Maredia).
Parasitoid, *Eriborus terebrans* (Doug Landis).
Adult multicolored Asian lady beetle (Scott Bauer), USDA–ARS.
Seed-eating ground beetles (Kelly Nelson).

Back cover, from top

Green lacewing larva (Jack Dykinga), USDA–ARS.
European corn borer infected with *Beauveria bassiana* (Doug Landis).

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Page 39 (W.A. Baker, W.G. Bradley and C.A.
Clark, 1949, USDA Bulletin 983, page 54).

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Midwest Biological Control News

This book summarizes information from past issues of Midwest Biological Control News that are of interest to field crop producers. The newsletter source and contributing authors are given at the end of each section. If you are interested in learning more about a particular topic, you may want to look up the original article and other articles of interest to you in the newsletter online index: <http://www.entomology.wisc.edu/mbcn/mbcn.html>.

Introduction

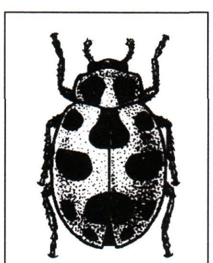
What is Biological Control?

Centuries ago, Chinese farmers observed that ants in their citrus orchards were feeding on caterpillars, beetles and leaf-feeding bugs. The farmers discovered that collecting the papery nests of a specific type of ant from trees in the countryside and moving them into their orchards gave them better control of some pests. They also provided aerial bamboo bridges among the citrus trees to help the ants move easily from tree to tree. These efforts to increase the numbers of ants in the orchard and to heighten their efficiency as predators is the first recorded occurrence of biological control of insects. Biological control is the manipulation of populations of living beneficial organisms, called natural enemies, to reduce the numbers of pests or the amount of damage caused by pests.

Agents of Biological Control

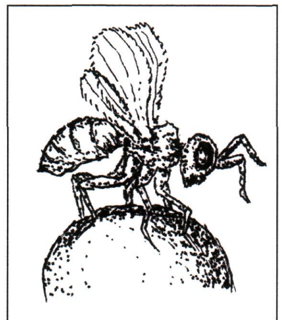
Most of us are familiar with spiders, ladybugs and praying mantids and how they feed on pests. Many other natural enemies also control pests. There are three major groups of natural enemies: predators, parasitoids and pathogens.

Predators may be insects or other arthropods, such as spiders. Each individual consumes many insect prey during its lifetime. Predators are often large, active and conspicuous in their behavior and are, therefore, readily recognized in the field.



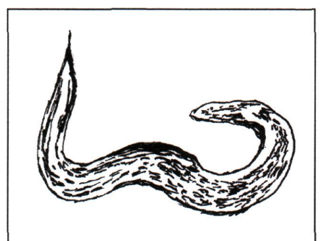
C. maculata

Parasitoids are insects that lay their eggs in or on the host insect. When the parasitoid egg hatches, the young parasitoid larva feeds on the host (sometimes an important pest) and kills it. Usually the parasitoid larva feeds on one host until it becomes an adult. Many parasitoids are very specific to the type of host insect they can attack and not harmful to humans. Though parasitoids are very common, they are small and often go unnoticed.



Wasp on an egg

Pathogens are viruses, bacteria, fungi, nematodes and other microorganisms that cause insect diseases. Disease epidemics among insects occur naturally when insect populations are very large or when environmental conditions favor the growth of the disease organism. Certain insect pathogens are available commercially as microbial insecticides and have been convenient and successful in achieving biological control of pests.

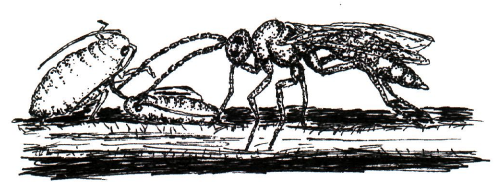


Nematode

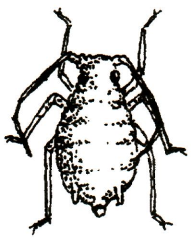
Approaches to Biological Control

There are three broad approaches to biological control. **Classical biological control** is conducted by federal and state agencies when pests are exotic in origin. Exotic natural enemies are imported and released to bring about control. Though you will not be importing natural enemies into the field, some important natural enemies such as parasitoids of alfalfa weevil and cereal leaf beetle are here because of past classical biological control programs. **Conservation biological control** improves the effectiveness of natural enemies through farming practices that provide necessary resources for their survival and protect them from toxins and other adverse conditions. **Augmentation biological control** temporarily increases the numbers of natural enemies through periodic releases, thereby increasing the overall numbers of natural enemies and improving biological control.

— *MBCN, v.1, n.1; D.L. Mahr and N.M. Ridgway, 1993, Biological control of insects and mites: An introduction to beneficial natural enemies and their use in pest management, North Central Region Publ. 481.*



Classical Biological Control



Many insects are serious pests because they are not native to our area — they were accidentally introduced through commerce or the transport of personal belongings. When an alien pest is accidentally introduced and established in a new area, it is usually without the complex of natural enemies that controls it in its native location. The most effective natural enemies are considered to be those that have developed with the pest in its native habitat. The first major successful example of classical biological control occurred more than 100 years ago and involved the control of cottony cushion scale, a serious pest of the California citrus industry.

The goal of classical biological control is to find useful natural enemies, introduce them into the area of the target pest, and permanently establish them so that they will provide continuing pest control with little or no additional human intervention. The search for natural enemies in other countries is referred to as foreign exploration. International agencies, federal agencies (U.S. Department of Agriculture) and state agencies (state departments of agriculture and the land-grant universities) are responsible for identifying potential target pests, locating their natural distributions, searching these areas for candidate natural enemies and introducing selected natural enemies into the necessary areas. Specific quarantine laws prohibit private individuals or agencies from introducing alien organisms (including natural enemies) without proper authorization from the USDA. Natural enemies must be carefully screened under rigid quarantine conditions to be certain that they will provide benefit in controlling the target pest; they will not, themselves, become pests; and they do not harbor their own natural enemies that might interfere with their effectiveness.

— *MBCN, v.1, n.3; D.L. Mahr and N.M. Ridgway, 1993, Biological control of insects and mites: An introduction to beneficial natural enemies and their use in pest management, North Central Region Publ. 481.*

Classical Biological Control of Alfalfa Weevil

The alfalfa weevil, *Hypera postica*, is an example of a highly successful case of the classical approach to biological control in the Midwest. The alfalfa weevil is a serious pest of alfalfa in the Midwest and throughout the United States. The weevil damages alfalfa by chewing and skeletonizing the foliage. Both adults and larvae feed on the plant, but the larvae are by far the more injurious stage.

The alfalfa weevil typically has just one generation per year, with larvae present during the spring. Alfalfa weevil adults emerge from pupae during late spring to early summer, feed for several weeks and then spend the remainder of the summer in aestivation, a state of arrested activity and development. Aestivation is completed by late summer or fall, and the adults become active while the weather remains favorable. They hibernate during winter and resume feeding and laying eggs the following spring. Understanding the biology of alfalfa weevil is critical in biological control because natural enemies must have compatible life cycles with that of the pest and be able to respond when the pest is growing in numbers.

The campaign — The alfalfa plant and alfalfa weevil are native to the Near East and Central Asia. Alfalfa weevil populations were accidentally introduced into the United States three times between 1939 and 1951. As an exotic pest, the alfalfa weevil was considered a good candidate for importation biological control, and a program of introducing natural enemies against the weevil was initiated by the Agricultural Research Service of the U.S. Department of Agriculture (USDA) in 1957. A number of parasitoid species (parasitic wasps) were introduced from Europe and the Middle East and released in the eastern United States, of which six became established. Only one species, *Bathyplectes curculionis*, was able to move effectively with the weevil as it spread westward from the eastern seaboard. A second alfalfa weevil biological control program was initiated in 1980 by the Animal and Plant Health Inspection Service of the USDA to redistribute the established parasitoid species throughout the eastern United States. This second phase lasted until 1988 and resulted in five parasitoid species becoming widely established in the Midwest.

Included also in Table 1 are two natural enemies that occur in the Midwest but were not introduced through the USDA programs. *Anaphes* (=*Patasson*) *luna*, an egg parasitoid, was probably accidentally introduced into the eastern United States. *Erynia* (= *Zoophthora*) *phytonomi*, a fungal pathogen that infects and kills alfalfa weevil larvae and pupae, is a more interesting story. This fungus first appeared in Ontario, Canada, in 1973 and now commonly occurs with the weevil throughout the Midwest, but it is not known to occur outside North America. Though there are several theories about where the fungus might have come from, its origin remains a mystery.

Impact on alfalfa weevil populations — A problem that many classical biological control programs share is lack of follow-up analysis to rigorously assess the impact of newly established natural enemies on the pest and document the success or failure of the program. This has not been the case with alfalfa weevil biological control in the Midwest. Two excellent studies have provided information on the impact that natural enemies are having on alfalfa weevil

Table 1. Alfalfa weevil natural enemies established in the Midwest.

Name	Type	Weevil stage attacked/killed
Anaphes luna	parasitic wasp	egg/egg
Tetrastichus incertus	parasitic wasp	larva/larva
Bathyplectes curculionis	parasitic wasp	larva/prepupa
Bathyplectes anurus	parasitic wasp	larva/prepupa
Erynia phytonomi	fungal pathogen	larva & pupa/larva & pupa
Microctonus colesi	parasitic wasp	larva/adult
Microctonus aethiopoides	parasitic wasp	adult/adult

populations in the Midwest. Moreover, a detailed economic evaluation concluded that the benefit:cost ratio accruing from the biological control program was an almost unimaginable 91:1!

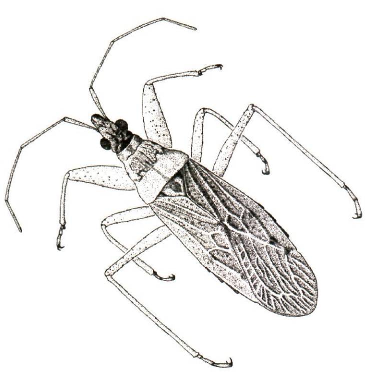
Why has biological control of the alfalfa weevil proven to be such a success in the Midwest? — Attributes of the crop, the pest and the natural enemies have all contributed.

Crop: Alfalfa is a perennial and thus provides a relatively stable habitat for natural enemies. In addition, flowering weeds in the crop may provide a nectar source for parasitoid adults, and alfalfa fields are generally treated with insecticide infrequently, if at all. Though frequent harvesting of the crop can be destabilizing, the successful natural enemies are not usually harmed by this practice.

Pest: The life history characteristics of alfalfa weevils — they eat only alfalfa, have limited dispersal ability and have a long generation time — make them vulnerable to attack by specialist natural enemies and thus well suited for biological control.

Natural enemies: The natural enemies important in alfalfa weevil biological control share two attributes that have been keys to their success. First, their seasonal life cycles are well synchronized with that of the alfalfa weevil. Second, the successful natural enemies tend to be resistant to harmful effects of alfalfa harvesting. Fortunately, the presence of weeds usually benefits parasitoids while having little impact on forage quality of alfalfa.

— *MBCN, v.4, n.7, Dave Hogg, University of Wisconsin-Madison.*



Conserving Natural Enemies

Conservation of natural enemies is arguably the most important concept in the practice of biological control. Conservation of natural enemies means avoiding practices that are harmful to natural enemies and implementing practices that benefit them. Sounds like good common sense! The tricky part comes in understanding exactly what practices are harmful and how beneficial practices can be integrated into your production system. That requires that we understand the biology of the natural enemies and are willing to modify our practices to accommodate them.

Avoid Harmful Practices

Reduce insecticide use — The most obvious practice is to avoid using insecticides, particularly when natural enemies will be harmed. Insecticides can directly affect natural enemies by poisoning them or indirectly affect them by eliminating their hosts and causing starvation. In some cases, insecticides can be successfully integrated into the system without causing harm to natural enemies. This may be through the use of a selective microbial insecticide such as *Bt*, timing the application to avoid times of the day or season when important natural enemies would be exposed, or placing the insecticide in a location where natural enemies will not contact it. Also, scout for pests regularly and spray only when pests are above a certain threshold. Low populations of pest insects can be tolerated, and they may provide food for maintaining beneficials in the area.

Reduce tillage — The act of tillage kills some ground-dwelling predators and removes organic matter at the soil surface. Why would a 3- to 6-inch layer of organic matter be important to ground-dwelling natural enemies in an agroecosystem? The mulch layer reduces soil temperature and increases soil moisture in the top 3 to 4 inches of soil. One thing that impresses people when they first start using no-till is the incredible number of organisms they find. Some growers become alarmed when they see so many insects concentrated in one area, thinking that this cannot be a good thing. In fact, most of these arthropods are beneficial decomposers: oribatid mites, collembola (springtails) and millipedes. They break large pieces of organic matter into small pieces while they are feeding; this makes it possible for fungi and bacteria to rapidly break down the material. They also provide a constant food source for arthropod predators that also feed on crop pests. No-till fields provide predatory mites, ground beetles, bugs, spiders and centipedes with alternative food sources besides pests and a conducive environment in which to live. No-till fields have from 50 percent to five times more predators than conventionally tilled fields.

Incorporate Beneficial Practices

Natural enemies require more than just pests to eat to complete their life cycles. Predators and parasitoids may need overwintering sites, protection from heat and desiccation, plant food sources and early-season prey to sustain themselves if pests are not present. Understanding the biology of the important natural enemies in your system is critical. The first step is to gather information on the types of natural enemies you want to conserve. Then consider these points:

- Where does the natural enemy overwinter? In England, a group of researchers discovered that important predators of aphids in wheat overwintered in tussock grasses at field edges. The predators migrated into the fields in the spring but got there too late to control aphids in the center of the fields. Planting a strip of tussock grasses in the center of the field sent overwintering predator numbers soaring and controlled aphid damage.
- What supplemental food sources do the natural enemies need? Are these present at the right times and close to my field? After emerging from overwintering, spotted lady beetles feed on plant pollen (dandelion, spring beauty) for several weeks before moving into alfalfa and wheat fields to feed on aphids. Many parasitoids also require the protein-rich pollen to develop new eggs. Parasitoids also feed frequently on nectar of flowering plants or aphid honeydew for sugar. Having a diversity of plants in and around fields has been shown in many cases to improve biological control.
- Do the natural enemies need alternative prey/hosts? Many predators and parasitoids require alternative hosts at some points in their life cycle. *Lydella thompsoni* is a tachnid fly that parasitizes European corn borer (ECB). It emerges before ECB larvae are present in the spring and completes its first generation on common stalk borers instead. Clean farming practices that have eliminated the stalk borer are thought to have contributed to the decline of this parasitoid. Alternative prey may also be important in building up predators in a field before the appearance of the pest you wish them to control. Lady beetles and minute pirate bugs can consume many ECB eggs, but alternative prey must be present in the field before ECB egg laying to maintain high predator numbers.

- What shelter is needed by the natural enemies during the growing season? Activity of ground-dwelling predators may be limited by high soil temperatures during the day. Incorporating cover crops or mulches may help reduce soil temperatures and extend the activity period of these organisms. Similarly, many parasitoids require moderate temperatures and higher relative humidity and may need to leave fields in the heat of the day to seek shelter in shady areas. For example, the activity of predatory paper wasps increased when they were given wooden boxes near fields to build their nests in.

Considering the biological and ecological needs of natural enemies is critical for the success of any biological control effort. It is one of the easiest ways for producers to initiate biological control on their farms and should be a major consideration in any importation or augmentation program.

— *MBCN, v.2, n.1, Doug Landis, Michigan State University; v.2, n.11, Jerry Brust, Purdue University.*

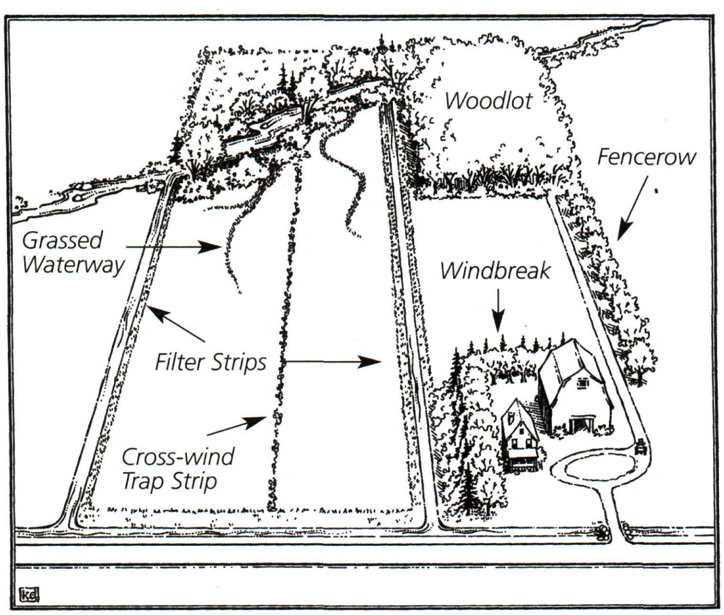
Conservation Buffers

You may have seen strips of permanent vegetation along streams, ditches and field borders or within fields. These conservation buffers can be filter strips, grassed waterways, shelterbelts and field windbreaks. Basically, these strips trap blowing soil particles and slow water runoff, thereby reducing soil erosion and pollution and sedimentation of waterways. Buffer strips also harbor many ground beetles, spiders and rove beetles because they serve as an overwintering site and a shelter during unfavorable periods, and they provide supplemental plant food and alternative prey. As a result, more natural enemies are available to subdue pests in the crop field.

There are several key elements to establishing conservation buffers. First, the buffer strips should be left undisturbed — this means minimal fertilizer and pesticide inputs and mowing. Second, strips should maintain plant cover year round, particularly when annual crop fields are bare. Third, they should include a mixture of plants: orchardgrass, legumes and perennial flowering plants. The grass provides protective structure, legumes keep the soil healthy, and flowers provide the nectar and pollen that many natural enemies need.

Contact your local USDA Service Center to find out what technical and financial help is available for the establishment of conservation buffers: <**http://www.mi.nrcs.usda.gov**>.

— *D. Landis and L. Dyer, March 1998, Conservation buffers and beneficial insects, mites and spiders, USDA Information Sheet, Agronomy Series.*



Farm with many types of conservation buffers

Experiment: Are Natural Enemies Sweet on Sugar Sprays?

Can spraying sucrose (table sugar) solutions on plants increase populations of natural enemies? Two studies, one in Honduras on corn and another in Colorado on alfalfa, showed increased numbers of predators in crops treated with sugar sprays. Several commercially available food spray supplements are designed to increase predators and parasitoids. Some of these are primarily sugar; others are based on yeast and contain more protein.
Evaluate your own applications of sugar sprays or commercial food sprays.

- Spray half of the plots with the sugar solution, the other half with plain water. Plot size can vary, but make sure they are large enough or separated by untreated areas to minimize insect movement. In corn, sprays should probably be applied in the whorl stage to allow enough time for beneficial insects to build up before pest populations increase.
- You can make your own sugar solution. Use a rate of 14 to 20 pounds of sugar dissolved in 10 to 20 gallons of water per acre. For smaller areas, use 1/3 pound of sugar in 2 pints of water.
- Count the number of predators, such as ladybugs and green lacewings, on 10 plants per plot just before treatment. Continue at weekly intervals after spraying. Yellow sticky traps can also be used to measure levels of predators.

Use Extension-recommended practices to monitor the important pest species in your area. In which plots did you find the most predators? Did they seem to have any effect on pest populations in those plots?

— *MBCN, v.3, n.6, Bob Wright, University of Nebraska.*

Augmenting Natural Enemies

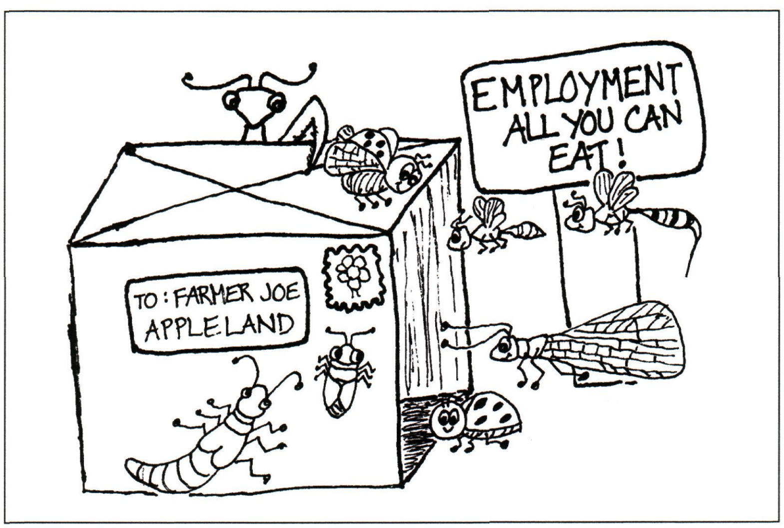
To many people, "biological control" means the purchase and release of beneficial natural enemies to control insect and mite pests. The augmentative approach is widely recognized because this technique relies on using commercial products that are advertised in farming magazines. Further, the historical use of pesticides has trained us to think about pest management in the context of purchased products. Of the three general approaches to insect biological control, augmentation is the least sustainable because it requires regular or periodic investment in purchased inputs. Nonetheless, in some pest situations, it is a highly useful and environmentally sound approach to pest management.

Augmentation should be used in situations where numbers or species of natural enemies are inadequate to provide optimal biological control. It requires a readily available source of large numbers of natural enemies. Many companies (insectaries) produce a variety of predators and parasitoids; other companies produce and market insect pathogens for use as microbial insecticides.

The two general approaches to augmentation are **inundative** and **inoculative** releases. Inundation involves releasing large numbers of natural enemies for immediate reduction of a damaging pest population. It is a corrective measure — the expected outcome is immediate pest control. The utilization of some microbial insecticides is also inundation. Inoculation involves releasing small numbers of natural enemies at prescribed intervals throughout the pest period, starting when the pest population is very low. The natural enemies are expected to reproduce themselves to provide more long-term control. The expected outcome of inoculative releases is to keep the pest at low numbers, never allowing it to approach an economic injury level. Therefore, it is a preventive measure.

Natural Enemies Available

Augmentative biological controls have not been developed for all pest problems. Indeed, relatively few situations are amenable to this approach. Augmentation is frequently used to protect greenhouse crops and control filth flies in livestock manure. In row crops, generalist natural enemies such as the egg parasite *Trichogramma*, green lacewings and microbial insecticides are used. In the United States, augmentation has probably been used the least on field crops, partly because the expenses may not be acceptable on low-value crops. *Bacillus thuringiensis* is commonly used for controlling European corn borer, and considerable research is aimed at making releases of *Trichogramma* a viable option for corn borer control.



More than 100 types of natural enemies are commercially available, including predatory insects and mites, parasitic insects, insect-parasitic nematodes and insect pathogens. Microbial insecticides are sold by many chemical companies and common in stores. If you are interested in purchasing predators or parasitoids, this is a good free source of information on insectaries:

Suppliers of Beneficial Organisms
in North America
by C. D. Hunter, from:
California Environmental Protection Agency
Department of Pesticide Regulation
Environmental Monitoring and Pest
Management
P.O. Box 942871
Sacramento, CA 94271-0001
<**http://www.cdpr.ca.gov/docs/ipminov/bensuppl.htm**>

Efficacy

"But do they work?" This is frequently asked about commercially produced natural enemies. The short answer is "Yes... and no." The long answer requires a few hundred more pages. There is no doubt that well researched applications of natural enemies can be very effective. These include the use of microbial insecticides as well as many specific uses of predators and parasitic insects. The best advice for pest managers interested in embarking on a new augmentation program is to first get as much information as possible.

It is important to keep in mind that principles in conservation biocontrol still apply to augmentation. Commercially reared insects will likely find it just as hard to survive insecticide exposure as your normal field insects. Released predators and parasitoids may leave the area or not survive if the field is unsuitable because it's too hot or doesn't have enough pollen or nectar. Thus, minimizing harmful practices and including a diversity of plantings will help natural enemies to remain in your crop doing what you paid for them to do.

Costs

Some natural enemies are much easier and less expensive to produce than others; this is reflected in their prices. Because of the differences in prices and usage patterns, it is hard to generalize on the cost effectiveness of purchased natural enemies. Other less obvious factors also have to be considered, especially when comparing the release of natural enemies to the use of pesticides. These include pesticide resistance management, worker protection, impacts on non-target pests, environmental considerations and marketing practices (such as conventional vs. organic). On low-value crops, the use of natural enemies must be inexpensive. In field crops, inundative controls such as *Bacillus thuringiensis* and *Trichogramma* may be cost effective, as can be inoculative releases that rely on relatively low numbers of natural enemies. Like any other production cost, the cost of natural enemy releases should be carefully evaluated.

— *MBCN, v.1, n.4, Dan Mahr, University of Wisconsin-Madison; R.L. Ridgway and S.B. Vinson, 1977, Biological Control by Augmentation of Natural Enemies, Plenum Press.*

Controlling European Corn Borer with *Trichogramma* Wasps vs. Insecticides

Trichogramma brassicae, originally collected in Moldavia (former USSR), is widely used in Switzerland, Germany and France. A French company has formulated these *Trichogramma* into capsules, each containing 500 wasps, that can be applied to fields using conventional equipment. U.S. researchers have been comparing the effectiveness of *Trichogramma* with insecticides that are currently used against European corn borer in the United States in both field corn and seed cornfields.

The results from a study in field corn plots are shown in Table 2. *Trichogramma* wasps controlled European corn borer larvae and damage as well as or better than insecticides! Wasps kill corn borer eggs before they hatch and so prevent larval damage to corn plants.

The cost of the wasps is one of the main limitations to using *Trichogramma* for European corn borer control in cornfields. They cost two to three times as much as a single insecticide application. If only a third to a half of the currently recommended rate could be released with equal results, however, the cost would also be reduced by the same proportion. Reduced release rates of *Trichogramma* have given excellent results in preliminary field trials. Over 72 percent parasitism of European corn borer eggs was achieved with wasp releases at two-thirds the recommended rate. Even the half rate was acceptable, achieving 55 percent parasitism. As costs are lowered, *Trichogramma* releases could become more common in U.S. agricultural systems.

— MBCN, v.2, n.1, David Orr and Doug Landis, Michigan State University.

Table 2. Suppression of second generation European corn borer in field corn plots treated with biological and chemical crop protectants, Centreville, Mich., 1993.

Treatment	Rate	% reduction of European corn borer larvae	% reduction of cavities	% reduction of cavity length
Trichogramma	(243,000/acre = 486 capsules)	78.3	74.2	77.1
Dipel 10G	10 lb/acre	33.7	34.8	43.7
Pounce 1.5G	6 lb/acre	64.9	60.8	65.2
Lorsban 15G	6.3 lb/acre	66.2	50.2	63.8

What to Consider When Ordering Natural Enemies

- Know the specific pests you need to control.
- Know the best natural enemies, either singly or in combination, for the target pest or pests.
- Know the proper timing of release of the natural enemies, based on their life cycles and that of the pest.
- Know the proper release rate for each natural enemy.
- Calculate the number of natural enemies needed on the basis of release rate, area to be covered and severity of pest infestation.
- Know the recommended frequency of release if multiple releases are necessary.
- Provide a safe delivery address, one where the shipment will be cared for as soon as it arrives and where it will not be exposed to temperature extremes.
- Understand proper release practices so that you will be prepared to make releases when the shipment arrives.
- Understand proper storage requirements if releases are not to be made immediately after arrival.

— *MBCN, v.2, n.3.*

What About Releasing Ladybugs and Praying Mantids?

No doubt, ladybugs are good biocontrol agents, but what about the ones you buy? Chances are that these ladybugs are *Hippodamia convergens*. Many convergent ladybugs overwinter in huge aggregations in the Sierra Nevada mountains. This makes it easy for suppliers to scoop them up, box them and sell them. Unfortunately, when you release these convergent ladybugs in your field, they behave as they do in the mountains — they fly away looking for the valley, their normal feeding grounds. Some suppliers are now preconditioning ladybugs — letting them fly around before you receive them — so the ladybugs will be less likely to fly away.

What about praying mantids? While they certainly do prey on pests, mantids are extreme generalists. Mantids will eat virtually anything they can catch, including their siblings and other beneficials. Large mantids, such as the commercially available Chinese mantid, will even catch and eat bees and other pollinators. Adult mantids are very mobile — they usually won't remain in the release site for long. If you wish to purchase them, do so as a source of education or interest. Just don't expect that they will provide much benefit in pest management.

— *MBCN, v.2, n.4, Dan Mahr, University of Wisconsin-Madison.*

Natural Enemy Release

Some natural enemies are readily available in large quantities for control of various pests. For the backyard gardener, it's easy to shake the beneficials out from the little containers or hang small cards containing wasps in host eggs onto individual plants. But getting buckets of green lacewing eggs or parasitic wasps evenly distributed over 160 acres of corn is another story!

Many beneficial organisms have always been applied mechanically. Bacteria, fungi, viruses and nematodes are released into the field by spraying with conventional pesticide application equipment. Use of these microbial beneficials has been facilitated by reliable spray technology that is familiar and available to operators. Larger organisms, including most predatory and parasitic arthropods, cannot be delivered as easily through conventional equipment. Development of efficient mechanical systems for delivery of natural enemies could encourage greater acceptance and utilization of these natural enemies.

Much of the initial work with mechanical delivery systems was done with green lacewing eggs or *Trichogramma* wasps inside host eggs. Eggs are inexpensive and can be delivered in dry or liquid media, making releases of large numbers practical. Mechanical devices were first developed to apply beneficial eggs in a dry solid carrier such as bran, rice hulls, corn grit or vermiculite. Dry carriers provide bulk to ease handling and provide cushioning, but there are disadvantages: plugging of mechanical devices during distribution, potential for mechanical damage to the eggs and difficulties with calibration. One of the biggest problems is that few of the biocontrol agents remain on the foliage — they end up on the ground. If eggs are released when the crop is tall, this may greatly reduce the efficacy of the natural enemy.

Using liquid carriers can alleviate some of these problems. Adhesives added to the liquid eliminate losses due to eggs falling to the ground because they attach the eggs to the leaf surfaces. Damage to the eggs during delivery is usually reduced, though the carrier must not be toxic to the natural enemy. Another advantage of liquid systems is that sprayer technology is familiar to the agricultural industry — growers already have liquid application equipment, calibration procedures are well developed and application is relatively simple. Keeping the biocontrol organisms uniformly suspended in the liquid carrier before application is one of the challenges of developing successful liquid application devices.

In many situations, aerial application may be more practical. In past experiments, the predatory mite *Phytoseiulus persimilis* was released by a conventional light aircraft onto field corn for the control of spider mites. The predators were mixed with corncob grits and released about 50 feet above the plant canopy with a mechanized, refrigerated delivery system in a near uniform distribution. The latest slant on aerial application is using a small remote-controlled aircraft. Advantages include lower initial cost of the aircraft itself, reduced maintenance costs, operator safety, small storage space and applications in inaccessible locations. A disadvantage is that electronic wave operation limits aircraft use near radio-transmitters and other sources of strong electric signals. Windy conditions dramatically affect the ability of the aircraft to operate and apply natural enemies uniformly.

Recent developments for the delivery of lacewing eggs, *Trichogramma* in host eggs and predatory mites have resulted in the commercialization of both air and ground equipment for the delivery of liquid and dry formulations of natural enemies. Though further refinements may be necessary, we are entering a period when large-area releases of natural enemies are becoming a reality.

— *MBCN, v.6, n.9, Susan Mahr, University of Wisconsin-Madison.*

Looking for the Silver Bullet

We often look to biological control to work the way chemical controls do. It would be nice if one natural enemy was the silver bullet that took care of the pest, but natural enemies often do not work that way. Releasing a fantastic predator and having it establish in the system requires effort. We need to know what the predator needs and make sure alternative food sources and protective shelter are provided. As you look through this book, you will notice that some natural enemies eat a variety of pests; others are very specific. Both are usually needed to obtain effective biological control. Some specific natural enemies can be very good at locating pests at low densities and keeping them low, while other specifics may be good at bringing down pest outbreaks. Generalists are important because they can feast on a variety of pests and tend to be more flexible in where they can live. When a particularly bad pest arrives, the generalist natural enemies are already in your field ready to do their share of eating away the pest population. Biological control of pests may take many natural enemies and effort on your part, but it can work on your farm!

Sampling for Natural Enemies

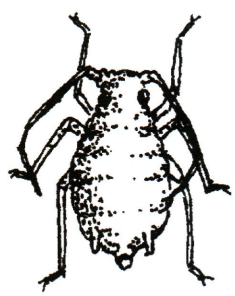
Your farm has a wealth of small six- and eight-legged creatures. While we tend to notice the bad ones, there are plenty more out there. Here are ways to find the good guys, the natural enemies in your field.

- Take sweep net samples. If an alfalfa field is available, go there. Alfalfa fields are often not sprayed with insecticides, so they contain a wide variety of pest and beneficial insects. Take 10 to 50 sweeps in the crop foliage with a standard sweep net. Dump the contents of the net into a shallow pan or clear plastic box. Insects that can fly may leave the pan, but those in the box can be restrained by covering the opening with a black cloth. You're likely to see green lacewing larvae and adults, minute pirate bugs, lady beetle larvae and adults, damsel bugs, small stingless wasps of various sorts, spiders and a wide variety of other critters. Which ones are most common? What do these beneficials eat? If you're lucky, after they settle down, you may see a predator feeding on another insect!
- Take some soil samples — dig up some soil and spread it out on a white surface. You'll probably see earthworms and little things jumping about. These are springtails, important decomposers and relatively harmless to crops. You may also see less mobile pupae and grubs as well as predaceous adult beetles that run frantically when disturbed.
- Put yellow sticky traps in various areas — at the field border, in the center, and in nearby old fields or grassy and weedy areas, if present. The yellow color is attractive to many pest and beneficial insects. Adult parasitoids often fly into these traps, and you may have never noticed these small wasps before in the field.
- Use pitfall traps made by placing plastic cups just below ground level so that walking insects will fall in. Leave them out there overnight and you may be surprised by the number of ground-dwellers active at night. Spiders, rove beetles and ground beetles, all good predators, will most likely dominate the traps. If you find insect remains, they may have gotten hungry and started eating one another.

— *MBCN, v.2, n.6, Susan Mahr, University of Wisconsin-Madison.*

Natural Enemies of Common Pests

With this table, you can quickly identify the particular natural enemies that can help control common pests in your fields. Look in the left column for the pest you want to control. The right column will guide you to the pages for more information.

Aphids	*Natural Enemies of Aphids*	*Page*
	Minute pirate bugs (predator)	25
	Damsel bugs (predator)	26
	Bigeyed bugs (predator)	27
	Green lacewings (predator)	28
	Ladybugs (predator)	29
	Ground beetles (predator)	34
	Hover flies (predator)	35
	Diaeretiella rapae (parasitoid)	46
	Beauveria bassiana (pathogen)	58
Specific aphid pests		
Greenbugs	*Lysiphlebus testaceipes* (parasitoid)	45

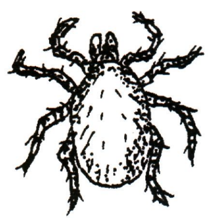
Beetles	*Natural Enemies of Beetles*	*Page*
	Bigeyed bugs (predator)	27
	Ground beetles (predator)	34
	Tachinid flies (parasitoid)	38
	Nematodes (pathogen)	52
	Bacillus thuringiensis (pathogen)	54
	Beauveria bassiana (pathogen)	58
Specific beetle pests		
Alfalfa weevil	*Microctonus aethiopoides* (parasitoid)	43
	Bathyplectes wasps (parasitoid)	48

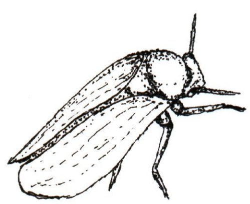
Bugs	Natural Enemies of Bugs	Page
	Assassin bugs (predator)	26
	Damsel bugs (predator)	26
	Bigeyed bugs (predator)	27
	Tachinid flies (parasitoid)	38
	Beauveria bassiana (pathogen)	58
Specific bug pests		
Tarnished plant bug	*Peristenus digoneutes* (parasitoid)	42

Caterpillars	Natural Enemies of Caterpillars	Page
	Minute pirate bugs (predator)	25
	Assassin bugs (predator)	26
	Damsel bugs (predator)	26
	Bigeyed bugs (predator)	27
	Green lacewings (predator)	28
	Ground beetles (predator)	34
	Hover flies (predator)	35
	Tachinid flies (parasitoid)	38
	Trichogramma wasps (parasitoid)	50
	Bacillus thuringiensis (pathogen)	54
	Beauveria bassiana (pathogen)	58
Specific caterpillar pests		
European corn borer	*Lydella thompsoni* (parasitoid)	39
	Macrocentrus grandii (parasitoid)	41
	Eriborus terebrans (parasitoid)	47
	Nosema pyrausta (pathogen)	53

Flies	Natural Enemies of Flies	Page
	Rove beetles (predator)	33
	Ground beetles (predator)	34
	Bacillus thuringiensis (pathogen)	54

Grasshoppers	Natural Enemies of Grasshoppers	Page
	Blister beetles (predator)	32
	Tachinid flies (parasitoid)	38
	Beauveria bassiana (pathogen)	58

Mites	Natural Enemies of Mites	Page
	Minute pirate bugs (predator)	25
	Damsel bugs (predator)	26
	Bigeyed bugs (predator)	27
	Green lacewings (predator)	28
	Ladybugs (predator)	29
	Rove beetles (predator)	33
	Fallacis mites (predator)	37

Whiteflies	Natural Enemies of Whiteflies	Page
	Bigeyed bugs (predator)	27
	Green lacewings (predator)	28
	Ladybugs (predator)	29

Predators

A dictionary definition of predation would say something such as "a way of life in which the primary source of food is obtained by the catching, killing and eating of other animals." Birds, bats, frogs, rodents, fish, insects, spiders and mites exhibit this predatory lifestyle and consume many of our unwelcome crop pests. Birds and other vertebrate animals are hard to manipulate and eat a variety of prey, so biological control of pests in agriculture has focused on small arthropod predators (insects, spiders, mites). Predatory arthropods are often larger than their prey and fast-moving, and have good searching capabilities. They have some way of catching and subduing their prey, such as a web, modified grasping legs or paralytic saliva. Also, predators consume many prey in a lifetime.

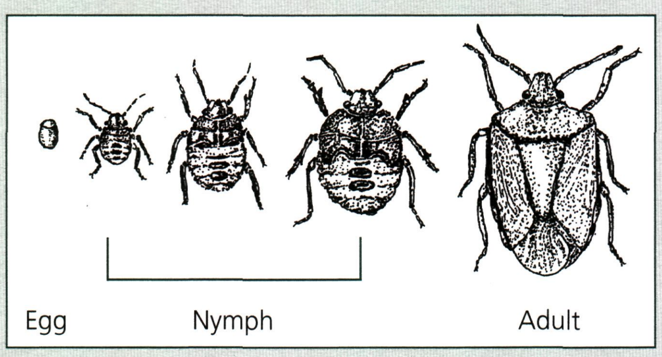
Though no one has taken a census of all the species of predatory arthropods important in agriculture, the number would likely reach into the thousands. For example, there are about 400 species of ladybugs in North America alone. Most predators are considered generalists in that they will capture and eat almost anything that they can find within the range of habitats that they live in. The adults of many important predators require or can subsist on alternative foods, especially floral nectar and pollen.

— MBCN, v.4, n.8, Dan Mahr, University of Wisconsin-Madison.

Development

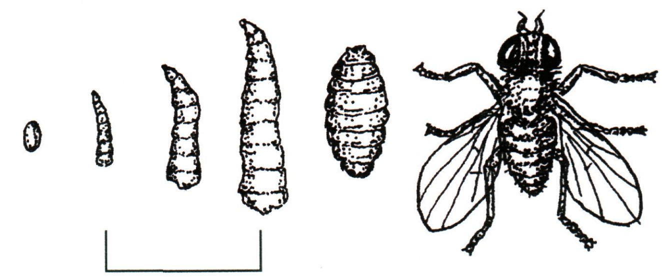
Insects grow in two major ways, and the type of development will influence the natural enemies' lifestyle and how you recognize them.

Hemimetabolous insects go from egg through several nymphal stages to winged adult. The young insects look like adult insects without wings.



Both nymph and adult tend to eat the same things. Predaceous true bugs are hemimetabolous. Arachnids, including spiders and mites, develop similarly to hemimetabolous insects but do not have wings.

Development *(continued)*



Holometabolous insects go from egg to larva, pupa and winged adult. The young insect looks drastically different from the adult.

The larva and the adult may feed on different foods and live in different habitats. Beetles, lacewings, moths, wasps and flies are holometabolous. Beetle larvae are usually called grubs; fly larvae are called maggots.

True Bugs in Action

All true bugs, those in the order Hemiptera, have piercing-sucking mouthparts. These mouthparts extend into a long "beak" known as a rostrum. Most true bugs are plant feeders, but many are predaceous, drinking the blood of other insects, and a rare few can attack humans. True bugs have various tricks of the trade for catching insects. The stink bugs and small flower bugs often attack less mobile victims such as caterpillars, slow larvae and aphids. The assassin bugs may lie in wait hidden and jump when a good-looking dinner item comes their way. Some bugs can even emit attractive odors to lure bees in.

Once a victim is seized, the sharp teeth at the tip of the bug's rostrum get busy cutting a hole. The bug then sticks its rostrum inside, pumps enzyme-laden saliva into the prey and sucks up the partially digested insect cocktail through its own personal straw.

Should we be wary of these blood suckers? Well, the human blood suckers, known as bed bugs, are relatively uncommon. The ones we find on our farms prefer to feed on other insects, but they can poke you if you bother them. Larger bugs can deliver more painful pokes that may cause blistering, so be careful if you handle them.

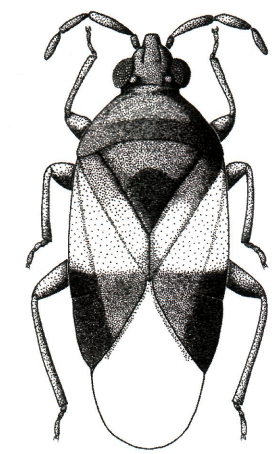
Minute Pirate Bugs

Order: Hemiptera, true bugs
Family: Anthocoridae

Minute pirate bugs are common insect predators found in many agricultural crops and pastures. Both nymphs and adults feed on a variety of small prey, including **spider mites, insect eggs, aphids, thrips, scales** and **small caterpillars**.

What you will see: Adults are very small — 1/8 inch long — somewhat oval-shaped and black with white wing patches. Females lay tiny eggs hidden within plant tissues. These eggs hatch into nymphs, small, wingless insects, yellow-orange to brown, teardrop-shaped and fast-moving. Growth from egg to adult takes a minimum of 20 days under optimal conditions. Several generations may occur during a growing season.

Orius insidiosus, sometimes called the insidious flower bug, is the most common species in the Midwest. It is one of the most common predators contributing to green cloverworm mortality in soybean. *Orius* bugs are also prevalent in corn and highly attracted to corn silks. This makes them a good predator of **corn earworm eggs**, which are laid primarily in the silks. *Orius* also eat **European corn borer eggs, corn leaf aphids, thrips** and **two-spotted spider mites**. *Orius* often persist well under humid conditions and are used in greenhouse biological control programs. In cornfields, *Orius* are valuable predators of spider mites — as both immature and adults can consume 30 or more spider mites per day.



Minute pirate bug

Giving them a boost: Minute pirate bugs are most common where there are spring- and summer-flowering shrubs and weeds because they feed on pollen and plant juices when prey are not available. Foliar applications of insecticides to crops can greatly reduce their numbers. Even soil-applied systemic insecticides may reduce their numbers because they at times drink plant juices. *Orius* are also available commercially from insectaries. They are shipped as adults in a carrier such as vermiculite along with a food source. The carrier can be shaken onto plants and the bugs will readily disperse and locate prey.

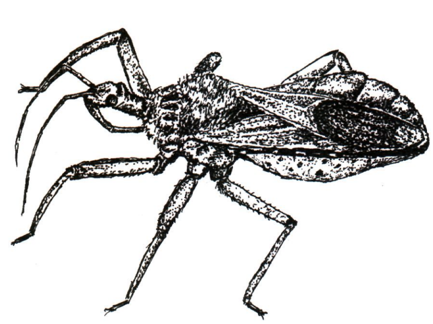
— *MBCN, v.1, n.1, Bob Wright, University of Nebraska-Lincoln.*

Assassin Bugs

Order: Hemiptera, true bugs
Family: Reduviidae

There are more than 160 species in the family Reduviidae in North America known as assassin bugs, ambush bugs and thread-legged bugs. Most assassin bugs are medium-sized to large predators of crop pests, but the family does contain a few blood-sucking species. Even the beneficial insect predators can inflict a painful bite if handled carelessly, resulting in an inflammation that can persist for a few days. Most assassin bugs are generalist predators in fields. They sit in wait of prey and are most likely to attack small flying insects, though they can subdue and kill medium-sized caterpillars and similar insects. Some common prey are **caterpillars, leafhoppers** and **plant bugs**.

What you will see: Adult assassin bugs are usually 1/2 to 3/4 inch long. Many species are brownish or blackish, but some species are brightly colored. The elongated head is narrow with a distinct "neck" behind the often reddish eyes. The long, curved beak is carried beneath the body, with the tip fitting in a groove on the underside of the body. The middle of the abdomen is often widened so the wings don't completely cover the width of the body. The female lays eggs in tight, upright clusters on leaves or in the soil. Nymphs resemble miniature, wingless adults.



Assassin bug

Giving them a boost: Assassins have not been specifically manipulated for biological control. Nevertheless, they do contribute to natural control, and judicious pesticide use will help conserve them in agricultural fields.

— *MBCN, v.3, n.5, Susan Mahr, University of Wisconsin-Madison.*

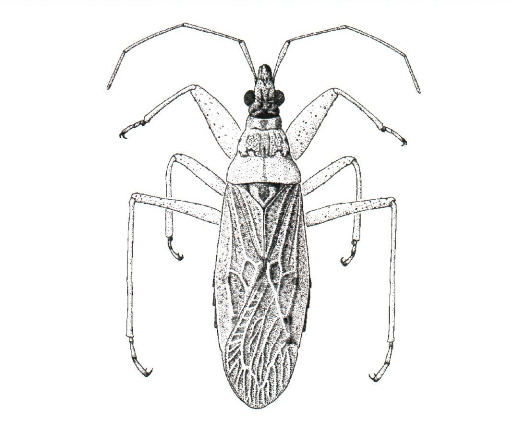
Damsel Bugs

Order: Hemiptera, true bugs
Family: Nabidae

Damsel bugs are generalist predators prevalent in soybean and alfalfa and found in row crops and orchards. They feed on **aphids, moth eggs, leafhoppers, small sawfly larvae, mites, tarnished plant bug nymphs** and small **caterpillars**, including **corn earworm, European corn borer** and some **armyworms**.

What you will see: Damsel bugs are slender, tan-colored bugs that resemble small, smooth-looking assassin bugs. Some have only one generation per year; others have two to five generations, depending on location. Most species of damsel bugs overwinter as adults.

Giving them a boost: They prefer to take shelter in low-growing grasses and ground covers. Maintaining such environments will encourage these predators. They can survive for up to two weeks without food, but if no



Damsel bug

other prey is available, they will turn to cannibalism. This can easily be avoided if other non-crop vegetation is available to harbor alternative prey for these hungry bugs.

— *MBCN, v.4, n.2, Susan Mahr, University of Wisconsin-Madison.*

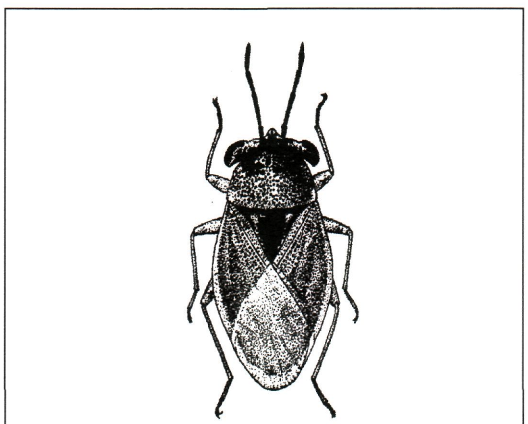
Bigeyed Bugs

Order: Hemiptera, true bugs
Family: Lygaeidae, seed bugs
Genus: *Geocoris*

The bigeyed bugs, *Geocoris* spp., are generalist predators commonly found in a variety of crops and non-cultivated plants nationwide. Bigeyed bugs are particularly common in cotton, peanut and soybean fields. Many *Geocoris* species found throughout the United States are capable of feeding on insect **eggs, aphids, mealybugs, spider mites, leafhoppers, bugs, whiteflies, small caterpillars** and **beetle larvae**. Amazingly, *Geocoris* may consume up to 1,600 spider mites and 250 soybean looper eggs as a growing nymph, and as many as 80 mites a day as an adult. Adult bigeyed bugs can devour up to four **lygus bug** eggs per day.

What you will see: As their name implies, they have rather large, protruding eyes. The adults range from black and white to tan. The nymphs resemble miniature grayish adults. They are small — 1/8 inch long. The immature nymphal stages resemble the adults except that they lack functional wings. Nymphal stages have similar behavior and feeding habits as adults but tend to feed on smaller prey. Most bigeyed bugs go through five nymphal stages. Under laboratory conditions, nymphal development takes about 30 days at 77 degrees F and 60 days at 68 degrees F. Though they are not well studied, it is reported that bigeyed bugs overwinter as adults or as eggs, depending on the species and location.

Giving them a boost: *Geocoris* survive best on a mix of plant and insect foods and are often found in grassy, flowering vegetation. Their plant feeding does not cause significant injury to plants, but their



Bigeyed bug

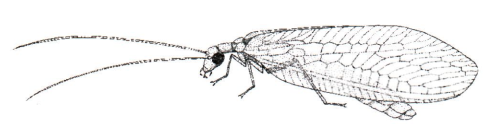
omnivorous feeding habits allow them to survive in a variety of habitats and contribute to biological control when pest species become abundant. Nevertheless, their plant feeding makes them susceptible to systemic insecticides. Bigeyed bugs may become increasingly available at the commercial level. USDA studies have found that bigeyed bugs can be raised on artificial diets of ground beef and beef liver. At $2.50 per pound, this diet is very cheap compared with $300 a pound for insect eggs.

— *MBCN, v.4, n.12, Bob Wright, University of Nebraska-Lincoln.*

Green Lacewings

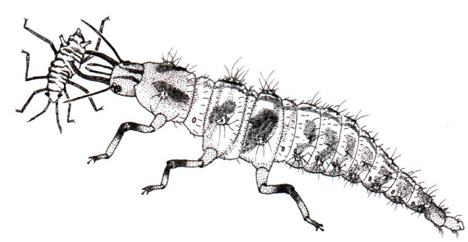
Order: Neuroptera
Family: Chrysopidae

Green lacewings are found in most environments throughout North America. The pretty and delicate adults generally feed on pollen and nectar. The larvae are called aphidlions — they consume up to 200 **aphids** per week. They also eat other soft-bodied pests, including **mites, insect eggs, thrips, mealybugs, scales, immature whiteflies** and **small caterpillars**. Aphidlions also will consume one another if no other prey are available.



Lacewing adult

What you will see: The light green adult has long, slender antennae, golden eyes, and large, veined, gauzelike wings 1/2 to 1/3 inch long. It is a slow-flying, nocturnal insect, and it emits a foul-smelling fluid from special glands if captured. The female lacewing lays eggs usually in groups on leaves, each egg held away from the leaf surface on the end of a slender stalk. This is done to prevent newly hatched and hungry lacewings from devouring the eggs of their brothers and sisters.



Lacewing larva

The aphidlion resembles a green-gray alligator with mouthparts like ice tongs. An aphidlion seizes and punctures its prey with its long sickle-shaped jaws, injects a paralyzing venom and sucks out the body fluids. After feeding and growing to 1/2 inch in length during a two- to three-week period, the larva spins a spherical, white silken cocoon in which it pupates. The adult emerges in about five days through a round hole that it cuts in the top of the cocoon. It overwinters as a pupa within its cocoon or as an adult, depending on the species.

Giving them a boost: Green lacewings are available from many commercial suppliers, generally offered as eggs. Aphidlions move around a lot and will travel 80 to 100 feet in search of prey. Once their food source is exhausted, they will leave the area. The predatory larvae feed for two to three weeks before they become adults. The adults must have a source of nectar, pollen or honeydew to stimulate egg laying or they will leave the area. Flowering cover crops or borders help lacewings remain and reproduce in the crop.

The number of lacewings needed for effective control depends on the pest population and climatic conditions. Two or three successive releases made at two-week intervals are better than a single release. These insects are extremely effective under certain conditions, especially in protected or enclosed areas such as a greenhouse, but they may fail to survive and provide control when conditions are not favorable.

— MBCN, v.1, n.3, Susan Mahr, University of Wisconsin-Madison.

Ladybugs, Ladybirds, Lady Beetles

Order: Coleoptera, beetles
Family: Coccinellidae

Ladybugs or lady beetles are among the best known predators. There are more than 450 species of lady beetles in North America. Most are native, but many have been introduced from other countries. Almost all of these species are predators that feed on soft-bodied insects such as **aphids, scales, mites, immature whiteflies, thrips** and **mealybugs.**

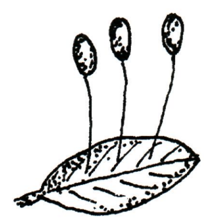
What you will see: The adults are often brightly colored to black, round and convex. The larval stages of these species are not as

Experiment: What Green Lacewings Eat on Your Farm

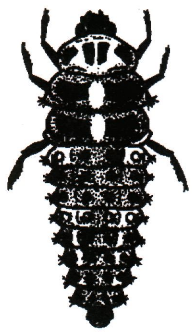
Green lacewings are common predators that will feed on a variety of small insects and are available from many commercial suppliers. If you release green lacewings in your field, which of your pests will they eat, and what do they like best? Let's find out.

- Order a small quantity of green lacewing eggs. After they have hatched, place a number of them individually in small containers.
- Collect whatever insect pests you can find in your crop. Check crop foliage for insect eggs, aphids, mites and caterpillars. You can pick foliage with the pests on them or remove larger pests from the plant.
- Place one pest insect (or foliage) in a container with a lacewing larva. What does the lacewing do? Will it eat the pest, or is it too big? If you put two pests in together, which does it prefer?
- Try to raise some of the lacewing larvae by feeding them small aphids until they are about 3/8 inch long. Once again, collect a variety of pests and offer them to the lacewings. Now that they are larger, do the lacewings accept different prey? What is their choice now if offered two different pests?

— MBCN, v.2, n.6, Susan Mahr, University of Wisconsin-Madison.

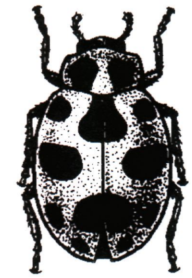


easily recognized as the adults, but they do a good share of devouring pest insects in the field. Larvae are soft-bodied and shaped like miniature alligators. Newly hatched larvae are gray or black and less than 1/8 inch long. Later stage larvae can be gray, black or blue with bright yellow or orange markings on the body.



Ladybug larva

Several species are common in the Midwest. **Twelve-spotted lady beetles *(Coleomegilla maculata)*** are about 1/4 inch long and have pink to light red wing covers with six black spots on each wing. Both adults and larvae feed on **aphids, mites, insect eggs** and small larvae of many insect pests, including the **European corn borer** and **alfalfa weevil**. Plant pollen and fungal spores are also important components of their diet. Females lay clusters of 10 to 20 yellow eggs on plants. This species has two to three generations per year in the Midwest. Large groups of adults overwinter in litter at the bases of trees or along buildings.

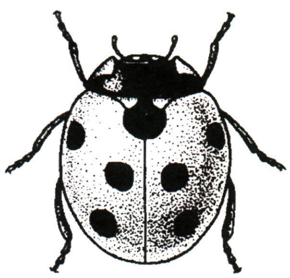


Twelve-spotted lady beetle

Convergent lady beetle *(Hippodamia convergens)* adults are also about 1/4 inch long with orange wing covers that typically have six small black spots on each one, though the number of spots can vary — some adults have no spots on their wing covers. The section of the body behind the head is black with white margins and two converging white lines (the reason for its common name, the convergent lady beetle). Adults and larvae feed primarily on **aphids**. Females lay clusters of 10 to 20 yellow eggs on plants infested with aphids. The larvae grow and molt through four stages. The life cycle is similar to that of the twelve-spotted lady beetle, but this species probably has one or two generations each year in the Midwest. This species is native to North America.

Convergent lady beetle

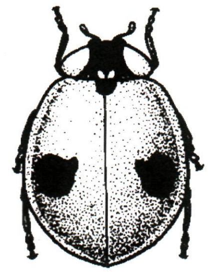
Seven-spotted lady beetle *(Coccinella septempunctata)* was introduced into North America from Europe. Adults are 3/8 inch long and have red wing covers with seven black spots. Females lay clusters of 15 to 70 yellow eggs on plants that are infested with **aphids**. Larvae grow and molt through four stages as they feed on aphid prey. The large fourth instar consumes more aphids than the previous three larval stages combined. Adult seven-spotted lady beetles overwinter in small groups in fencerows or in leaf litter on the ground near the bases of plants.



Seven-spotted lady beetle

Two-spotted lady beetle *(Adalia bipunctata)* is commonly found in trees and bushes and, as one might expect from its common name, is red with two black spots. The 1/4-inch-long adults overwinter in or around buildings or other protected locations and emerge in early to midspring. This species is common in most agricultural and garden habitats in the Midwest.

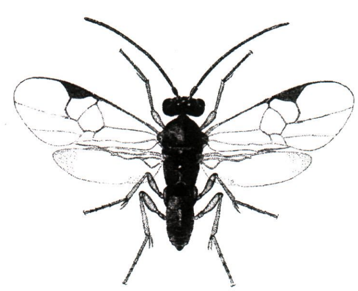
Giving them a boost: Reduce insecticide use or pick selective insecticides. Plant a variety of crops so that ladybugs have a variety of prey available throughout the season. Adults need nectar and pollen, so make sure flowering plants are around. Using sugar sprays in the field may help



Two-spotted lady beetle

attract ladybugs to the area. In a study in alfalfa, crop edges were sprayed and ladybug numbers increased not only in and near the sprayed areas but also well into the unsprayed center of the field. Sugar sprays might be used as a management technique to remove adult lady beetles from fields scheduled to be treated with insecticides — spraying adjacent crops with artificial honeydew could attract beetles from the fields to be sprayed with insecticides.

— *MBCN, v.2, n.4, John Obrycki, Iowa State University; v.4, n.12; E.W. Evans and D. R. Richards, 1997, Managing the dispersal of ladybird beetles (Col.: Coccinellidae): Use of artificial honeydew to manipulate spatial distributions, Entomophaga, 42 (1/2): 93-102.*



Ladybugs Dislodge Aphids

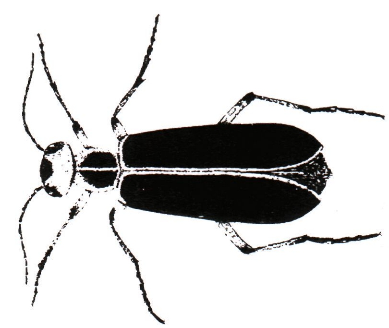
Aphids use a variety of defenses to avoid insect natural enemies. One defense measure is to drop off the host plant when disturbed. As lady beetles begin feeding on aphids, the first contacted aphid secretes a chemical alarm pheromone that alerts nearby aphids to drop off the plant. Aphids falling to the ground may be exposed to additional biological and climatological mortality factors such as ground predators, high soil temperatures and rainfall. Thus, we may be underestimating the importance of ladybugs if we only evaluate them by the number of pests they can eat. In a study in grain sorghum, three to five times as many greenbug aphids were dislodged as were consumed by seven-spotted ladybeetles. If only 25 percent of the dislodged aphids failed to reestablish on a plant, lady beetle efficacy would be 75 to 125 percent greater than estimated in the past.

— *MBCN, v.4, n.11; J.A. McConnell and T.J. Kring, 1990, Predation and dislodgment of Schizaphis graminum by adult Coccinella septempunctata, Environmental Entomology, 19: 1798-1802.*

Blister Beetles

Order: Coleoptera, beetles
Family: Meloidae

Can insects have a split personality? Blister beetles common in many parts of the Midwest may qualify. Though blister beetles are best known for infesting hay and causing blisters in horses, the larvae of most species are actually good insects that feed on **grasshopper eggs**. Some other species are parasitic in the cells of various soil-nesting wild bees. The common name, blister beetle, comes from the body fluids of adults of some common species that contain cantharadin, a compound that may cause blisters when applied to the skin. This compound has killed livestock as well as people who misused it as an aphrodisiac known as Spanish fly.



Blister beetle

What you will see: The adults are generally 1/2 to 1 inch long, narrow and elongate, and the outer wing covering is often soft and flexible, unlike those of many other beetles. Many species of blister beetles are usually dark, metallic blue, green, copper or rose. They may be striped or solid-colored. The clumsy beetles often feed together in groups and move around a lot. They can live four to six weeks as they feed on foliage and flowers of vegetable and ornamental crops.

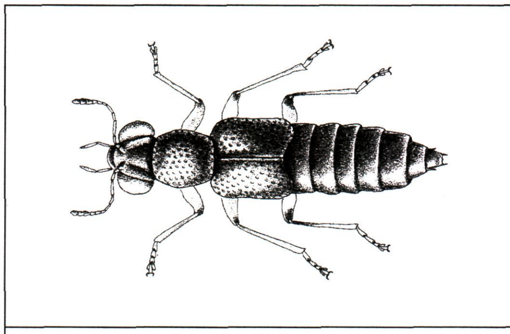
The life history of blister beetles is quite complex — they undergo hypermetamorphosis, with additional life stages not found in other insects. They have several distinct larval stages with very different appearances. The females lay elongate, cylindrical, yellow eggs in clusters of 100 to 200 in shallow burrows in the breeding grounds of the host. The eggs hatch in two weeks. This first instar larva, known as triungulin, is an active, strong-jawed, long-legged larva that burrows through the soil until it finds a grasshopper egg mass. It gnaws into the egg pod and feeds on one or two eggs before molting. During the next four weeks, the larva continues to feed on the egg mass and molt. With each molt, its legs, mouthparts and other appendages grow progressively smaller so that the larva eventually looks like an immobile grub. The beetle will pass through five to seven instars before it pupates in the soil. Most species overwinter as later instar larvae and pupate to complete their development in the spring. The adult beetles emerge rather suddenly, often in great numbers, in June and July.

— *MBCN, v.5, n.6, Susan Mahr, University of Wisconsin-Madison.*

Rove Beetles

Order: Coleoptera, beetles
Family: Staphylinidae

Rove beetles are the largest family of North American beetles, with about 2,900 species. Most are small and of cryptic habits, and though common, the group as a whole is not well studied. Not all rove beetles behave the same — some species are predaceous as both adults and larvae; the larvae of other species are parasitoids; many others are scavengers. They are often found in agricultural soils. Predaceous rove beetles may consume **root maggot eggs** and **larvae, mites,** small **soil insects, insect eggs** or **small insects** on foliage. *Aleochara bilineata* is part predator and part parasitoid of some **root maggots**. *Platydracus* is a voracious predator of **armyworms** in cornfields; *Tachinus* attacks **fly maggots**; and *Paederus* is a generalist predator.

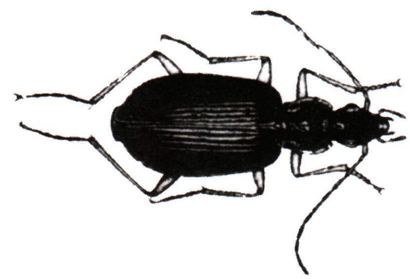


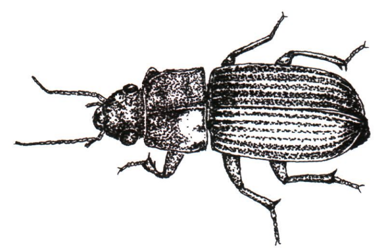
Rove beetle

What you will see: Adult rove beetles are generally less than 3/4 inch long. They are easily recognized by their slender black or brown body and shortened front wings (elytra), which may look like pads on the abdomen. They have a tendency to curl the tip of the abdomen upward when disturbed or running. Adults are usually strong fliers. You may find rove beetles under debris or rocks, in compost piles or crawling on plants. Adults have even been found in sweet corn tassels and silks late in the season.

Giving them a boost: Make sure grassy cover is present near or in your field during winter — rove beetles hibernate in these sites in great numbers. Be selective with chemicals — they are very sensitive to insecticide exposure. Reduced tillage will encourage their abundance.

— *MBCN, v.4, n.4, Susan Mahr, University of Wisconsin-Madison.*


Ground beetle

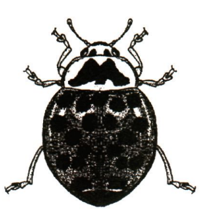

Ground beetle

Ground Beetles

Order: Coleoptera, beetles
Family: Carabidae

Ground beetles are important predators found in most agricultural settings and probably the most numerous predatory insects in some fields. "Why haven't I seen them?" you might ask. Many are nocturnal and spend the day hiding under leaves or in cracks in the soil. Some species also climb into trees, shrubs and crop plants looking for prey. Adult ground beetles run quickly when disturbed but generally do not fly. The adults are fierce predators that chew up their prey with their large, sharp mouthparts. **Aphids, caterpillars, grubs, fly maggots** and **pupae, earthworms, slugs** and other small soil dwellers are commonly eaten by ground beetles. Amazingly, many can consume more than their body weight a day! Some species also eat plant material and **weed seeds**. Though some have herbivorous habits, ground beetles are rarely considered crop pests and tend not to feed on crop seeds — they are often too big.

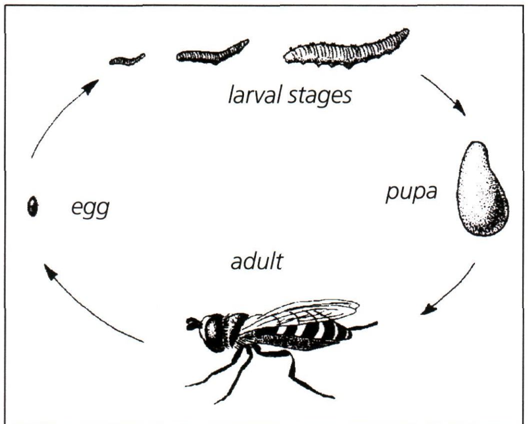
What you will see: Hundreds of species of carabids occur in the Midwest. They vary in size from less than 1/4 inch to greater than 1 1/2 inches long. The adults of most species are dark brown or black, shiny and somewhat flattened, with slender legs for running. A few are iridescent blue or green.



Eggs are deposited either on objects aboveground or in cavities made in the soil. Larvae are important predators that usually remain out of our sight in the soil. Many species overwinter as adults in the soil, then emerge and breed in spring. Others overwinter as larvae, emerge as adults later in the summer and breed. Either way, it takes one year to complete development, and ground beetles often live two to three years.

Giving them a boost: Ground beetles are not commercially available for use in augmentation. However, they can be conserved by avoiding disruptive farming practices. The ground is their home, and tillage and broad-spectrum soil insecticide application are very detrimental to them. In early spring, many ground beetles are still in diapause and cannot escape disruptive agricultural practices. Ground beetles could be encouraged by leaving undisturbed vegetative sites near or in the field. Ground beetles overwinter in hedgerows and grassy strips in very high densities and will later disperse into the crop field. Also, ground beetles are sensitive to drying out, and having cover crops or mulches in the field will encourage adults to remain in the field during the hot summer months.

— *MBCN, v.3, n.4, Susan Mahr, University of Wisconsin-Madison.*



Hover fly life cycle

Hover Flies

Order: Diptera, flies
Family: Syrphidae

Hover fly larvae are common predators of **aphids**, consuming up to 400 aphids each. They will also eat **small caterpillars, thrips** and other **small insects**. Because they are not as conspicuous as lady beetle adults or larvae, they may not be given credit for the effect they have on aphid colonies. They have even been noted as predators of small **European corn borer** and **corn earworm larvae**.

What you will see: As the name suggests, you will see adults hovering over flowers. They may be mistaken for wasps or bees — many have black and yellow stripes on their abdomens. But hover flies have only one pair of wings, a characteristic of all flies (wasps have two pairs). The many hover fly species range in size from less than 1/4 inch to more than 3/4 inch long. Some are hairy with a long, thin abdomen. All have short antennae.

Females lay tiny, white eggs singly on leaves or shoots near or among aphid colonies. Each female may deposit several hundred eggs through midsummer. The larvae hatch in two to three days into small, legless maggots that range from creamy-white to green or brown. These sluglike larvae complete their development in two to three weeks. Some species pupate on the foliage near the feeding site, while others leave the plant and enter the soil to pupate. The smooth, tan pupae are often teardrop-shaped. Hover flies overwinter as pupae. During the growing season, adults emerge in one to two weeks. There may be five to seven generations per year.

Giving them a boost: The adults need flowers as nectar and pollen sources. Some flowers that are especially attractive to hover flies include Queen Anne's lace, wild mustard, sweet alyssum, coriander, dill and other small-flowered herbs.

— *MBCN, v.2, n.11, Susan Mahr, University of Wisconsin-Madison.*

Spiders

Class: Arachnida
Order: Araneae

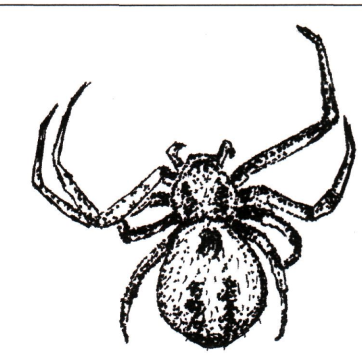
Spiders are highly beneficial, and about 15 families of spiders are frequently found in crops. Virtually any active stage of an insect's life cycle can fall prey to a spider. Some will even eat insect eggs or pupae. Each spider species is more likely to catch a certain prey type because of its method of prey capture. For example, orb weavers are more likely to capture adult flying insects than crawling insects. Spiders are part of the overall natural enemy complex that helps add stability and a buffering capacity to keep pest populations from rapidly expanding.

How they find dinner: As you well know, many spiders construct a web of some sort to capture prey. Common families of web spinners are the orb weavers (family Araneidae); the sheet web spiders (family Linyphiidae); the comb-footed spiders (family Therediidae), which construct a very haphazard type of web; and the funnel web spiders (family Agelenidae). Other spiders are hunters. These do not construct webs to capture their prey, though they may make a silken refuge. These spiders are very active and often run down their prey to capture it. Their good vision helps them detect movement of prey. Examples of hunting spiders include the wolf spiders (family Lycosidae), the jumping spiders (family Salticidae), the lynx spiders (family Oxyopidae) and the two-clawed hunting spiders (family Clubionidae). One large family, the crab spiders (Thomisidae), exemplifies the ambush method of prey capture. These spiders are common on flowers and vegetation and sit motionless until their prey comes within easy grasp.

Giving them a boost: Chances are that many spiders are already present in your field. You can help maintain their populations by not using broad-spectrum insecticides. Insecticides not only directly kill spiders but also kill many non-pest insects that the spiders use for food during periods of low pest numbers. Harvesting and tillage are damaging, and when conducted in late summer or fall, these practices can destroy much of the overwintering spider population. In general, spider diversity is greater in less disturbed perennial crops (forests, orchards, vineyards) than in annual crops. Therefore, annual crops should have nearby undisturbed vegetation to provide shelter for spiders during disruptive farming practices and the overwintering period.

No spiders have been successfully used in classical biological control programs, and none are commercially available for augmentative releases. However, there are a few examples of human manipulation of spider populations for improved natural control. In vegetable plantings, mulches increased spider activity and brought about greater pest control.

— *MBCN, v.3, n.10, Dan Mahr, University of Wisconsin-Madison.*



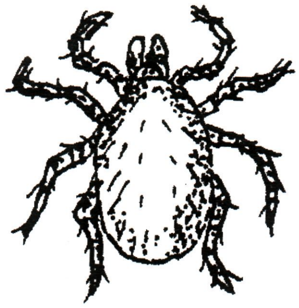
Crab spider

Fallacis Mite

Class: Arachnida
Order: Acari

The fallacis mite, *Neoseiulus fallacis*, is an important predator of **spider mites** in field crops. Though there are many predators of spider mites, the mites are primarily effective in controlled greenhouse settings. The fallacis mite can feed on the **Banks grass mite** (*Oligonychus pratensis*), a pest on corn, and the **two-spotted spider mite** (*Tetranychus urticae*), a pest on corn, soybean, alfalfa and apple trees. Adult mites eat 15 mites per day during their 70-day lifespan. When pest mites are present, the fallacis mite can quickly build its population and significantly reduce pest mite numbers.

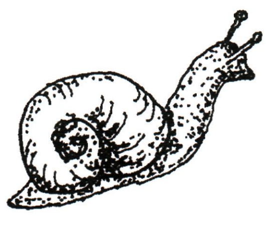
What you will see: These mites are slightly larger than the pest mites, pear-shaped and uniformly pale brown or straw-colored. In addition, they do not have the dark pigmentation characteristic of the pest mite species. Predatory mites are generally recognized on foliage because they are more mobile than pest mites. Fallacis mite eggs are laid in pest mite colonies and, under summer conditions, hatch in 1 1/2 days. After hatching, the juveniles feed on four pest mite eggs per day for the eight days it takes them to reach the adult stage. Female mites will mate and begin to lay about three eggs per day for about 13 days.



Mite

Giving them a boost: Fallacis mites are particularly effective during cooler, moist periods in early and midsummer when pest mite reproduction is slowed. Though high temperatures do not reduce the development rate of the fallacis mite, low relative humidity may be the cause of low adult survival and high egg mortality. Under conditions of higher humidity, such as those found in well watered, non-stressed field corn, the fallacis mite can control Banks grass mite. Planting cover crops will increase humidity and help predatory mites. When making pest management decisions, consider the abundance of predatory mites and the long-range weather forecasts.

—MBCN, v.2, n.7, Ron Seymour, West Central Research and Extension Center, North Platte, and Bob Wright, South Central Research and Extension Center, Clay Center, University of Nebraska-Lincoln.



Parasitoids

Parasitoids also eat their prey, but they differ from predators in the following ways:

- They are slightly to substantially smaller than their host insect.
- All have holometabolous development that includes larval and pupal stages; the larval stage is parasitic, often feeding on the inside contents of the host.
- Each larva kills one host during its development.
- The larvae are totally restricted to parasitizing the single host insect and are often found internally in the host and, therefore, are not mobile in the environment.
- Adult parasitoids are usually winged, mobile and short-lived; they may feed on plant sources, and some also feed on the hosts, which means they kill more pests in a lifetime.
- Parasitoids tend to be more host-specific than predators.

Most agricultural pests are attacked by one or more parasitoid species. About 68,000 species of parasitoids have been given scientific names. This constitutes a little under 10 percent of all known insect species. Entomologists generally believe that only about 10 percent of all insect species are known to science, so possibly as many as 800,000 species of parasitoids actually exist! The most important parasitoids are flies and wasps. The term "wasp" may bring to mind hornets and yellow jackets, which sting and can be aggressive toward people. Parasitoid wasps, however, are harmless to people, and their presence usually goes unnoticed. The long, slender tubes at the ends of their bodies are not stingers but ovipositors, specialized structures for laying eggs. Parasitoids are often very small — some are no bigger than the period at the end of this sentence.

The physical descriptions of parasitoids are not very detailed. Most entomologists have a hard time telling them apart! Nevertheless, anyone can spot their activities. Parasitized aphids often turn black or brown and develop a hard casing. Unfortunate caterpillars may be cleaned out on the inside, with only their skin remaining after the parasitoid emerges.

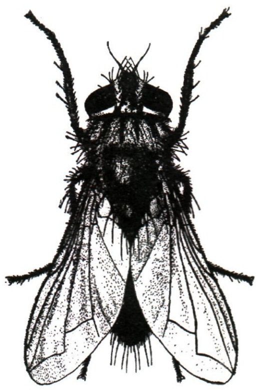
— *MBCN, v.5, n.6, Dan Mahr, University of Wisconsin-Madison.*

Tachinid Flies

Order: Diptera, flies
Family: Tachinidae

Tachinid flies are by far the largest and most important group of insect parasitic flies, with more than 1,300 species in North America. All species are parasitic in the larval stage, and many are important natural enemies of major pests. Many species of tachinids have been introduced into North America from their native lands to suppress populations of alien pests. Most tachinids attack **caterpillars** and **adult and larval beetles**. Other species kill **sawfly larvae**, various types of **true bugs, grasshoppers** or other types of insects.

What you will see: Tachinid flies differ in color, size and shape, but many somewhat resemble house flies. They usually are either gray, black or striped, and they often have



L. thompsoni

many distinct abdominal bristles. Most if not all tachinids are internal parasites — they feed inside their hosts. Most species are solitary, but some are gregarious, with anywhere from two up to a dozen or more capable of developing within a single host. Development of egg and larva is rapid for most tachinids, and pupation often occurs within four to 14 days after egg laying. Many species are capable of several generations per year, but others are restricted to only one generation, especially if their hosts have only a single generation.

Lydella thompsoni is a solitary internal parasitoid of **European corn borer larvae**. This tachinid fly was introduced as part of a classical biological control program and was one of the few species that established in the United States and has also spread to many areas where it was not released. For many years after its introduction, *L. thompsoni* was the most important parasitoid of European corn borer in many areas of the United States. Parasitization of up to 75 percent of the second borer generation was recorded in the early years, and it was considered a major controlling factor of borer populations. But there was an abrupt, unexplained decline in populations around 1960 and the fly disappeared from many places. In much of the Midwest, *E. terebrans* and *M. grandii* are the predominant parasitoids. Also, pathogens such as *Beauveria bassiana* and *Nosema pyrausta* may cause significant mortality and affect parasitoid populations.

The adult fly resembles a large, very bristly house fly. The female retains her eggs inside her body for about five days, until eggs are ready to hatch. She can be found on cornstalks, searching from side to side. She is drawn to volatiles of the frass (insect excrement) that was pushed out of the corn borer tunnel and may even "taste" the frass when she encounters it. As the female deposits her eggs, hatching takes place. Living maggots are deposited from the mother's ovipositor at the entrance of the borer tunnel. This first instar must then move into the tunnel and find its way to the borer, preferring to attack fourth instar borers. The maggots have a sharp tooth to penetrate the host body. In defense, the corn borer may squirm or wiggle or bite at the area being attacked, but it rarely succeeds. The maggot enters the host and feeds first on the body fluids, then on the fatty tissues and internal organs. When the borer dies, the maggot forces an opening in the skin but continues to feed until its development is complete. Thereafter, it leaves the host remains and pupates in the tunnel nearby. Larval development takes about eight days, and the pupal stage takes another eight days.

In the Midwest, *L. thompsoni* emerges from overwintering before corn borer larvae are available and thus will parasitize the common stalk borer, which allows the population to survive until the next generation of the corn borer is available to parasitize. There are usually two generations a year, but three generations often occur when another host is utilized for the first generation. *L. thompsoni* pass the winter as second instar maggots in the hibernating host larvae.

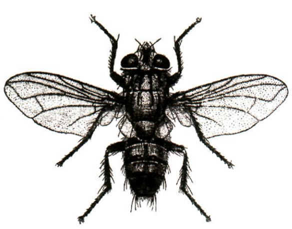
Giving them a boost: Adult tachinid flies feed on nectar, especially from plants such as Queen Anne's lace and meadowsweet. Adults also depend on aphid honeydew, so having non-crop plants with some aphids is welcomed. Though many tachinid flies have been introduced for classical biological control programs, they are not augmentatively released.

— *MBCN, v.4, n.9; v.6, n.3, Susan and Dan Mahr, University of Wisconsin-Madison.*

Biological Control of European Corn Borer

The European corn borer (ECB), *Ostrinia nubilalis*, is native to Europe. It was first found in Massachusetts in 1917, later spreading to Illinois, Minnesota, Iowa, South Dakota, Nebraska, Kansas, Missouri, Indiana and Ohio and becoming a serious pest of field corn and sweet corn. The ECB bores in cornstalks, reducing plant vigor and causing lodging.

From 1920 to 1938, the USDA waged a campaign against ECB, importing into the United States 24 species of parasitoids from Europe and Asia. Six species established, and of these the ichneumonid wasp *Eriborus terebrans*, the braconid wasp *Macrocentrus grandii* and the tachinid fly *Lydella thompsoni* became widespread and effective biological control agents. *E. terebrans* and *M. grandii* are the predominant parasitoids in the Midwest; *L. thompsoni* is more common in the eastern United States. The fungal and microsporidial pathogens *Beauveria bassiana* and *Nosema pyrausta* may cause significant ECB mortality and affect parasitoid populations, though infection rates vary from year to year. The bacterium *Bacillus thuringiensis* has controlled ECB in field and sweet corn so successfully that it has been introduced into transgenic corn. Using transgenic *Bt* corn may be more convenient and effective than spraying, but it increases the risk of ECB and other insects developing resistance to *Bt* and requires careful management.



Braconid Wasps

Many of the parasitoids described in this section are braconid wasps (family Braconidae). There are more than 1,700 braconid species in North America — all are parasitoids of insects or other arthropods. Braconids attack caterpillars, flies, sawflies, wood-boring beetles, weevils, leafmining insects, true bugs, ants and aphids. Most are small wasps, ranging in size from 1/10 to 1/2 inch. They are generally black or brown, but some have yellow, orange or red markings. They have long and noticeable antennae, and the ovipositor may also be long and readily apparent. The generation time of most braconids is relatively short — 10 to 30 days. Braconids are important in the natural and biological control of many serious pests of the farm, forest and garden. Several exotic species have been introduced and permanently established for the control of alien pests. A few species are available commercially for augmentation biological control.

Macrocentrus grandii

Order: Hymenoptera, wasps
Family: Braconidae

Macrocentrus grandii was first released in Massachusetts and became the dominant parasitoid in the East, parasitizing up to 56 percent of **European corn borer larvae**. *M. grandii* became established in the Midwest during the late 1940s and was soon considered an important mortality factor of the corn borer. Wasp populations declined, however, in the early 1960s when the microsporidian pathogen *Nosema pyrausta*, which affects both the wasp and the borer, established here.

What you will see: Adult wasps are about 3/16 inch long, with a black head and a yellowish brown to blackish brown body. The ovipositor of the female is longer than the rest of the body. The female is attracted to larval tunnels with frass and webbing. Upon finding hosts, she deposits her eggs singly in second or third instar corn borer larvae. The female raises the end of her abdomen and probes rapidly in the area where the borer has been feeding. She then inserts her ovipositor through the plant material into the borer (this is why she needs such a long ovipositor). Females deposit 200 to 300 eggs. Each egg develops into 15 to 25 embryos, a process called polyembryony. Eggs laid in first generation corn borers hatch in a few days, but eggs in second generation borers remain in the over-wintering host larva and hatch in early April

M. grandii

of the following year. The new larvae feed internally through three instars. After the third molt, the larvae leave the body of their host through the skin and feed externally until the borer is emptied. They construct glossy, light brown silk cocoons in an elongate group to form a 1-inch-long, cigar-shaped mass attached to the shriveled remains of the host. The adults emerge in 10 days in late June to July to mate and lay eggs parasitizing new European corn borer larvae.

There can be a dramatic difference in parasitization rates between the first and second corn borer generations. In surveys in Illinois, parasitism of first generation European corn borer averaged 18 percent, while parasitism in the second generation was less than 5 percent. In a study in Michigan, *M. grandii* was present only in the second generation one year but not at all in the following year. Today *M. grandii* is considered a minor mortality factor of the European corn borer in the Midwest, though it may be locally abundant in some areas and have a significant impact on borer populations.

Giving them a boost: Having cover crops and flowering vegetation near or in fields may help protect them from heat and provide nectar sources.

— *MBCN, v.6, n.8, Susan Mahr, University of Wisconsin-Madison.*

Peristenus digoneutis

Order: Hymenoptera, wasps
Family: Braconidae

Peristenus digoneutis is a braconid wasp parasite of **tarnished plant bugs** (*Lygus* spp.). Starting around 1978, entomologists collected *Peristenus* wasps in Europe and shipped them to the United States. These wasps were first released in northern New Jersey in 1979 for control of tarnished plant bug on alfalfa. *Peristenus* was recovered in low numbers and was determined to be established there by 1988. Within a few years, parasitism levels began to rise, reaching 50 percent by 1990-92. It had become the dominant parasitoid species in northern New Jersey and has spread to six new states: Pennsylvania, Massachusetts, New Hampshire, Vermont, Connecticut and New York.

P. digoneutis has reduced tarnished plant bug numbers by 75 percent in New Jersey alfalfa. This reduction in plant bug numbers not only benefits the alfalfa crop but also may benefit valuable fruit and vegetable crops — when alfalfa is harvested, fewer tarnished plant bug adults will be flying into and damaging other nearby crops. Researchers are trying to find out if *P. digoneutis* disperses and remains in perennial fruit crops, annual bean crops and several seed crops. If *P. digoneutis* is found in other crops, it may be exerting greater biological control of tarnished plant bug than we are aware of.

What you will see: *P. digoneutis* is a 1/8-inch-long brown wasp. The adults emerge from overwintering cocoons in May and June and live two to four weeks. Females lay eggs singly in the abdomens of lygus bug nymphs. They hatch in five to seven days. The wasp larva develops inside the bug for seven to 10 days. Then the mature larva emerges from the dying host to spin a cocoon just under the soil surface. A second generation of adults emerges in July to attack the next generation of lygus bugs. There may also be a partial third generation in August if the host population has another generation. In each wasp generation, an increasing proportion of individuals enter diapause — they delay emerging from their cocoons until the following spring. This behavior ensures that parasitoids will be present the next year even if hosts become scarce at the onset of winter.

Giving them a boost: Weeds around fields may be a suitable habitat for the adult parasites, especially if they harbor tarnished plant bugs. Cruciferous flowers, goldenrod and Queen Anne's lace provide nectar for the wasps. *P. digoneutis* is difficult to raise and thus not available commercially. Most suitable areas will eventually have self-sustaining, natural populations of *P. digoneutis*, however, because it has been dispersing naturally. It may move into the Midwest on its own, or releases of wasps collected in the East will be made in the Midwest.

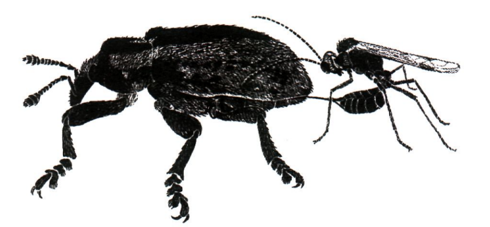
— *MBCN, v.5, n.10, Bill Day, USDA-ARS Beneficial Insects Research Lab, Newark, Del., and Susan Mahr, University of Wisconsin-Madison.*

Microctonus aethiopoides

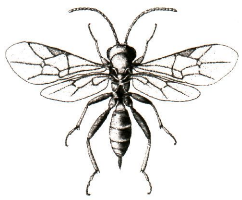
Order: Hymenoptera, wasps
Family: Braconidae

Unlike the other weevil parasitoids, *Microctonus aethiopoides (=aethiops)* attacks **adult alfalfa weevils**. It was first imported into the United States from Europe for use against the sweetclover weevil. Scientists later discovered that there are several strains of the wasp that are very specific for particular weevil species. From many releases made by the USDA at various locations from 1957 through 1988, *M. aethiopoides* has become well established throughout the alfalfa-growing areas of the upper Midwest and northeastern United States. *M. aethiopoides* is one of the most important parasitoids in maintaining alfalfa weevil at or below economic levels.

M. aethiopoides not only kills adult weevils but also sterilizes them. Parasitized female alfalfa weevils cease oviposition within three days; male weevils are castrated shortly after parasitization. Though the parasitized summer generation weevils will survive until the following spring, they are unable to reproduce and hence contribute nothing to the alfalfa weevil population. A female alfalfa weevil deposits an average of 1,350 eggs before the



M. aethiopoides



first alfalfa cutting, so each successful parasitization eliminates the potential damage of many alfalfa weevil larvae.

What you will see: The small, stingless *M. aethiopoides* wasps are about 1/8 inch long. Females are reddish brown and males are black. Females will lay eggs only in moving adult weevils. Why? An adult weevil has a hard casing — a parasitoid would have a hard time piercing it with the ovipositor. But a weevil in motion exposes its membranous abdominal tip (back end), and *M. aethiopoides* takes advantage of the exposed soft spot, laying a single egg directly inside the body cavity of the weevil. The larva hatches, feeds internally and completes its development in 22 to 26 days. Adult weevils show no external signs of parasitism until the larva is fully grown and forces its way out of the back end of the weevil. The wasp larva spins a whitish silk cocoon and pupates in the soil or under debris. An adult wasp emerges six to nine days later. *M. aethiopoides* overwinters as first instar larvae inside hibernating weevils.

M. aethiopoides has two generations per year that are well synchronized with the adult weevil's activity. The first generation attacks and lays eggs in the surviving overwintered weevil adults (spring population) that lay eggs in mid-May. The second generation attacks newly emerged adult weevils (summer population) in late June. Parasitism rates of alfalfa weevil adults vary from year to year, sometimes averaging 40 and 52 percent for the spring and summer weevil populations, respectively.

Giving them a boost: Avoid using insecticides when adult parasitoids are active. Leave parts of the alfalfa crop uncut — this refuge allows some parasitized weevils to survive and thereby maintains the parasitoid population.

— *MBCN, v.4, n.7, Abdul Aziz Mohamed, University of Wisconsin-Madison.*

Nealiolus curculionis

Order: Hymenoptera, wasps
Family: Braconidae

The braconid wasp *Nealiolus curculionis* is the most abundant parasitoid attacking the larvae of **sunflower stem weevil**, *Cylindrocopturus adspersus*, in both wild and cultivated sunflowers. In North Dakota, 96 percent of parasitized weevil larvae from 1980 to 1991 were parasitized by this species. The ability of the female *N. curculionis* to effectively locate and attack hosts under varying host population densities and in crops planted on different dates is one reason for the success of this parasitoid.

What you will see: *Nealiolus curculionis* adults are active from late June to late August. Females deposit eggs in early larval stages of the weevil while they are feeding within sunflower stalks. The immature parasitoids overwinter within diapausing weevil larvae in the sunflower stalks.

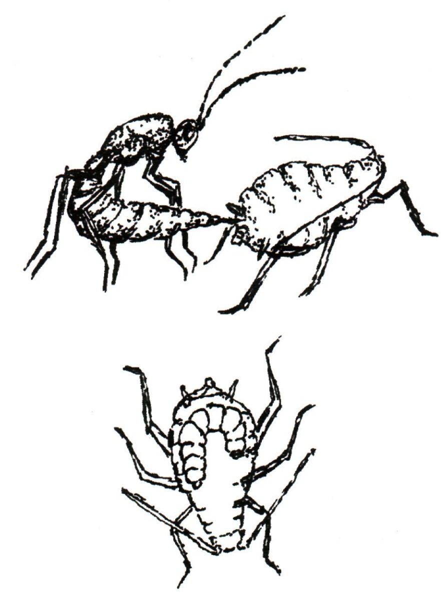
Giving them a boost: Delay planting — this will reduce weevil numbers in sunflower stalks and subsequent damage but will not harm parasitoids. Crop rotation also helps keep weevil numbers and damage low. Use chemical treatments only when weevil densities exceed the economic threshold — this will spare unnecessary killing of the parasitoid.

— *MBCN, v.2, n.7, Larry Charlet, USDA, ARS, Northern Crop Science Lab, Fargo, N.D.*

Lysiphlebus testaceipes

Order: Hymenoptera, wasps
Family: Braconidae

Lysiphlebus testaceipes is the most common wasp attacking **greenbug aphids** in wheat and grain sorghum as well as other **aphids**. Wasps are quite mobile, capable of flying more than 218 yards in a day. Sometimes the larva gets a free ride inside winged aphids that undertake long migration flights.



L. testaceipes

What you will see: *L. testaceipes* is a dark, tiny wasp less than 1/8 inch long. Each female wasp can parasitize about 100 greenbugs during her four- to five-day life span. The female inserts an egg into the greenbug; the tiny wasp larva hatches and feeds internally for six to eight days until the aphid dies. As the wasp larva moves inside the aphid, it expands the aphid, giving it a swollen appearance. The larva cuts a hole in the bottom of the aphid and attaches the aphid to the leaf with silk and glue. The dead greenbug changes color from green to brown and is referred to as a mummy. Then the wasp larva pupates. After four to five days, an adult wasp emerges by cutting a circular hole in the top of the mummy. The newly emerged wasp mates and begins to search for new aphids to attack. At 70 degrees F, development from egg to adult takes about 14 days. *L. testaceipes* overwinters as a grub or pupa inside a parasitized aphid.

Giving them a boost: Insecticides applied as sprays will kill adult wasps and immature wasps developing inside greenbugs killed by insecticides. If an insecticide must be used, one with short residual activity is preferable — it will allow parasitoids to recolonize the field quickly and maintain remaining greenbugs at low levels. Sometimes *L. testaceipes* may occur too late in the season to prevent economic damage. Planting strips of a greenbug-susceptible sorghum hybrid in a field of greenbug-resistant sorghum or leaving some areas unsprayed with insecticide can help encourage early activity of parasitoids. Greenbugs would develop first in the susceptible or unsprayed strips and become parasitized by *L. testaceipes*. Then the wasps would disperse into the rest of the field to begin controlling greenbugs. As a general rule of thumb, if 20 percent or more of the greenbugs present are mummies, insecticide treatment is not needed — greenbug populations decline naturally through the activity of the wasp.

— MBCN, v.2, n.9, Bob Wright, University of Nebraska; v.4, n.1, O. Fernandes, University of Nebraska-Lincoln.

Diaeretiella rapae

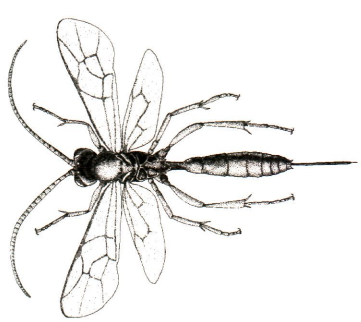
Order: Hymenoptera, wasps
Family: Braconidae

The parasitic wasp *Diaeretiella rapae* is distributed worldwide and is known to attack more than 30 species of **aphids**, including **greenbugs, Russian wheat aphid, corn leaf aphid** and **English grain aphid**. *D. rapae*, the previously mentioned *L. testaceipes* and other greenbug parasitoids suppress greenbugs by directly killing them and reducing their reproductive rate. Parasitized greenbugs stop reproducing within one to five days; healthy greenbugs give birth to three to four live greenbugs a day for 25 to 30 days. Thus, the activity of these wasps can greatly reduce the rate of greenbug increase. Greenbug wasps are constrained by temperature. They develop rapidly when temperatures are above 65 degrees F, but adults are not active if temperatures are below 56 degrees F. Greenbugs are much more tolerant of cool temperatures and continue to reproduce until temperatures drop to 40 degrees F, so wasps may not be effective in controlling greenbugs in wheat during cold weather in the fall and spring.

What you will see: These tiny, black wasps are not commonly seen, but the distinctive aphid mummies that remain on leaves after the parasite has killed the greenbug can be easily detected. Greenbugs parasitized by *D. rapae* are beige or tan, round and swollen. Parasitoid activity in the field can be monitored by looking for greenbug mummies on crop leaves. As a general rule, a greenbug infestation usually declines rapidly after 20 percent of the greenbugs are mummies because, at this point, most of the living greenbugs also have been parasitized but have not yet turned into mummies. Normally mummies appear eight to 10 days after wasps lay their eggs in the greenbugs.

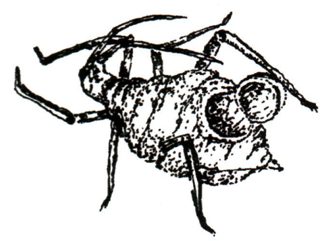
Giving them a boost: Maintaining a diversified cropping system and having several potential aphid hosts available allow *D. rapae* to maintain itself in the area. When pest aphids do build in numbers, *D. rapae* populations will be present to control them. Plants in the families of Chenopodiaceae (beets, lambsquarter), Cruciferae (mustards and cole crops), Solanaceae (horsenettle, potato) and Liliaceae (onions, iris) can harbor other non-pest aphid species and will help maintain *D. rapae* populations.

— *MBCN, v.2, n.9, Bob Wright, University of Nebraska; v.4, n.10; K.S. Pike, P. Stary, T. Miller, D. Allison, G. Graf, L. Boydston, R. Miller and R. Gillespie, 1999, Host range and habitats of the aphid parasitoid Diaeretiella rapae (Hymenoptera: Aphidiidae) in Washington State, Environmental Entomology, 28: 61-71.*



Activity: What's Inside Those Aphid Mummies?

You may have noticed some aphids that have a hard casing and tan or dark color. These aphid mummies are parasitized. With a magnifying lens, take a closer look.



Aphid mummy

Is there an exit hole? That means the parasitoid already left. Collect some mummies without exit holes, keep them in a jar and watch what emerges.

Ichneumonid Wasps

Ichneumonid wasps are one of the largest groups of insects, with more than 3,100 species in North America. Adult ichneumonids vary a lot in size but are generally larger than braconid wasps. Size is somewhat host dependent, and some that parasitize large hosts may be 1 1/2 inches long. The ovipositor is often quite long, sometimes longer than the body, and the antennae are long and noticeable. Most are black, brown or tan, but some are more brightly colored. Ichneumonids attack many types of insects, including caterpillars and the larvae of beetles and sawflies. The larval stage of ichneumonids varies from about 10 days to several weeks. Many species have a single generation per year; others have two or more generations annually. Though ichneumonids are very important in the natural control of many plant pests, surprisingly few have been actively used in biological control programs.

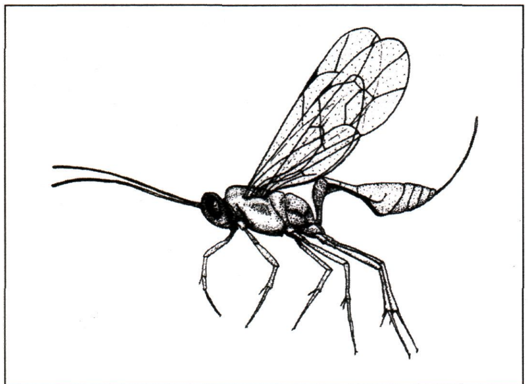
— MBCN, v.5, n.4, Dan Mahr, University of Wisconsin-Madison.

Eriborus terebrans

Order: Hymenoptera, wasps
Family: Ichneumonidae

Eriborus terebrans was introduced into the United States as part of a classical biological control project to control **European corn borers**. Wasps collected from Asia and Europe were released from 1927 through 1940 in 13 states from Vermont to Virginia and west to Indiana and Michigan. It became established and is currently one of the most widely distributed parasitoids of the corn borer in the north central region.

What you will see: *E. terebrans* overwinters as a larva inside overwintering corn borers and resumes development in the spring. The first generation of *E. terebrans*



E. terebrans

emerges with the first larval generation of European corn borers. Females quickly mate and can lay eggs within a day after emergence. The frass and webbing of corn borer attract female parasitoids, which then prefer to lay eggs in second to fourth instar corn borers. Second generation *E. terebrans* adults emerge before peak numbers of second generation corn borer larvae. For this reason, *E. terebrans* is considered to have a stronger impact on first generation corn borer.

Giving them a boost: Wasps may live seven to 10 days under ideal conditions at 75 to 80 degrees F with access to water and sugar — that is, flower nectar or aphid honeydew. Their life span is reduced to three to four days when temperatures are above 90 degrees F and they do not have access to sugar sources. During the first corn borer generation, prior to corn canopy closure, maximum temperatures in cornfields may often exceed 90 degrees F. Also, sources of nectar or honeydew may be scarce in the middle of cornfields. Therefore, it is very important to have nearby flowering vegetation to provide wasps with shade and sugar. Past studies showed that wasps survived better in wooded field borders and that the first generation European corn borers near the wooded edges were parasitized at rates two to three times higher than those in the center of the field.

— *MBCN, v.3, n.11, Bob Wright, University of Nebraska.*

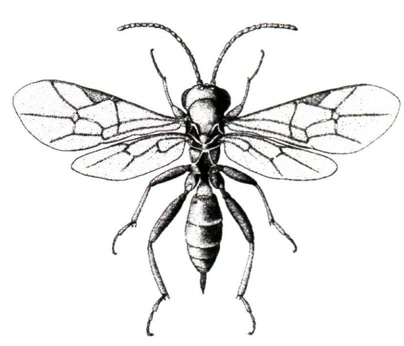
Bathyplectes wasps

Order: Hymenoptera, wasps Family: Ichneumonidae

Bathyplectes are small, non-stinging parasitoids of **alfalfa weevil larvae**. *Bathyplectes* are very specific natural enemies that occur only in and around alfalfa fields and attack only the alfalfa weevil, *Hypera postica*. There are two species of *Bathyplectes* in the Midwest, *B. curculionis* and *B. anurus. B. anurus* is considered the superior biological control agent, partly because *B. anurus* has a 50 percent greater reproductive potential than *B. curculionis* (300 vs. 200 eggs). Also, alfalfa weevil larvae are able in many cases to kill *B. curculionis* eggs through a process known as encapsulation. The weevil larva's immune system recognizes the parasitoid egg as a foreign invader and its specialized cells aggregate around and seal off the egg.

What you will see: The two species are similar in appearance and habits. Adults are about 1/8 inch long with black, robust bodies. Both lay their eggs in alfalfa weevil larvae, preferring to oviposit in the early instars. The wasp larva that hatches from the egg feeds internally and slowly devours the weevil larva, ultimately killing the weevil after the weevil has finished spinning its cocoon. The parasitoid larva emerges from the weevil and spins a cocoon of its own. Only one parasitoid can successfully develop in a host weevil. *Bathyplectes* cocoons are about 1/7 inch long, brown and football-shaped with a white band around the middle. The cocoons of the two parasitoid species are the most visible life stage and also the easiest stage for distinguishing the species. In *B. anurus*, the white band is raised, and the cocoon has the unusual habit of jumping when disturbed. In *B. curculionis*, the white band is not raised and the cocoons do not jump.

The flight activity of both *Bathyplectes* species synchronizes with the spring activity of the alfalfa weevil larvae. The flight lasts up to several weeks, and peak parasitism levels occur one to two weeks prior to the peak in numbers of weevil larvae. *B. anurus* has just one generation a year, with all parasitoid pupae produced by spring parasitism undergoing diapause (hibernation) and emerging as adults the following spring when weevil larvae are abundant. *B. curculionis*, on the other hand, has a partial second generation. Many of the parasitoid pupae from spring parasitism are in diapause, but some develop and emerge as adults that must find and parasitize weevil larvae during the summer.



Bathyplectes wasp

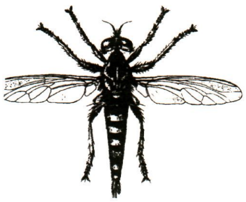
Giving them a boost: *Bathyplectes* are not available commercially, but they occur virtually everywhere the alfalfa weevil occurs in the Midwest. The best way to enhance the effectiveness of *Bathyplectes* species is conservation. Leave uncut refuge areas of alfalfa where some parasitized weevils can give rise to more parasitoids. *Bathyplectes* need sugar sources. A moderate level of aphids in the field may be desirable because aphid honeydew is the main food source when flowers are not available during early spring or late fall.

— *MBCN, v.1, n.2, Dave Hogg, University of Wisconsin-Madison; v.5, n.3; S. England and E.W. Evans, 1997, Effects of pea aphid honeydew on longevity and fecundity of the alfalfa weevil parasitoid Bathyplectes curculionis, Environmental Entomology, 26:1437-1441.*

Activity: Parasitism of Alfalfa Weevil

Though alfalfa weevil is a common pest of alfalfa, both the larval and adult stages are attacked by parasitoids. Rear some parasitoids in a homemade growth chamber.

- Collect adults and larvae in the spring from unsprayed alfalfa fields for rearing to identify any parasite species present in your location.
- Place the adult weevils in containers with some alfalfa stems. Cover the top of the container with a piece of cheesecloth held on with a rubber band to prevent weevil escape. Replace the stems every few days and



frequently check the bottoms of the containers for the white silken cocoons of the parasitoids.

- Place the weevil larvae in paper grocery bags, along with a handful of alfalfa stems from unsprayed fields. Fold the top of the bag over and paper clip it shut. Add additional stems every three to four days as needed. Check the condition of the larvae after 15 days. By this time there may be newly emerged light brown adult alfalfa weevils and parasitoid cocoons at the bottom of the bags.

Some common parasitoids in the Midwest include two species of *Bathyplectes*, a tiny wasp that parasitizes the weevil larvae and spins a brown, football-shaped cocoon with a white band around the middle, outside the host pupa; the eulophid wasp *Tetrastichus incertus*, which attacks larvae and emerges from the mummified host body; and *Microctonus aethiopoides*, a braconid wasp that attacks and emerges from adult weevils. There is also a common fungal pathogen, *Zoophthora phytonomi*, that infects larval alfalfa weevil.

- What percentage of the larvae or adults you collected were parasitized? What types of parasites did you find? Did you notice whether any larvae you collected were diseased?

— *MBCN, v.3, n.6, Dave Hogg and Abdul Aziz Mohamed, University of Wisconsin-Madison.*

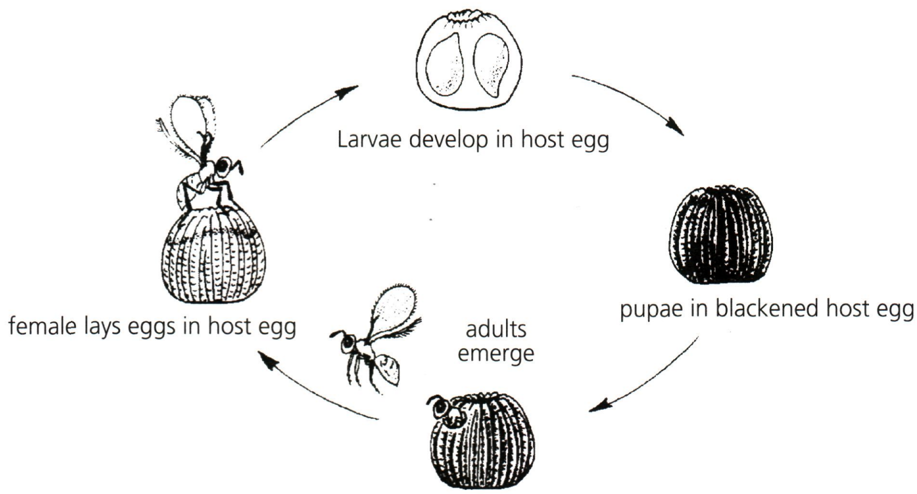
Trichogramma wasps

Order: Hympenoptera, wasps
Family: Trichogrammatidae

Numerous species of *Trichogramma* wasps attack the **eggs of more than 200 species of moths and butterflies**. These almost microscopic parasitoids are very important in preventing crop damage because they kill their hosts before the insects can cause plant damage. These wasps are harmless to people, animals and plants. Though *Trichogramma* wasps occur naturally throughout the United States, they usually do not occur in high enough numbers to effectively suppress pest populations.

What you will see: You probably won't see them at all. Adults are 1/25 inch long — about the size of the period at the end of this sentence. The female *Trichogramma* lays an egg within a new host egg, and as the wasp larva develops, the host egg turns black. Each female parasitizes about 100 eggs and may also destroy additional eggs by host feeding. The short life cycle of eight to 10 days allows the wasp population to increase rapidly.

Trichogramma wasp



Trichogramma life cycle

Giving them a boost: *Trichogramma* are readily available in large numbers from commercial suppliers for augmentative releases. Determining the best species or strain to release may be difficult. Most suppliers provide detailed instructions for strain selection, release and rates to use *Trichogramma*, but their recommendations may not always be accurate. Frequent releases made over several weeks result in better parasitism and control than a single large release. Releases should begin at the time of the first moth flight, before the pest population has built up. Regular scouting to determine the appearance of caterpillar eggs is a good method to determine when hosts for *Trichogramma* are present.

The wasps are shipped as immatures inside moth eggs glued to small cards that can be attached by hand to infested plants. Keep the cards in a warm, humid place out of direct sunlight until the emerging adults can be seen as small dots moving around in the closed container. When most of the adults have emerged, place the cards in a shaded spot upwind of the areas where moths are suspected or egg laying is occurring. The adult wasps will fly onto the plants in search of new host eggs to attack. Do not put the cards out before the wasps have emerged because ants and other predators may eat them. The emerging wasps will have the best chance of finding and parasitizing eggs when the weather is moderate. The best time to release is early morning or evening when direct sunlight will not hit the cards. Avoid making releases under extremely hot, cold, rainy or windy conditions.

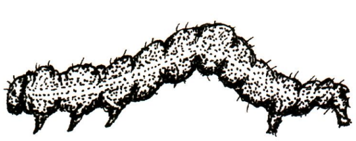
— *MBCN, v.1, n.4, Susan Mahr, University of Wisconsin-Madison.*

Pathogens

You may have seen a limp, dark caterpillar hanging on a branch or a fly stuck to a window coated with white mold. These insects have succumbed to pathogens. Many microorganisms — bacteria, fungi, nematodes, protozoans and viruses — can naturally suppress pest populations in the field if certain environmental conditions are right. Because we cannot control the climate, pathogens are hard to manipulate, so their use in biological control is either through introduction and establishment or augmentation. Some pathogens are sold commercially as microbial insecticides.

All pathogens except nematodes are regulated much the same as chemical insecticides and must be registered by the Environmental Protection Agency. This can be advantageous for the consumer because more information is available about them than other natural enemies. However, these microbes are more sensitive than chemicals and have a shorter shelf life and special storage requirements and application procedures.

Microbial insecticides are generally harmless to animals and humans and can specifically target certain pests. They do not persist long outdoors, and this reduces the risk of insects becoming resistant to them. When used as instructed, these microbes can be valuable biocontrol agents and help conserve predators and parasitoids from more harmful chemical pesticides.



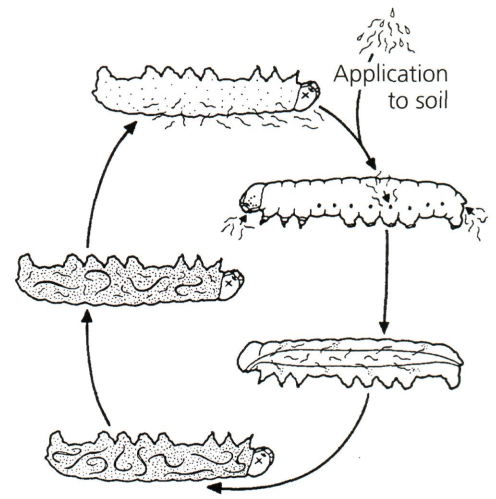
Nematodes

Phylum: Nematoda
Families: Steinernematidae and Heterorhabditidae

Insect-attacking nematodes in the families Steinernematidae and Heterorhabditidae have received a great deal of attention in the past 10 to 15 years because of their potential as biological control agents for a **wide range of insect pests**, especially those living in the soil, such as **beetle larvae**. These nematodes attack many pest insects, can search for and kill their hosts rapidly, and are safe to non-target organisms. Advances in production, application and storage technologies have made it possible to produce them economically in large numbers and encouraged their commercialization.

Life of a nematode: Insect-attacking nematodes have a life cycle consisting of an egg, four juvenile stages and the adult. Both steinernematid and heterorhabditid nematodes have a specialized third juvenile stage, the infective juvenile, which is the stage that attacks insects. The infective juvenile can survive in the soil for extended periods until it is able to find a susceptible host.

They do not have eyes but find hosts by orienting to carbon dioxide and other excretory products of the host. Infective juveniles enter hosts through the mouth, anus or breathing pores (spiracles). These nematodes carry a special species of bacterium in their intestines. When they enter the host, they release the bacteria, which rapidly multiply. The bacteria release



Nematode life cycle

protein-destroying enzymes that kill the host, usually in 24 hours. Thereafter, the nematodes feed on the bacteria and host remains and complete two to three generations inside the host. When the host is cleaned out, infective juveniles leave and search for new victims.

When a host is infected with steinernematid nematodes, it takes seven to 10 days at room temperature for new infective steinernematid nematodes to emerge from its dead host. If the host is infected with heterorhabditid nematodes, it takes about 12 to 15 days.

What you will see: The fact that different species of bacteria are associated with steinernematid and heterorhabditid nematodes causes differences in the appearance of infected hosts. Insects infected by steinernematid nematodes are limp and cream to dark brown, while those infected by heterorhabditid nematodes turn brick red and glow in the dark.

Giving them a boost: When you buy nematodes, you are getting the third stage larvae (infective juveniles). This stage is adapted for host finding and survival in moist soil. Using nematodes effectively depends on proper selection of nematode species or strains for the desired target pest and providing proper conditions for their survival after application. They depend on water film for movement and survival and should be watered into the soil. Most nematode species are not very active when soil temperatures are below 60 degrees F. If nematodes are applied to cool soil, they may sun themselves at the soil surface, dry out, be exposed to ultraviolet light and die. To help these sensitive creatures, apply nematodes late in the day and water the area after application so any nematodes on leaf surfaces are washed down to the soil. Nematodes often need to be applied regularly because there are many sources of mortality, including springtails, mites and fungi, which abound in the soil.

— *MBCN, v.2, n.1 & n.2, Bob Wright, University of Nebraska; A. Hom, Future directions for nematodes in biological control, The IPM Practitioner, April 1994; A. Hom, Current status of entomopathogenic nematodes, The IPM Practitioner, March 1994.*

Nosema pyrausta

Protozoa

Nosema pyrausta is an obligate pathogen in a group called Microsporidia. It infects **European corn borer**. This pathogen varies in abundance from year to year and has been found to infect 22 percent of the field

population. It may readily spread among corn borers in close proximity.

Life of *Nosema pyrausta:* The infective stage is a spore. European corn borers unknowingly ingest the spore. The spores germinate inside the caterpillar's stomach, infect and multiply inside cells of the caterpillar's body. Infections are often sublethal, though infected caterpillars under nutritional and climatic stress can die. Sublethally infected corn borers take longer to develop and develop into smaller, short-lived and less fecund moths. The corn borer releases spores back into the environment through its frass, spun silk, regurgitated food and cadaver. Because individuals can survive infection, female moths can pass the infection onto their offspring in the eggs.

Giving them a boost: *Nosema pyrausta* is a naturally occurring pathogen and is not available as a registered microbial insecticide.

— MBCN, v.4, n.3, Lee Solter, Illinois Natural History Survey.

Bacillus thuringiensis (Bt)

Bacterium

Bacillus thuringiensis, otherwise known as *Bt*, has been the most widely used microbial insecticide in the United States since the 1960s. Bacterial pathogens in the genus *Bacillus* are spore-forming, rod-shaped bacteria. They commonly occur in soils, and the more effective strains have been formulated as bacterial insecticides. An insect must eat the bacteria to become infected — bacterial insecticides will not kill by contact alone. *Bacillus* species and subspecies vary in their specificity — they may target an entire order of insects or one or a few species. The bacterial cells usually produce a spore and a crystalline protein toxin, called an endotoxin, as they develop. This toxin is the ingredient that kills insects. Most commercial *Bt* products contain the protein toxin and spores, but some contain only the toxin component.

Life of *Bt*: Case scenario: a farmer applies commercial *Bt* on crop foliage. A wandering caterpillar chews on the leaf and ingests *Bt*. The caterpillar's gut is alkaline and full of enzymes. These conditions activate the protein toxin in *Bt*. The activated toxin attaches to specific receptor sites on the gut wall, causing the cells to swell and burst. If the caterpillar cannot repair this damage to its gut wall, the gut contents will enter the caterpillar's body cavity. This caterpillar will stop feeding and die in two to three days. The bacteria may multiply in the caterpillar, but because few spores or crystalline toxins are produced, few infective units are released after the caterpillar dies. Consequently, *Bt* products are applied much like synthetic insecticides. *Bt* treatments are inactivated by ultraviolet light exposure within one to a few days, and repeated applications may be necessary for some crops and pests.

Until the early 1980s, commercial *Bt* products were effective only against caterpillars. In recent years, however, additional strains that kill other types of pests have been identified and developed.

***Bt* formulations that kill caterpillars** — The best known and most widely used *Bt* insecticides are formulated from *Bacillus thuringiensis* var. *kurstaki (Btk)* isolates, which are pathogenic and toxic only to larvae of butterflies and moths (Lepidoptera). Many such *Bt* products have been registered by the U.S. Environmental Protection Agency (EPA). These products are available as liquid concentrates, wettable powders, and ready-to-use dusts and granules. They are used to control many caterpillars that attack vegetables, gypsy moth and other forest defoliators, and European corn borer in field corn. *Bacillus thuringiensis* var. *aizawai* is another *Bt* strain that kills caterpillars.

Though these *Bt* products kill only caterpillars, they do not kill all caterpillars. Caterpillars that live in the soil or bore into plant tissues do not consume a significant amount of the *Bt* applied to plant surfaces. The corn earworm in corn and cutworms that clip off field crops are examples of caterpillars seldom controlled by *Bt* treatments.

***Bt* formulations that kill mosquito, black fly and fungus gnat larvae —** *Bacillus thuringiensis* var. *israelensis (Bti)* kills the larvae of mosquitoes, black flies and fungus gnats; it does not kill larval stages of "higher" flies such as the house fly, stable fly or blow fly.

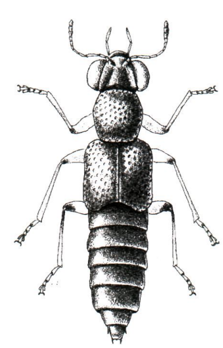
***Bt* formulations that kill beetles —** *Bacillus thuringiensis* var. *san diego* and var. *tenebrionis* are toxic to certain beetles. Beetle species exhibit great differences in susceptibility to these strains, presumably because of subtle differences in their guts, where *Bt* toxins are active. *Bacillus thuringiensis* var. *san diego* is commonly used against Colorado potato beetle larvae. Considerable research effort is now directed to identifying and developing additional *Bt* isolates that are active against more or different beetles, particularly western corn rootworm.

What you will see: Insects infected with *Bt* become sluggish, cease feeding and excrete liquid. Once it's dead, the body darkens and softens and degrades into dark, putrid mush.

Giving them a boost: After you have chosen the right *Bt* product registered for your pest, follow the label instructions. Proper timing and application procedures are critical for success.

- Keep an eye out for pest activity and apply *Bt* when pests are out there. *Bt* formulations are not long-lived in the outdoors.
- Try to use *Bt* when pests are still small — this will minimize feeding damage. Also, *Bt* is often more effective on younger larvae.
- *Bt* sprays should thoroughly cover all plant surfaces, including the leaf undersides, because insects need to ingest *Bt* to die.
- It is best to treat foliage in the late afternoon or evening because ultraviolet radiation deactivates *Bt*. This allows active *Bt* to be ingested by unsuspecting herbivores overnight. Treating on cloudy (but not rainy) days provides similar results.
- Take advantage of technology. Some companies encapsulate *Bt* spores or toxins in a granular matrix (such as starch) or within killed cells of other bacteria, and this provides protection from ultraviolet radiation. There are also spreader or sticking agents available that help *Bt* adhere to the smooth surfaces of plants.

— MBCN, v.2, n.7, Rick Weinzerl and Lee Solter, University of Illinois.

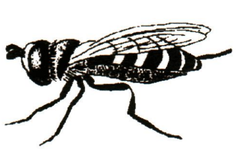


Bt Corn and European Corn Borer: Long-term Success through Resistance Management

The European corn borer (ECB) is the primary target of a new technology to manage insect pests, transgenic *Bt* corn. *Bt* corn hybrids were created by inserting genes from the bacterium *Bacillus thuringiensis* (*Bt*). These genes produce a protein toxic to some caterpillars, such as the ECB.

These hybrids provide protection against the ECB usually far greater than even optimally timed insecticides — most larvae die after taking only a few bites. Though conventional *Bt* insecticides may perform as well as synthetic insecticides, their performance is not always consistent because the toxin degrades with ultraviolet radiation, and *Bt* must be applied very thoroughly on the crop and when new larvae are present. Modifying a corn plant to produce its own *Bt* protein overcomes these limitations. The protein is protected from rapid environmental degradation. Plants produce the toxic protein in tissues where larvae feed, so coverage is not an issue. Finally, the protein is present whenever newly hatched larvae try to feed, so timing of *Bt* application is not a problem.

However, because *Bt* corn provides unprecedented control of ECB through a simple seed choice, widespread use could set the stage for resistance. Insects are known for their ability to develop resistance to certain insecticides rapidly, particularly when insecticides are used repeatedly and at high concentrations. Lab colonies of Indian meal moth, tobacco budworm, beet armyworm, pink bollworm and Colorado potato beetle have developed resistance to *Bt*. Moreover, the diamondback moth, a worldwide pest of cole crops, has developed high levels of resistance to *Bt* insecticide in field populations in Hawaii and Florida.

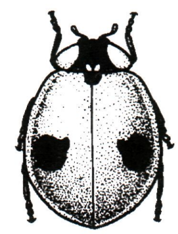


Resistance development by ECB may likely follow this scenario. In any population of ECB, a few of the borers will have two copies of genes for resistance (rr), some will have one copy of the gene (rs) and most will have none (ss). Resistance genes are likely to be rare because there are usually disadvantages to carrying this gene. On *Bt* corn, ECB with one or more copies of resistance genes will survive better and produce more offspring. This improved survival or reproductive success results in a selective advantage. As the *Bt* corn acreage increases, more larvae carrying resistance genes will survive to adulthood. The overall population of *Bt*-resistant individuals increases with each generation. At some point, resistant larvae will dominate and *Bt* cornfields will have similar pest infestation levels as non-*Bt* cornfields.

The potential threat of resistance by ECB to *Bt* corn necessitates a management plan to delay or avoid the risk of resistance. Current resistance management in *Bt* corn is based on two complementary principles: high dose and refuge areas of non-*Bt* corn. Plant geneticists designed *Bt* corn to produce very high levels of *Bt* proteins, much higher than levels found in *Bt* insecticides. The intent is to kill all ECB larvae with no genes for resistance, plus those with one copy of a resistance gene. The assumption inherent in this resistance management approach is that *Bt* hybrids have achieved this high-dose objective. If a high-dose objective is not achieved, then corn borer larvae with one copy of a resistance gene may survive to adulthood and mate with other resistant moths. Most of the offspring from these matings would be resistant to *Bt* corn. The second principle of the resistance management plan is the use of refuges. The purpose of a refuge is to allow susceptible ECB to develop in non-*Bt* corn and later mate with potential resistant moths emerging from nearby *Bt* corn. The goal is to produce an overwhelming number of susceptible moths to every resistant moth. A refuge is any non-*Bt* host of ECB, including non-*Bt* corn, potatoes, sweet corn, cotton or native weeds that occur near *Bt* corn.

What size refuge is needed to provide enough susceptible moths? In any given year, approximately 20 to 30 percent of ECB larvae should not be exposed to *Bt* proteins. To be effective, ECB moths must emerge from the refuge at the same time as resistant moths and be close enough to mate with resistant moths. Though some ECB moths can fly substantial distances, many moths fly less than a mile from their emergence site. Consequently, each farm should have one or more refuge areas next to *Bt* corn. In continuous corn and corn-soybean rotations, the primary available refuge is non-*Bt* corn, so 20 to 30 percent of the corn acreage should be non-*Bt* corn. Where the total corn acreage is small, a smaller refuge may be suitable. Monitoring for the development of resistance to transgenic plants will provide information that is essential to managing ECB resistance.

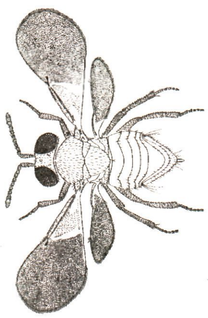
— *MBCN, v.4, n.10; K.R. Ostlie, W.D. Hutchison and R.L. Hellmich, 1997, Bt Corn and European Corn Borer, NCR Publication 602, St. Paul, Minn.: University of Minnesota.*



Experiment: *Bt* Friendlier to Natural Enemies

One of the advantages of *Bacillus thuringiensis* for controlling European corn borer in whorl stage corn is its selectivity in controlling certain pests while conserving naturally occurring predatory and parasitic insects. This can be tested in the following experiment.

- Set up side-by-side plots. Plot size can vary, but plots at least 10 rows wide and 100 feet long will help minimize insect movement between plots. Treat one with a *Bt* product (granular formulations) and the other with a conventional insecticide used against ECB.



- If you can return to the plots regularly, make counts of common predators (lady beetles, green lacewings, spiders, etc.) at various intervals after treatment (be sure to stay out of the field until the restricted entry interval has expired).

Are there more natural enemies in the *Bt*-treated plot? If so, which ones are most common?

- Three or four weeks after the treatment, compare the efficacy of *Bt* vs. conventional insecticide used against corn borers. Select 25 corn plants from each of the two plots and split the stalks lengthwise with a knife. Count the number of tunnels present and the number of live corn borers.

How do the counts differ in the two treatments? You can also look at what happened to other pests that were present at the time of application (fall armyworm, armyworm, aphids, etc.). How much armyworm damage was in the two plots? Are aphid populations different? Do you think these differences might be due to naturally occurring predatory and parasitic insects?

— *MBCN, v.2, n.6, Bob Wright, University of Nebraska-Lincoln.*

Beauveria bassiana

Fungus

Beauveria bassiana is a common soilborne fungus that occurs worldwide. It attacks a wide range of both immature and adult insects. The extensive list of hosts includes important pests such as **whiteflies, aphids, grasshoppers, termites, Colorado potato beetle, Mexican bean beetle, Japanese beetle, boll weevil, cereal leaf beetle, bark beetle, lygus bug, cinch bug, fire ant, European corn borer, codling moth** and **Douglas fir tussock moth**. Immature and adult insects are susceptible. Natural enemies such as ladybugs are susceptible, too. The many strains of the fungus exhibit considerable variation in virulence, pathogenicity and host range. It occurs in the soil, where it lives on decaying plant material.

Life of *Beauveria*: *Beauveria* produces spores that are resistant to environmental extremes. These are the infective stage of the fungal life cycle. The spores, called conidia, infect directly through the outside of the insect's skin. Under favorable temperature and moisture conditions, a conidium (singular of "conidia") adhering to the host cuticle will germinate. The fungal hypha growing from the spore secretes enzymes that attack and dissolve the cuticle, allowing it to penetrate the skin and grow into the insect's body. Once inside the insect, it produces a toxin called beauvericin that weakens the host's immune system. After the insect dies, the fungus unleashes another toxin, an antibiotic (oosporein) that enables the fungus to outcompete intestinal bacteria. Eventually the entire body cavity is filled with fungal mass.

In addition to infecting insects, *B. bassiana* can colonize corn plants and live in the vascular tissue of certain corn cultivars as an endophyte. European corn borer tunnelling is reduced in corn plants with the fungus. In studies, the fungus colonized the plant when applied as a granular formulation of conidia on foliage at whorl stage, moved internally in the plant and persisted throughout the season to provide significant suppression of corn borers.

What you will see: When conditions are favorable, the fungus will grow through the softer parts of the insect's body, producing the characteristic "white bloom" appearance. Relative humidity must be 92 percent or more for *B. bassiana* to grow outside the insect. These external hyphae produce conidia that ripen and are carried by the wind to infect new hosts.

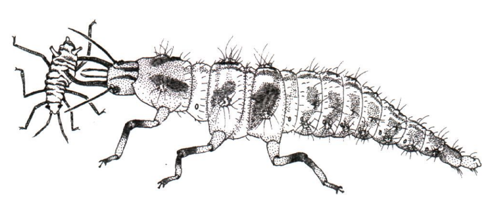
Giving them a boost: *B. bassiana* is available commercially as a microbial insecticide. Commercial formulations allow the fungus to withstand ultraviolet light and temperature and humidity extremes commonly encountered in the field. It takes three to seven days to kill an insect with *B. bassiana*, so be aware it will take some time to suppress the pest population when using these products. Thorough spray coverage is essential because fungal spores must contact the insect for infection to occur.

— *MBCN, v.4, n.10, Susan Mahr, University of Wisconsin-Madison.*

Handling Microbial Insecticides

Bt won't cause our guts to cave in and *Beauveria* won't cause us to bloom white, but all microbial insecticides need to be handled cautiously. Bacterial spores, mold spores and virus particles become "foreign proteins" if they are inhaled or rubbed into the skin and can cause allergic reactions. The dusts or liquids used to dilute and carry these microorganisms also can act as allergens or irritants. Avoid breathing dusts or mists of microbial insecticides. You should wear gloves, long sleeves and long trousers during application and wash thoroughly afterwards. These are commonsense precautions that will help prevent unexpected reactions.

— *MBCN, v.2, n.7, Rick Weinzerl and Lee Solter, University of Illinois.*

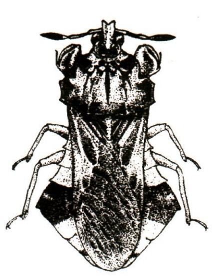


Biological Control of Weeds

Weed biological control has enjoyed numerous success stories. In rangelands, the beetle *Chrysolina quadrigemina* controlled Saint John's wort. The plant pathogen *Phytophthora palmivora* subdued strangler vine in citrus orchards. Another plant pathogen, *Colletrotrichum gloeosporioides*, stopped the spread of northern joint vetch in rice.

Biological control agents such as herbivorous insects or plant pathogens are often effective against a single species or at best a few closely related species. Research on biocontrol agents for weed species common in corn and soybean fields has been conducted, but corn and soybean fields are invaded by many annual weeds. Under these circumstances, if a single weed species is controlled, other weed species will replace it. Thus, one biological control agent is not expected to be the cure-all for weed problems in row crops, but utilizing several biocontrol agents will help control the complex of weeds.

Weed Biological Control Agents



Allelopathy — Many plants release chemicals that suppress a wide spectrum of weeds. Production systems with allelopathic crops or rotational cover crops may be a way to manage a range of weed species. Allelochemicals will not control all weed species, particularly perennial weeds. Another hurdle is that allelopathic crops must control weeds through the critical weed-free period, which can be as long as 12 weeks, and cannot reduce yields or delay crop maturity. Therefore, allelopathic cropping systems are probably best considered a replacement for preemergent herbicides. These systems may require postemergent herbicide applications to provide seasonlong weed control.

Pathogens — Microorganisms (fungi in most cases) can control weeds. Fungal pathogens are being developed by companies into mycoherbicides. For the farmer, these commercially available biocontrol agents are applied much like other herbicides and are convenient to use. Biotechnology may increase the range of biocontrol agents commercialized.

Vertebrates — Birds and rodents are important weed seed and plant eaters. Grazing by sheep and geese has been utilized to remove weeds in agricultural fields.

Invertebrates — Many invertebrates, primarily insects, eat all parts of the weed plant: leaves, roots, flowers and seeds. More than 250 insects — mainly beetles, flies and moths — have been introduced into the United States to control weeds. In field crops, ground beetles and crickets are very common and also important weed seed eaters. A female cricket can eat more than 200 redroot pigweed seeds in one day! By consuming weed seeds, they reduce the number of seeds that will germinate. Naturally, there is concern that the same insects that feed on weed seeds may also feed on crop seeds. These insects' small size means they cannot as easily penetrate large crop seeds and so prefer to feed on small weed seeds.

Beneficial Farming Practices

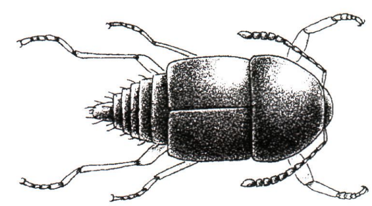
Certain farming practices can increase the availability and activity of these weed biocontrol agents.

No-till — No-till leaves a desirable mulch that can have allelopathic qualities. The organic matter of the mulch decays, releasing chemicals that affect other plants and their germinating seeds. The mulch also keeps out light, which some weed seed species need to germinate, and so effectively suppresses several weed species. The mulch in no-till fields also keeps the soil moist and cool and provides good hiding places from the hot midday sun for weed seed-consuming ground beetles and crickets. In addition, no-till leaves many weed seeds on or near the soil surface, where they are likely to be eaten by birds, insects and rodents, or degraded by microorganisms.

Refuge habitat — Leaving fencerows, filter strips or herbaceous strips near fields provides an overwintering home, food and shelter for insects, birds and rodents, which later colonize a field to eat weed seeds. Refuge habitats composed of perennial plants will not likely create weed problems in the crop area. If you are planting new herbaceous strips, fast-growing grasses will help keep weeds from invading the area.

Though herbicides are a multimillion-dollar industry and primarily used in fields crops, weed biocontrol agents continue to play an important role with these new technological advances. Sooner or later, weeds will develop resistance to herbicides, and biocontrol agents may have the important role of controlling resistant biotypes. Also, as Roundup-Ready soybeans and corn are more widely used, biocontrol agents might become important for managing difficult to control weeds such as nightshades (*Solanum* spp.) and perennial weeds such as Canada thistle (*Cirsium arvense*) in those systems. Weed biocontrol agents may not be widely used in row crop systems, but incorporating beneficial farming practices can help increase the abundance of these biocontrol agents and thus their impact on weeds.

— *MBCN, v.5, n.10, John Masiunas, University of Illinois; F. Menalled, D. Landis, J. Lee, S. White and K. Renner, 2000, Ecology and Management of Weed Seed Predators in Michigan Agroecosystems, Extension bulletin E-2716, East Lansing: Michigan State University Extension.*

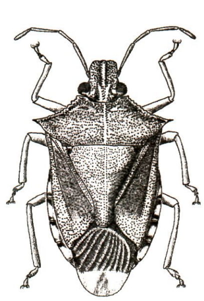


Biological Control of Plant Pathogens

Plant diseases are caused mainly by fungi, bacteria, viruses and nematodes. Biological control of plant disease includes management of resident populations of microorganisms — the black box approach — and introductions of specific microorganisms to reduce disease — the silver bullet approach.

The Black Box Approach

The phenomenon of disease-suppressive soils has fascinated plant pathologists for decades. Suppressive soils are those in which a specific pathogen does not persist despite favorable environmental conditions. The pathogen establishes but doesn't cause disease, or disease occurs but diminishes with continuous monocultural crops. The phenomenon is believed to be biological in nature because fumigation or heat sterilization of the soil eliminates the suppressive effect, and disease is severe if the pathogen is reintroduced.



A classic example of suppressive soils is take-all disease of wheat. At first, take-all increases in severity with each successive wheat crop, but with continued monoculture, disease stabilizes at a low level. The suppressive effect is lost with crop rotation. Disease suppression has been attributed to an increase in non-pathogenic microorganisms that are well adapted to growth on wheat roots. These bacteria utilize root exudates, depriving the take-all fungus of a potential food source. Many of these root-colonizing bacteria may also produce antibiotics that further inhibit growth of the pathogen. However, wheat monoculture is not recommended, nor would it be economical for a grower to endure several years of severe disease losses while waiting for suppression to develop. The nature of disease-suppressive soils remains largely an enigma, but continued studies will further develop biocontrol strategies.

There are many other examples of biological control involving complex microbial communities, including the use of green manures or composts to control soilborne pathogens. For example, incorporation of green manures from Sudan grass or corn seems to reduce the incidence of potato death from *Verticillium*. Intercropping two or more plant species can also result in disease suppression. Intercropping oats with peas seems to reduce the severity of *Aphanomyces* root rot of peas. The suppressive effect may result from oat root exudates that cause the motile spores of this fungus to stop swimming, preventing them from reaching and infecting pea roots. Alternatively, oat root exudates may influence some other component of the soil microflora that in turn affects the fungus.

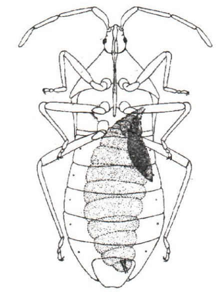
The Silver Bullet Approach

The difficulties in understanding the complex interactions of the "black box" approach to biological control have led some researchers to introduce individual strains of microorganisms as biocontrol agents. This "silver bullet" approach, while simplistic, has yielded some practical solutions and led to the development of several commercially available biopesticide products. There are three main mechanisms by which one microorganism may limit the growth of another microorganism: antibiosis, mycoparasitism and competition for resources.

Antibiosis is defined as the inhibition of one microorganism's growth by another as a result of diffusion of an antibiotic. Antibiotic production is very common among soil-dwelling bacteria and fungi. In fact, many of our most widely used medical antibiotics (e.g., streptomycin) are made by soil microorganisms. Antibiotic production appears to be important to the survival of microorganisms through elimination of microbial competition for food sources, which are usually very limited in soil. For example, the antibiotic zwittermicin A, produced by the biocontrol agent *Bacillus cereus* UW85, appears to be important in biocontrol of *Phytophthora* root rot of alfalfa.

Destructive mycoparasitism is one fungus parasitizing another pathogenic fungus. It involves direct contact between the fungi that results in death of the plant pathogen and nutrient absorption by the parasite. The electron microscope has afforded us stunning views of mycoparasites coiled around the hyphal strands of pathogenic fungi. Mycoparasites produce cell wall-degrading enzymes, which allow them to bore holes into other fungi and extract nutrients for their own growth. Many so-called mycoparasites also produce antibiotics, which may first weaken the fungi they parasitize.

Nutrient competition occurs when microorganisms compete with one another for carbon, nitrogen, oxygen, iron and other micronutrients. For example, microbes often compete for the soluble form of iron, $Fe^{3}+$, in terrestrial environments. Some fungi and bacteria produce very large molecules called siderophores, which bind $Fe^{3}+$ in such a way that the iron becomes inaccessible to other microorganisms, including pathogens. In some cases, siderophore production and competitive success in acquiring $Fe^{3}+$ is the mechanism by which biocontrol agents control plant diseases. Siderophores produced by certain strains of *Pseudomonas* have been implicated in suppression of several fungal diseases.



The past few years have seen a proliferation of many small companies bringing new biocontrol products to the marketplace. Many of these companies are working with university researchers and other public sector scientists to develop biocontrol research as a practical alternative to chemical pesticides. Traditional pesticide companies are also taking a strong interest in biocontrol products because the registration costs are so much less for these than for traditional chemical pesticides. These are exciting times for biological control of plant diseases!

— *MBCN, v.3, n.3, Jennifer L. Parke, Department of Plant Pathology, University of Wisconsin-Madison.*

Trichoderma harzianum, strain T-22

Fungus

Trichoderma are filamentous fungi that can be isolated from many soil types. They are part of a healthy soil environment, and numerous species are found worldwide. A few select strains of *T. harzianum* have been shown to suppress plant pathogens. They are limited in the scope of plants they protect, however, and in the pathogens they control. For example, one strain can control

Pythium and grow in cooler soils, while another can control *Rhizoctonia* and colonizes the root system.

A new breed: To overcome these limitations, researchers at Cornell University produced a hybrid strain that enhanced attributes of both parents. The strain, T-22, protects the root systems of a number of crops against **fungal pathogens *Fusarium, Pythium*** and ***Rhizoctonia***. Crops include corn (field, sweet, silage), soybeans, beans (green and dry), cabbage, cotton, peanuts, trees, shrubs and ornamental crops. T-22 can grow in a range of soil types at temperatures above 50 degrees F. Because of its superior attributes, T-22 has been commercially developed as one of the first biofungicides.

Life of T-22: T-22 controls various plant pathogens in two ways. First, T-22 can grow along the entire length of the root system (rhizosphere), where it establishes a barrier against pathogen attack. As long as the root system remains active in its growth and development, T-22 will continue to grow along with it by feeding on the waste products naturally released by roots. Early applications of T-22 protect plant roots by removing secreted nutrients that other pathogens might use. Here squatter's rights apply. Most importantly, T-22 does not seem to interfere with the activity of mycorrhizae or nitrogen-fixing *Rhizobium* at the roots.

A second line of defense by T-22 against root-rotting fungi is the release of hydrolytic enzymes. Many plant pathogens contain chitin as a component of their cell wall. T-22 releases enzymes called chitinases, which dissolve the cell wall and create holes in the pathogen. Once damaged, the pathogen itself becomes the prey of other soil microflora. These enzymes work best in an acidic environment. Insects also contain chitin as a constituent of their exoskeleton, but their pH is typically alkaline. Thus, the T-22 chitinases will not work on these non-target organisms; plants, birds, fish, humans and other organisms are also not affected by T-22.

T-22 maintains the root system, allowing for larger root biomass to develop. Once the plant is harvested, T-22 levels in the soil drop. The levels remaining after harvest will not be high enough for efficacious fungal control in new plantings.

Giving them a boost: Use of T-22 is approved for certified organic production in several states. T-22 can protect plant roots previously not protected by chemical fungicides. It can be used at the time of planting as a seed treatment. The T-22 planter box formulation is compatible with many standard chemical seed treatments and is applied directly over chemically treated seeds at the time of planting. The chemical allows for stand establishment, but that's all. T-22 then kicks in to protect the root system from fungal attack. In addition, T-22 is available in a granular formulation for incorporation in soilless potting mixes and as a wettable powder for drenching greenhouse or agricultural plants.

— MBCN, v.5, n.4, Dr. Chris Hayes, BioWorks, Inc., Geneva, N.Y.

Gliocladium virens

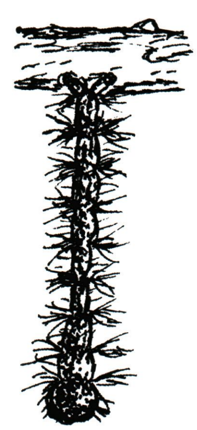
Fungus

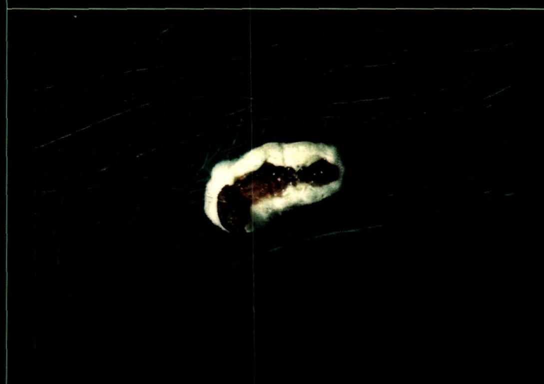
Gliocladium virens is a naturally occurring, ubiquitous soil fungus found throughout the United States in various soil types. It has been shown to suppress a variety of **soilborne plant pathogens** — including ***Pythium* spp.**, ***Rhizoctonia solani*** and ***Sclerotium rolfsii*** — that cause damping-off and root rots on snapbeans and cabbage, southern blight of tomato and various other seedling diseases.

Life of *G. virens*: *G. virens* reproduces asexually, producing masses of conidia (spores). The spores are dispersed only in water or carried in soil or organic matter — they are not airborne. *G. virens* is known to parasitize some soil pathogens, such as *R. solani*. It will actually wrap itself around the pathogen and release enzymes that destroy the pathogen's cuticle, leaving the pathogen susceptible to attack.

Giving them a boost: This fungus is one of the first to be registered for biological control of plant diseases. SoilGard™ is an available commercial formulation that controls plant pathogens through parasitism, antibiosis and competition. The fungus does not persist at the inoculated high concentrations and declines over a period of a few weeks.

— *MBCN, v.5, n.9, Susan Mahr, University of Wisconsin-Madison.*





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