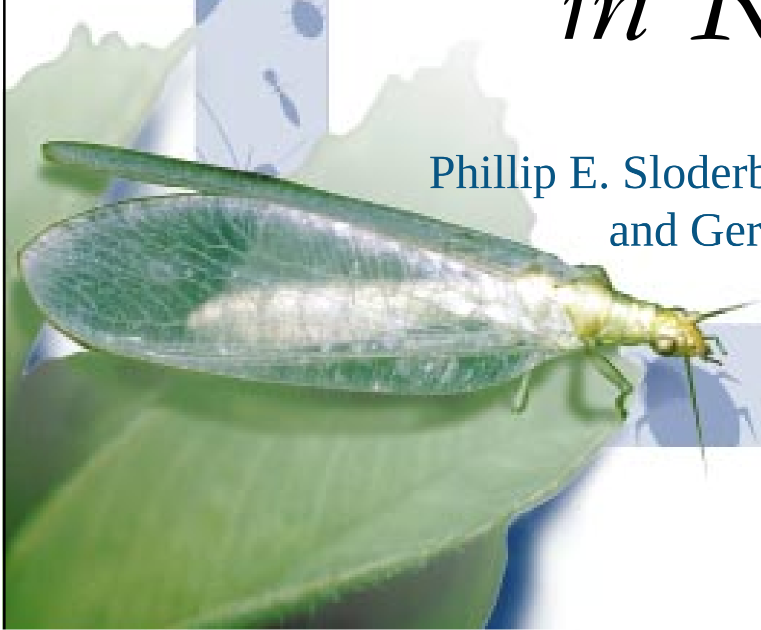
Biological Control of Insect Pests on Field Crops in Kansas

Phillip E. Sloderbeck, James R. Nechols
and Gerald L. Greene



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Biological Control

In the simplest terms, biological control is the reduction in pest populations from the actions of other living organisms, often called natural enemies or beneficial species. Virtually all insect and mite pests have some natural enemies. Learning to recognize and manage these natural enemies can help reduce pests populations and, thus, reduce crop losses and the need for costly chemical and/or other control measures.

Biological control is most effective when used with other compatible pest control practices in an integrated pest management (IPM) program. Practices that are often compatible with biological control include cultural control; planting pest resistant varieties and using selective insecticides when other practices fail to keep pest numbers below the economic threshold.

To be used effectively, biological control requires a good understanding of the biology of the pest and its natural enemies, as well as the ability to identify the pest's life stages in the field. Frequent field scouting also is necessary to monitor natural enemies and evaluate their impact on pest populations.

Biological control programs are categorized in three basic ways: conservation, importation and augmentation.

Conservation of Natural Enemies

Conservation of natural enemies is arguably the most important concept in the practice of biological control and, fortunately, is also one of the easiest to understand. Simply put, conservation of natural enemies means avoiding practices that harm natural enemies and implementing practices that benefit them. It may sound like good common sense, but the tricky part comes in understanding exactly what practices are harmful and how beneficial practices can be integrated into a production system. This requires understanding the biology of natural enemies and being willing to modify practices to accommodate them.

The most obvious harmful practice is the use of insecticides at times when natural enemies will be harmed. Insecticides can have direct effects on natural enemies by killing them, or indirect effects by eliminating their hosts and causing starvation. In some cases, insecticides can be successfully integrated into the system without harming natural enemies. This may be accomplished by using selective insecticides such as *Bacillus thuringiensis* (B.t.), timing the application to avoid periods when important natural enemies would be exposed, or placing the insecticide in a location where natural enemies will not contact it. In other cases, adequately protecting natural enemies may require not using an insecticide.

Certain cultural practices also can be detrimental to natural enemies. Plowing, cultivation, mowing or harvesting operations can be disruptive to natural enemies at critical points in their life cycle—if detrimental, the practice should be avoided. Excessive amounts of dust from roads or cultural operations also can reduce control by disrupting the activities of predators and parasitoids. Burning crop residues or inappropriately timed irrigation also can kill many natural enemies. Finally, the ambiguous category of "clean farming," which includes removing weeds and non-crop habitats, has been found to be detrimental to many natural enemies. Increased crop residues have been shown to favor ground beetles, spiders and other general predators.

To better conserve natural enemies, the following questions need to be answered: Where do the natural enemies overwinter? Do they need alternative prey/food sources to meet their nutritional needs at times when the pests are not abundant? Do they need shelter during the growing season in the form of wooded areas, surface residue, or weedy field borders? Until these questions are answered, the benefits of the natural enemies of any pest cannot be realized.

Importation of Natural Enemies

Many insects become serious pests when they are introduced into a new area which lacks their native natural enemies. Examples of European or Eurasian insects that have become important pests on Kansas field crops include the European corn borer, alfalfa weevil, greenbug, Hessian fly and Russian wheat aphid. The importation of new natural enemies to control imported pests often is referred to as "classical" biological control. Some dramatic successes in biological control have resulted from importing effective natural enemies that are well-adapted to the pest from an area where the pest is thought to have originated.

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. Classical biological control differs from the other general methods (conservation and augmentation) because it is not directly conducted by the farmer or gardener. International agencies, federal agencies (especially the United States Department of Agriculture [USDA]), 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. Indeed, there are specific quarantine laws that prohibit private individuals or agencies from introducing non-native organisms (including natural enemies) without proper authorization from the USDA. Natural enemies must be carefully screened by trained personnel under rigid quarantine conditions to be certain that (1) they will provide benefit in controlling the target pest, (2) they will not, themselves, become pests, and (3) they do not harbor their own natural enemies that might interfere with their effectiveness or that of other natural enemies. Although most farmers are not directly involved in the classical biological control process, they can help to conserve or distribute exotic natural enemies that become established.

Augmentation of Natural Enemies

To many people, biological control means buying and releasing beneficial natural enemies to control insect and mite pests. This approach is known as augmentation. The underlying reason for the wide recognition of this technique is that it relies on commercial products which may be advertised in magazines and publicized in the media. Further, the use of pesticides has trained us to think about pest management in the context of purchased products. However, of the three general approaches to insect biological control, augmentation is the least sustainable because it requires the regular or periodic purchase of products. Nonetheless, in some pest situations it is a highly efficacious, cost effective and environmentally sound approach to pest management.

The practice of augmentation is based on the idea that, in some situations, there are not adequate numbers or species of natural enemies to provide optimal biological control, but that the numbers can be increased (and control improved) by releases. This may require a readily available source of large numbers of natural enemies. This need has fostered the development of companies to produce and sell these organisms. Many companies (called insectaries) produce a variety of predatory and parasitic insects; other companies produce and market insect pathogens for use as microbial controls.

There are two general approaches to augmentation: inundative releases and inoculative releases. Inundation involves releasing large numbers of natural enemies for immediate reduction of a damaging or near-damaging pest population. It is a corrective measure; the expected outcome is immediate pest control. Inoculation involves releasing small numbers of natural enemies at intervals, sometimes throughout the period of pest activity, starting when the pest population is low. In some cases, the natural enemies will reproduce to provide more long-term control. The expected outcome of inoculative releases is to keep pest numbers low, never allowing them to approach an economic injury level. Therefore, it is more of a preventive measure.

There are over 100 kinds of commercially available natural enemies including predatory insects and mites, parasitic insects and nematodes, and pathogens. Although this appears to be a large number, it is small compared to the total number of pests in the United States. Further, many of these natural enemies are specialized for pests on crops such as cotton and citrus which are not grown in the Midwest. Other commercially available natural enemies, such as the praying mantis, are of questionable value, even though they are commonly used by many gardeners and some farmers.

Well-researched applications of natural enemies can, and do, result in very effective biological control. This includes the use of microbial insecticides as well as many specific uses of predators and parasitic insects. On the other hand, many natural enemies that are sold do not control the intended target pest(s). Although the reasons for poor control can be very complex, probably the most common cause of these "failures" is a lack of knowledge. This includes both a lack of research needed to make recommendations for successful implementation, and the user's lack of knowledge about the biology of the pests, their natural enemies, and their environment, all of which are crucial for making augmentation work. The best advice for pest managers interested in starting an augmentation program is to get as much information as possible to assure a reasonable chance for success. Progress continues to be made towards developing more user-friendly recommendations for effectively using commercially produced natural enemies.

As with any pest management program, the bottom line of a natural enemy augmentation program is cost. Because of the differences in prices and patterns of use, it is hard to generalize on the cost effectiveness of purchased natural enemies. There is a wide variance in prices because some natural enemies are much easier and less expensive to produce than others. Inoculative releases may be less expensive than inundative releases if the timing and conditions are right. 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 market differences in conventional versus organic produce). Another problem is that, for many commercial natural enemies and their potential target pests, there is not adequate research to recommend specific release rates based upon pest population levels. There are, however, many situations where augmentative biological control is cost competitive with the use of pesticides or other pest management practices. On high-value crops, the expense of biological control may be relatively low when compared to overall production costs. On low-value crops, the use of natural enemies must be inexpensive to be justified; or, release numbers have to be low with the expectation that natural enemies will reproduce and build up their own numbers during the growing season. This does not preclude the use of augmentation in field crops. For example, 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. Managers should carefully evaluate the cost of a natural enemy, as with any other production cost, before making a decision on any augmentative release.

Important questions to ask when considering an augmentation program:

1. Has research shown that a release program is effective for the particular pest, crop and local situation?
2. Are the proposed release rates sufficient to protect crop yields?
3. When is the best time to release the natural enemy in relation to the pest's life cycle?
4. Are releases compatible with the need to apply insecticides for other crop pests and with other crop production practices?
5. What quality control practices does the company use to ensure that the natural enemies will be alive and active when released?
6. What directions and assistance does the company provide regarding the handling, release and evaluation of the natural enemy?

Discuss your pest situation with all available Extension personnel as well as with several different companies to obtain the most information about the natural enemy product and pest problem.

In summary, Extension personnel receive more questions about the release of purchased natural enemies than all other approaches to biological control. However, in many cases, it is an area where there are the fewest answers. It also is important to point out that augmentation cannot be considered "the silver bullet" of biological control. It is not foolproof, and it requires a certain level of knowledge and understanding to make it work. However, augmentation may provide a safe alternative for controlling pests.

Recognition of Common Biological Control Agents

Predators

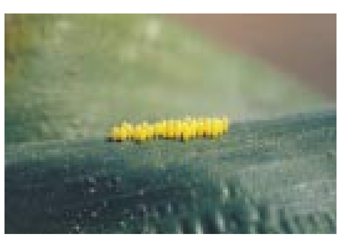
Predatory insects and mites live by hunting or trapping other insects (prey), and killing them for food. Over 100 families of insects, spiders and mites contain species that are predaceous, either as adults, immatures or both. About 12 of these families play major roles in the biological control of field pests. Following, are summaries of some of the most important families.

Lady beetles

Lady beetles or "ladybugs" probably are the most universally known group of beneficial insects. They are found almost anywhere and feed on aphids and a variety of soft-bodied insects. Several species are present in Kansas fields, including the following common species.

Twelvespotted lady beetle

Adults of the twelvespotted lady beetle (*Coleomegilla maculata*) are about ¼ 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 also are 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 and overwinters as large groups of adults in litter at the base of trees or along buildings.



Lady beetle eggs

Convergent lady beetle

Adults of the convergent lady beetle (*Hippodamia convergens*) also are about ¼ inch long and have orange wing covers that typically have six, small black spots. However, the number of spots can vary, and some adults have no spots on their wing covers. The section of the body behind the head is black with white margins and has two converging white lines—from which the species gets its common name. Adults and larvae feed primarily on aphids. Females lay clusters of 10 to 20 yellow eggs on plants infested with aphids. The life cycle is similar to the twelvespotted lady beetle, but this species only has one or two generations each year in the Midwest. This species is native to North America.

Sevenspotted lady beetle

The sevenspotted lady beetle (*Coccinella septempunctata*) was introduced into North America from Europe. Adults are large (about ⅜ inch), have reddish-orange wing covers with seven black spots. Females lay clusters of 15 to 70 yellow eggs on plants that are infested with their aphid prey. Adults also are predaceous. Adult sevenspotted lady beetles overwinter in small groups in hedges, or in leaf litter on the ground near the base of plants.

Some other, smaller, lady beetle species (for example, *Stethorus* and *Scymnus*) play an often hidden, but nonetheless important, role in controlling field crop pests ranging from aphids to corn borers.

The size and coloration of lady beetle larvae vary some among the species, but generally, they are soft bodied and shaped like a miniature alligator. Newly

Lady beetle larva

hatched larvae are gray or black and less than ⅛ inch long. The larvae of most species molt through four instars. Later stage larvae can be gray, black, or blue with bright-yellow or orange markings on the body. The fourth instar larvae consume more aphids than the previous three instars combined. The larvae are not as easy to identify to species as are the adults.

Hover flies

Hover flies (or flower flies) are common and important natural enemies of aphids, thrips, and other small, slow-moving insects. They have been noticed as predators of small European corn borer and corn earworm larvae, although this is rare. The adults resemble bees or wasps, and often are seen hovering over flowers. There are many different species that range in size from less than ¼ inch long to more than ¾ inch long. Many have the typical black and yellow stripes on the abdomen that give them a bee-like appearance, but others are hairy with a long, thin abdomen. All have short antennae.

The adults need flowers as nectar and pollen sources. They are attracted to weedy borders or mixed garden plantings that also are infested with aphids. Some flowers that are especially attractive to hover flies include wild carrot or Queen Anne's lace, wild mustard, sweet alyssum, coriander, dill, and other small-flowered herbs.

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, which hatch in two to three days, are small, legless maggots that range in color from creamy-white to green or brown. They look somewhat slug-like and are tapered towards the head. The larvae feed on aphids

Hover fly (or flower fly)

or other insects and move around on the plants in search of prey. They complete their development in two to three weeks while consuming up to 400 aphids each.

Some hover fly species pupate on the foliage near the feeding site, while others leave the plant and enter the soil to pupate. The pupa is enclosed within a puparium, which is the hardened skin of the last larval instar. The smooth, tan puparia often are teardrop

Hover fly larva

shaped. Hover flies overwinter as pupae. During the growing season, adults emerge in one to two weeks. Generation time depends on temperature, species and availability of food; there may be five to seven generations per year.

Hover flies can be effective in suppressing aphid populations in gardens and mixed plots. However, compared to other aphid predators like lady beetles and green lacewings, hover flies need more aphids to be present before they will lay their eggs. Therefore, control is best achieved when a variety of natural enemies are present. This may partly explain why hover flies are more noticeable later in the growing season after aphid infestations have become established. Because they are not as conspicuous as lady beetle adults or larvae, hover flies may not be given credit for the effect they have on aphid colonies. Their impact on aphids in large commercial plantings, however, has not been studied. At this time, hover flies are not commercially available.

Lacewings

Lacewings are common predators of aphids and other soft-bodied insects on a wide variety of crops grown in the field and greenhouse. One of the most common species is the green lacewing, *Chrysoperla carnea*. Adults of this species are green in coloration and have large green-veined, clear wings which cover the top and sides of their body. The head has long thread-like antennae, large protruding golden eyes and distinct markings on the face. Adult green lacewings often are seen resting on leaves or in a slow, fluttering flight in or above the plant canopy. Eggs are borne at the end of a long, thin stalk attached to the plant. This stalk may be ½ inch or longer. Lacewing larvae, also called aphidlions, feed on aphids, mites, thrips, leafhoppers and mealybugs. The larvae actively search plants for prey, and capture prey in their pincher-like mouthparts.

Green lacewing adult

Lacewing eggs

Lacewings that will attack pests on field crops and other non-arboreal habitats are commercially sold. Although they are extremely important predators of aphids and other pests in nature, their usefulness as purchased biological control agents has been limited by insufficient knowledge about release numbers and other technical and biological data.

Lacewing larva

True bugs

There are numerous beneficial "true" bugs that are predacious on other insects. This includes bigeyed bugs (*Geocoris*), damsel bugs (nabids), minute pirate bugs (*Orius*), and some stink bugs. Unlike many predators that have chewing mouthparts, true bugs have sucking mouthparts. It is common to see these insects with their pointed, straw-like mouthparts inserted into their prey. These insects will feed on caterpillars of various sizes, other soft-bodied insects, and insect eggs. Minute pirate bugs and stink bugs are available for purchase.

Predacious stink bug nymph

Damsel Bug nymph

Ground beetles

Ground beetles are commonly found in all cultivated crops. Both the larvae and adults are predaceous. Ground beetles likely help to regulate pest populations. However, their contribution in field crops as compared to other predators has not been well studied. There is some variation in their body shape and coloring, most are shiny and black (some are metallic) and have ridged wing covers. Another characteristic common to ground beetles is a smaller head than thorax, and thread-like antennae. Adults are active at night and tend to hide under rocks or debris during the day. Much of the predation occurs near the soil surface. Likely targets include caterpillars, root maggots, snails and other soft-bodied insects. Most species do not use their wings, but a few may fly to lights at night. Ground beetles are not commercially available in the United States.

Spiders

While spiders are not insects, they play an important role in the natural regulation of insect populations. As a group, spiders are exclusively predaceous, many specializing on insects. Spiders will feed on a wide variety of insects including moths, beetles, caterpillars and grasshoppers. There are many groups of spiders commonly found in cultivated fields, some are active searchers; others trap their prey. This is a diverse and important group of beneficial insects.

Parasitoids

Parasitoids are insects that, in the immature stages of their life cycle, parasitize other insects but have free-living (nonparasitic) adults. Adult parasitoids serve mainly to transport their offspring to new hosts. Two major groups of parasitoids are discussed in this publication: parasitic wasps and tachinid flies.

Parasitic wasps

Parasitic wasps are the largest group of insects that serve as biological control agents. They also are the most diverse in terms of size, shape and lifestyle. Worldwide, it is estimated that there are more than 1 million species of parasitic wasps. Almost all insect pests are attacked by at least one species of parasitic wasp, and many are parasitized by more than one species. Many of these wasps specialize on one target pest. For these reasons, parasitic wasps are an extremely important source of naturally occurring or human-managed biological control.

Parasitic wasps may be colorful and large (1 to 4 inches in length) as adults. However, most are small to tiny, dark-colored insects. A few have bizarre body shapes, but the majority are narrow-waisted and ant- or wasp-like in appearance. Because of their small size, many parasitic wasps are easily overlooked or, if seen, appear only as black specks. Most adult parasitic wasps have wings and can fly to locate new hosts.

Parasitic wasp attacking aphid

Parasitic wasps reproduce in two basic ways. Most commonly, females mate with males and the offspring are made up of both sexes. Unmated females also can produce viable eggs but they are all male. In the second type of reproduction, females do not mate and produce all female offspring. The female wasp uses a sword-like appendage, called the “ovipositor,” to lay its eggs on or inside the host’s body. Wasp larvae hatch and live parasitically—often hidden from view—eventually killing the host. Larvae develop into pupae in or on the host body, and adults develop from the pupae, completing the life cycle. In addition to parasitism, females of some wasp species use their ovipositor to wound a host so that they can feed on its body fluids. Thus, parasitic wasps can kill pests in two ways—by larval parasitism or adult feeding. This adds to their value as biological control agents.

Some parasitoids develop individually (one per host); while others develop gregariously (two or more wasps living on or in the same host). Gregarious parasitism results when either the adult female wasp lays more than one egg; or when a single egg cleaves multiple times to create clones (a condition known as polyembryony).

Tachinid flies

The family Tachinidae represents the second largest group of parasitoids and the second largest family of true flies. In North America alone, there are well over 1,000 species, all of which parasitize other insects or close relatives. Some species of tachinids are colorful (see figure). But most are drab, brownish- or blackish-colored insects that closely resemble house flies. In general, tachinids are very hairy and this helps to distinguish them from other kinds of flies.

Tachinid fly

Adult females typically glue one or more eggs onto the body of an insect. The resulting larva then bores its way inside the body of the host insect where it feeds. Some tachinids enter the host's body by being swallowed as the insect eats. Larval feeding almost always causes host death. Therefore, tachinids are very useful biological control agents. Many species occur naturally in North America and others have been imported and released.

Tachinid fly eggs on armyworm

Pathogens

A pathogen is a parasitic organism, often a microbe, that causes disease in its host. Typically, pathogens are smaller than their hosts, and usually numerous pathogens infect a single host. Two categories of pathogens are useful as biological controls of insects: nematodes, which are multicellular; and various microbial pathogens, which consist of single cells or subcellular units.

Nematodes

Nematodes that serve as biological control agents are specific to insects and will not harm crop plants. These tiny, worm-like animals occur in nature, but also are produced in large numbers and sold commercially. They have the ability to remain active for long periods if cold-stored, and they can be applied as a spray suspension much like liquid pesticides. However, sufficient moisture must be present for them to be effective, and extremes of pH—especially highly alkaline soil—reduce their survival and control

Nematodes

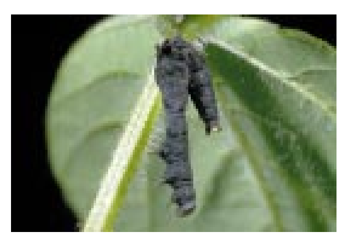
potential. Nematodes act as carriers of a kind of bacterium which causes disease in host insects. The nematodes invade the body of the host larva and then release some bacteria from their guts. The bacteria grow and kill the insect host. The nematodes feed on some of the bacteria and dead insect tissue, complete development, and leave the dead host to find new ones.

Microbial pathogens

Microorganisms parasitize insects, causing disease and death. These microbial "pathogens" include viruses, bacteria, protozoans and fungi. Numerous species in each of these groups serve as important biological control agents of insect pests.

Green cloverworm killed by a fungus

The most commonly used microorganism is *Bacillus thuringiensis*. This bacterium is commercially produced and sold at an affordable price. It does not infect natural enemies of field crops so it can be used in combination with other biological control agents.



Green cloverworm killed by a virus

Examples of Biological Control of Major Pests of Kansas Field Crops

Alfalfa weevil

The alfalfa weevil is the number one pest of alfalfa in Kansas and most other alfalfa production areas of the United States. Like many other U.S. agricultural pests, the alfalfa weevil is not native to this country.

When the weevil entered the United States, it did so without its natural enemies, which help keep its population in check in its native countries. Beginning in 1959, the USDA's Agricultural Research Service began importing tiny parasitic wasps from Europe to help control the alfalfa weevil. Five different species of wasps have been imported and released throughout much of the United States. Some of these wasps parasitize alfalfa weevil larvae while others attack the adult weevils. The young wasps feed inside the weevil, destroying it in the process. The wasps complete their life cycles in the host and emerge as adults to seek more alfalfa weevils to continue the cycle. The two dominant species are *Bathyplectes curculionis* and *Bathyplectes anuris,* both of which attack alfalfa weevil larvae.

In areas where the parasitoids have become established, the need for insecticide applications have been greatly reduced. Farmers need to be aware that most insecticides kill beneficial insects such as parasitoids more readily than weevils. For this reason, farmers need to consider an integrated pest management program that uses a balance of biological, cultural and chemical controls.

Growers need to learn how to evaluate weevil damage and become familiar with the economic damage thresholds in order to avoid unnecessary insecticide applications. Weevil damage is very conspicuous and small amounts of injury may lead you to believe that insecticides are warranted when they are not. Insecticides should only be applied when weevil populations exceed the established economic thresholds so that parasites will be better able to increase in numbers—decreasing the need for future chemical controls. Total levels of parasitism can be estimated, but only after crop damage already has occurred. Therefore, parasitism rates are currently not used when determining threshold levels for treatment of the alfalfa weevil. However, parasitism throughout the season reduces the numbers of alfalfa weevil larvae and, thus, represents an important management component for this pest.

European corn borer

The European corn borer is a major pest of corn in Kansas and often the target of repeated insecticide applications. Several naturally occurring predators are capable of suppressing European corn borer populations in the Midwest. The most prominent of these are various species of lady beetles, the common green lacewing (*Chrysoperla carnea*), minute pirate bugs, hover flies, predatory mites and ground beetles. These predators feed on the egg and early larval stages of corn borers. Levels of control vary with the year and location, and different natural enemy species dominate at different times. Although several biological control agents have been aimed at this pest, none have been completely effective at reducing its population below economic levels.

Minute pirate bug

Imported natural enemies include a few species of parasitic wasps and the tachinid fly, *Lydella thompsonii*. In the early 1900s, *Lydella* was a very common parasitoid and an important biological control agent of European corn borer larvae. Subsequently, it underwent a decline in the Midwest and elsewhere. This fly has been reintroduced into the United States and, in some places, appears to be having an impact on the corn borer. However, rates of parasitism have not reached previous levels. Other imported parasitoids of corn borer larvae are the braconid wasp, *Macrocentrus grandii* and the ichneumonid wasp, *Eriborus terebrans*. Recent studies in Michigan have shown that *Eriborus* lives longer and is more effective near wooded field borders, where

Minute pirate bug nymph

temperatures are cooler and adult food sources are available, than in the interior areas of corn fields. More research of this kind is needed to find ways to preserve and increase the action of native and imported biological control agents.

Current attention is focused on a group of tiny parasitic wasps called *Trichogramma*. These wasps attack the eggs of the European corn borer and can be quite effective at reducing corn borer larval populations. However, the trick is to ensure they are present in the proper place at the proper time in high enough numbers to destroy the European corn borer eggs before they can hatch into the damaging larval stage. Several projects are currently underway throughout the United States to improve the efficacy of augmentative releases of *Trichogramma*. Data suggests that there is a strong relationship between egg mass parasitism and larval population reduction. There also is a high level of variability between parasitoid release rates and egg mass parasitism rates. Thus, one of the key areas of research is to determine the factors that influence parasitism rates, such as environmental conditions, parasitoid release techniques, parasitoid species or strains. Ways also must be found to reduce the cost of the parasitoids before augmentative releases of *Trichogramma* will become economically viable on field corn. However, if research continues, these parasitoids may become a part of the pest management system for corn borer control in the foreseeable future.

A naturally-occurring protozoan, *Nosema pyrausta*, infects corn borers and may reduce populations by shortening the adult lifespan and egg-laying period. This pathogen also has been applied to corn borer populations with some degree of success. It has no negative effect on green lacewing predators or the tachinid fly parasitoid *Lydella*. However, *Nosema* is not compatible with the egg parasitoid *Trichogramma nubilale.* Infected *Trichogramma* have lower survival rates and a reduced reproductive capacity. The microbe *Bacillus thuringiensis* also has been used as a corn borer insecticide that protects other natural enemies.

Greenbug

One of the most important natural enemies of the greenbug is the parasitic wasp, *Lysiphlebus testaceipes.* This shiny black wasp can be seen on warm, sunny days crawling across wheat leaves and stinging (parasitizing) greenbugs. The female pierces (stings) the greenbug and deposits an egg inside. In about two days the tiny egg hatches into a grub which feeds internally on the living greenbug. The parasitoid becomes mature in about six to eight days and then begins to twist and turn inside the greenbug host. The parasitized greenbug stops moving and grabs the leaf with its legs. Movement of the parasite larva expands and molds the greenbug's body, giving it a swollen appearance. The parasitoid larva cuts a hole through the bottom of the greenbug's body and fastens it to the leaf surface with silk and a glue. The swollen greenbug cadaver turns a beige to tan color and is then called a "mummy."

Greenbug mummy

The parasitoid larva then enters the pupal stage inside the mummy and the adult parasitoid emerges four to five days later. The adult escapes through a circular hole it cuts in the top of the mummy. The adult parasitoid mates and repeats the life cycle by stinging additional greenbugs. At a constant temperature of 70°F, development from egg to adult requires about 14 days.

Each female adult *Lysiphlebus* can parasitize about 100 greenbugs during her four to five days of life. More important than the death of individual greenbugs is the reduction in potential greenbug reproduction. All greenbugs are females which give live birth to three or four offspring per day. Parasitized greenbugs stop reproducing within one to five days, while unparasitized greenbugs reproduce for 25 to 30 days. As a result, parasitism can greatly reduce the rate at which greenbug infestations increase.

Parasitoid activity in the field can be monitored by looking for greenbug mummies on leaves. Weather conditions will largely determine how quickly parasitoids can prevent a greenbug outbreak. Remember that aphids that appear healthy may actually have parasitoids developing within, as the mummy stage does not develop until eight to 10 days after parasitism. As a general rule, a greenbug infestation declines rapidly once 20 percent of the greenbugs are mummies, because at this point most of the living greenbugs are already parasitized though they have not yet entered the mummy stage. This parasitoid is most effective during warm weather from late spring to early fall. Adults are inactive at temperatures below 56°F. Other aphids such as the corn leaf aphid can serve as an alternate host for this parasitoid.

Insecticides applied as sprays will kill adult wasps and indirectly kill immature parasitoids by killing their greenbug hosts. Methyl parathion and chlorpyrifos (Lorsban) are more toxic to adult wasps and to immature parasitoids inside greenbugs than the systematic insecticides dimethoate and disulfoton (DySyston), especially at lower rates. However, the short residual toxicity of methyl parathion allows parasites to recolonize a field sooner than when insecticides with longer residual activity are used. In addition, immature parasitoids inside greenbug mummies gain some protection from insecticides. Higher insecticide rates increase the mortality of immature *Lysiphlebus* and extend the time before adults can survive on treated foliage. The fungicide Bayleton, used to control leaf rust on wheat, also is very toxic to adult parasitoids.

The parasitoid overwinters as a larva and pupa inside a parasitized greenbug. Wasps disperse by flying and by being carried as immature parasitoids inside winged greenbugs. Unfortunately, *Lysiphlebus* often is attacked by other species of parasitic wasps, which can limit its control of greenbug.

More research is needed to better define when and how soon the parasitoid will eliminate greenbug populations and in ways to decrease the lag time between when greenbug populations begin to cause damage and when the parasitoid becomes active.

Spider mites

The Banks grass mite, *Oligonychus pratensis* (Banks), and the twospotted spider mite, *Tetranychus urticae* (Koch), are serious pests of corn in the western third of Kansas. One of the most promising natural control agents of these pests are predatory mites.

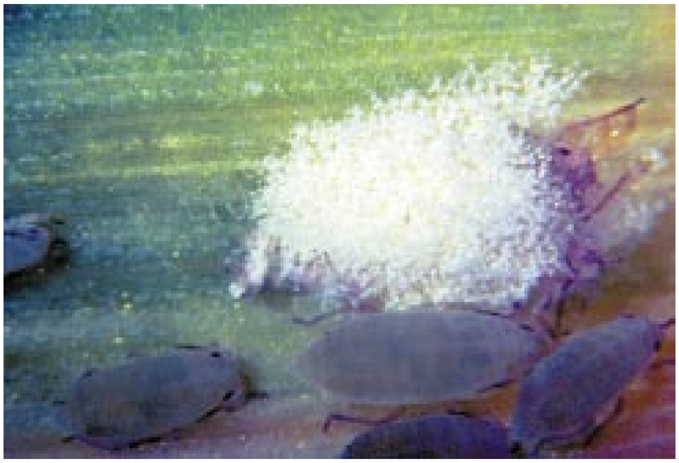
Predaceous mite

The most common predatory mite in Kansas is *Amblyseius fallacis.* It is slightly larger than the Banks grass mite and twospotted spider mite, pale brown or straw colored and ovoid in shape with the head being at the narrow end. They often can be recognized as they move about on the corn leaves in a zigzag pattern as they search for prey. Other small-sized, naturally occurring predators are *Stethorus* lady beetles, minute pirate bugs, hover fly larvae and predatory thrips. The fungal pathogen, *Neozygites*, also causes mortality to spider mites.

Although these mites are very effective in reducing spider mite numbers, they often do not control spider populations soon enough to avoid economic damage. Studies in Texas have shown that inoculative releases of predatory mites during the growing season could be useful in controlling spider mites on corn. However, the current costs of producing predatory mites precludes their commercial implementation. Therefore, more research is needed to develop more efficient ways to distribute mites into fields and to rear them. Currently, research is being conducted to determine if predatory mites can be released in the overwintering sites of the spider mites so they can move into the corn fields with the spider mites early in the season; reducing the numbers of predator mites that would need to be released and the area that would need to be treated.

Russian wheat aphid

The Russian wheat aphid (RWA) is a new pest of small grains in North America. It is attacked by a number of natural enemies already present on other aphids in the United States and Canada including predators, parasitoids (parasitic wasps), and pathogens (mainly disease-causing fungi). Some of the most common predators on RWA are the convergent lady beetle, the common green lacewing, hover flies and chamaemyiid (cammy-my-ee-id) flies. The species of predators that have the greatest impact on RWA depends on location and climate and can vary from year to year. Naturally-occurring parasitic wasps also can attack RWA, but these are not specific to RWA and their impact is not well understood. Two of the species recovered from RWA are *Diaeretiella rapae* and the greenbug parasitoid, *Lysiphlebus testaceipes.* Parasitized RWAs can be distinguished from other grain aphids based on body shape. The RWA and its parasitized "mummy" are more cylindrical and tapered at both ends than the pear- or oval-shaped mummies of greenbugs and other grain aphids. The RWA's antennal length and other appendages also are much shorter than those of other grain aphids. Periodically, fungal infections cause high mortality to RWA. These are most common in moist weather and in areas that have generally wet



Russian wheat aphid killed by fungus

climates. Infected RWAs can be identified by their fuzzy, sometimes whitish, appearance. This fuzziness is caused when fungal spores coat the dead aphid's body. These spores are carried through the air to other aphids which can then become infected.

No imported predators are known to be established on RWA. However, four species of imported wasps have been collected from parasitized RWA and are believed to be established in the United States. All four have been recovered in Kansas. These parasitic wasps represent two families that are most easily identified by the appearance of the dead aphid mummy, which remains attached to the tillers. Mummies from species in the family Aphidiidae are tan or gold-colored and swollen in shape. Mummies from the family Aphelinidae are blackish and more flattened. Adults of both families are very small, black insects. Adult Aphidiids are more slender and slightly longer than Aphelinid adults.

To date, native aphid predators and parasitoids appear to be having more of an impact on RWA than the imported parasitoids where both are present. Two reasons for this difference are that the newly introduced species are not widely distributed, and they are presently much less abundant than most of the native natural enemy species.

Sampling RWA is a problem because it often is a sporadic pest that occurs in patches in fields. This is especially the case in the Midwest. However, a sequential sampling plan has been developed for growers. Determining where and when natural enemies are active is a more difficult problem. In fact, at the present time there is no practical way of relating natural enemies' presence and abundance to their impact on RWA. Some work is currently being done to assess predation by lady beetles, parasitism levels based on mummies, and the overall impact of natural enemies on RWA in the field. This kind of research will be necessary before biological control can be incorporated into pest management decision-making models. The relationship between RWA density and damage has been determined. Therefore, eventually it may be possible to use presence and abundance data for natural enemies to predict when pesticide applications can be delayed or avoided. However, even in situations where RWAs exceed damage thresholds requiring treatment with insecticides, biological control agents contribute to suppressing and containing the aphid, thereby reducing the likelihood of new infestations and pest outbreaks in wheat and barley fields.

One known obstacle to natural enemy effectiveness is that early feeding by RWA causes tillers to roll up tightly. Once enclosed, aphids continue to feed and reproduce within these protective barriers which prevent or slow down the entry of most predators and all but the smallest parasitoids. The recent discovery that some RWA-resistant wheat varieties do not roll their leaves may allow greater efficacy of biological control agents.

Chinch bug

The chinch bug *(Blissus leucopterus leucopterus)*, is a pest of wheat, corn, sorghum and various grasses, including lawns and commercial turf. It is an especially difficult pest to control in dry years when large populations occur. Few natural enemies are known to attack the chinch bug. For this reason, biological control

Beauveria bassiana on chinch bug

has not been incorporated into IPM programs in the way that resistant varieties have. Naturally occurring biological controls that do exist include a tiny wasp—*Eumicrosoma beneficum*—that parasitizes individual eggs of the chinch bug and a few closely related species (for example, the hairy chinch bug), and the widespread, nonspecific, fungal pathogen, *Beauveria bassiana*.

Of the two, only *B. bassiana* seems to serve as a natural suppressive agent of the chinch bug. However, it does not provide consistently high levels of control year after year. Research has shown that chinch bug infection rates are highest when soil moisture is low and temperatures are high. However, mortality is greatest when these conditions are followed by a combination of high temperature, soil moisture and relative humidity. Other factors such as availability of overwintering grasses at field borders, which harbor reservoirs of infected bugs and fungal spores, increase the chances of natural disease outbreaks in chinch bugs during the next crop season. Higher populations of bugs also help spread disease-causing spores. Even with this knowledge, at present there are no good predictive models for forecasting the timing and levels of chinch bug mortality from *B. bassiana*.

Corn rootworms

Corn rootworms cause extensive losses to corn and other field crops in the Midwest. The most important species are the northern corn rootworm (NCR), *Diabrotica longicornus barberi*, and the western corn rootworm (WCR), *D. virgifera virgifera*. The western corn rootworm is a major pest in Kansas. Surveys have shown that these pests are relatively free from attack by insect predators and pathogens. However, periodically, certain ant species play an important role by preying on corn rootworm larvae. Predation by ground beetles and soil-inhabiting mites probably occurs; but the effect of these natural enemies on rootworm populations is not well understood.

The use of parasitic nematodes to control corn rootworm larvae holds some promise. Nematodes do not have the adverse effect on nontarget organisms (including naturally occurring biological controls) that broad-spectrum insecticides do. Field trials using a center-pivot irrigation application method have shown that high rates of the nematode, *Steinernema carpocapsae*, were as effective as conventional insecticides in controlling WCR larvae. In addition, parasitic nematodes have been successfully incorporated into pellets that can be conveniently applied to the soil. However, because of the higher cost of nematodes compared to insecticides, and the need to make repeated applications, this pest management procedure is prohibitively expensive on field corn at this time.

Conclusions

As a natural process, biological control plays an important role in the suppression of field crop pests in Kansas. It also shows considerable promise as a management approach for field crop pests. However, to reach its potential, either as a single tactic, or as a component in integrated pest management programs, research is needed to increase the effectiveness and predictability of natural enemies and to make biological control more economical. Efforts should be continued to establish new natural enemies for the many foreign pests that affect Kansas field crops. Much work also is needed to find ways to better conserve natural enemies. This protection extends both to native and imported species, and to those released into the environment as well as populations that are already established. Finally, improved methods for handling and rearing natural enemies are needed to increase efficacy and reduce costs of augmentatively released biological control agents. One step in the right direction would be for farmers who are interested in using biological control to become more active in working together, and with public officials, to promote the research and development of biological control.

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