UNDERSTANDING BIOLOGICAL CONTROL AND ITS POTENTIAL FOR MANAGING INSECT PESTS ON CRANBERRY IN WISCONSIN

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INTRODUCTION

Five major issues facing agriculture into the 1990s include (1) insuring food safety, (2) increasing agricultural sustainability, (3) improving farm profitability, especially for family farmers, (4) improving the health and safety of farm workers, and (5) reducing negative environmental impacts of traditional agricultural practices. Pest management is a component of each of these issues. Other specific pesticide related issues of importance include loss of effectiveness of products because of development of pest resistance and loss of specific products through the reregistration process. Whenever possible, traditional broad spectrum insecticides and other high input pest management practices should be replaced with low input, non-polluting, and self sustaining methods of pest control. A frequently mentioned alternative to chemical control is biological control.

Biological control can be a very successful approach to pest management, but unfortunately it is poorly understood by farmers, environmentalists, policy makers, and the general public. Attempts at biological methods of insect control have met with both fabulous success and dismal failure. The differences in result can be attributed to (1) the specific target pest and the type and extent of damage done to the crop, (2) the efficiency of the natural enemies available for the target pests, (3) the type, value, and use of the crop, (4) the amount of research conducted on the biological control of the target pests, including studies of the natural enemies involved, and (5) the level of knowledge and the degree of commitment of the biological control user. The last factor may very well be the most crucial for the success of biological control.

Biological control is the active utilization of natural enemies to regulate the numbers of pests. Biological control is the logical extension of natural control, and a knowledge of natural control is helpful in the development of an understanding of biological control.

NATURAL CONTROL

Natural controls consist of various environmental factors that have a negative impact on the population of a species, thereby limiting its capacity to build up to large numbers. There are many different environmental factors that can have this influence, and these factors are usually divided into two groups: (1) biotic factors and (2) abiotic factors. Biotic factors (“bio” referring to life) are those environmental factors involving living organisms, and include such things as predators and disease organisms, and starvation caused by competition when the food supply is inadequate. Abiotic factors (“abiotic” meaning without life) are those environmental factors not related to living organisms, and

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include such things as drought, freezing,. flooding, and topographic features such as high elevation or desert.

The size of every population of every type of organism is regulated by natural environmental factors. These factors differ by location and change through time. At some times various factors combine to dramatically reduce a population, and that species becomes uncommon in that location. At other times the environment is more favorable resulting in greater survival and reproduction of the species, and consequently the population increases, sometimes dramatically. Pests respond to environmental factors just as do non-pest organisms, and the relative impact of natural controls. influences when pest numbers are going to be high or low.

Natural control is a very important but often overlooked form of pest control. It is overlooked because the actions of nature are often subtle and not always apparent, and because humans are not directly involved in applying natural controls. However, as we continue to reduce our reliance on pesticides and other preventive forms of pest control, it will be necessary for pest managers to become more knowledgeable about natural controls. This will mean increasing our knowledge in the following areas:

1) being able to distinguish pests from non-pest species;
2) better understanding the life cycle of the pest and the severity and type of damage done;
3) understanding how populations of a pest respond to abiotic and biotic factors in the environment;
4) being able to recognize the beneficial organisms (“natural enemies”) that help naturally control the pest;
5) understanding and conscientiously utilizing sampling practices to routinely monitor for pest and natural enemy activity; and
6) using effective and environmentally safe methods of controlling a pest when natural and biological controls are not being effective; such methods should not interfere with the natural and biological controls of other pest species in the system.

NATURAL ENEMIES

A natural enemy is an organism which kills, seriously debilitates, reduces reproduction of, or otherwise interferes with individuals of another species. All species, including all types of cranberry pests, have natural enemies. Some natural enemies affect many different species, and these are referred to as **generalist natural enemies.** Other natural enemies may affect one or a very few closely related species, and these are called **specialists.** Specialist natural enemies are better suited to find their prey and cause it injury, and therefore are usually more efficient in biological control programs. Natural enemies of pest insects fall into three main categories: predators, parasites, and insect pathogens.

Predators.

Although predators include such things as birds, rodents, and frogs, all of which are important in natural regulation of many types of insects, the most important predators in insect pest management are other insects. Two major factors characterize predators: 1) they are usually free-living and often very mobile, and (2) they consume many prey (pests) during their lives. Predators are often generalist natural enemies although a few types are highly specialized. A large percentage of insects are predators and many are beneficial natural enemies in crop settings. It is not possible here to discuss all types of predators and their importance in natural and biological control. A few common examples include ladybird beetles, lacewings (aphid lions), mantids, syrphid flies, assassin bugs, minute pirate bugs, spiders, and predatory mites.

Parasitic insects.

Parasitic insects, often simply called "parasites" or "parasitoids", belong primarily to two major groups of insects, the flies and the wasps. Parasites have a more complex life cycle than most predators. The general life cycle consists of the following stages: egg, larva, pupa, and adult. The adult is a free-living insect such as a fly or tiny stingless wasp. It seeks out the **host** insect (prey or pest) and deposits one or more eggs in, on, or near it. The egg hatches into the larval stage, which is often maggot-like in appearance. The larva feeds on the host insect, consuming and eventually killing it. Most parasite larvae actually feed and develop within the body of the host insect. Once the larva is fully grown and done feeding, it changes into the pupa, which is a transitional stage between the larva and adult fly or wasp which eventually develops from the pupa. Depending on the species of parasite, the adult stage has various foods, including flower nectar, pollen, other sugar and carbohydrate sources such as rotting fruit, or other insects (in which case, the adult can be classified as a predator). A parasite larva is very closely tied to its individual host insect, is generally incapable of much movement on its own, and kills only one host insect during its development. Many parasites are very specialized natural enemies with phenomenal abilities to locate and kill their particular host species. Parasites are generally considered more efficient natural enemies than predators against many types of pests.

Most plant-feeding insects (as well as many other types of insects) are attacked by one or more species of parasites. Indeed, there are many thousand different species of parasites in North America. Most are small (some are extremely tiny, less than 1 mm when fully grown) and rather non-descript, and it is often difficult to differentiate them from other small insects. Most belong to one of the following groups: tachinid flies, ichneumonid wasps (ichneumons), braconid wasps (braconids), and chalcid wasps (chalcids). The parasitic wasps are small and mostly incapable of stinging, differentiating them from their larger relatives such as hornets and yellowjackets.

Insect pathogens.

Insects, like other organisms, are subject to diseases. There are many types of insect pathogens which are very important in natural and biological control. **Insect viruses** tend to be fairly host specific and often work very rapidly when host population levels are high. Some **bacterial pathogens** are host specific while others are more general. The pathogen in commercial insecticides containing *Bacillus thuringiensis,* used for controlling some cranberry caterpillars, is a bacterium. **Fungal pathogens** usually require high humidity to be effective and are fairly common in the Midwest, especially during periods of higher moisture. **Insect protozoans** are also common but often debilitate their host rather than killing it outright. **Insect parasitic nematodes,** such as those available for controlling cranberry girdler, are often grouped with insect pathogens, and are highly effective for controlling certain soil insects and other insects living in moist habitats. Most insect pathogens are not harmful to plants, humans, or other types of organisms. However a few have a relatively broad host range that includes beneficial insects.

Some insect pathogens, such as *Bacillus thuringiensis,* have been mass-produced and made commercially available for pest management. Such products are called **microbial insecticides.** The use of these is an excellent example of the biological control method called **augmentation** which will be discussed below.

BIOLOGICAL CONTROL

As stated earlier, biological control is the human extension of natural control, specifically, the use of natural enemies. The primary difference between natural control and biological control is the human role in manipulating the natural enemies of the pest. As will be shown below, such intervention may be relatively brief and the results relatively permanent, a situation approaching natural control. In other cases the human input may need to be fairly frequent and routine, a situation more similar to other forms of traditional pest control such as sanding cranberry beds or use of pesticides.

Biological control has been used successfully against certain pests in every major pest group, including insects, mites, nematodes, plant pathogens, weeds, and even vertebrate animals such as rabbits. The specific methods of biological control vary somewhat depending upon the type of target pest. This paper will focus on the biological control of insects.

Biological control scientists and practitioners recognize three approaches to insect biological control: (1) **importation** of exotic natural enemies which do not currently exist in the area of interest, **(2) conservation** of existing natural enemies, and **(3) augmentation** of natural enemies to bolster those that naturally occur. Background information on these three general approaches is given below. My outlook for using each of these approaches on cranberry pests is presented later in this paper.

IMPORTATION of exotic natural enemies.

This method is based, in part, on the knowledge that many serious crop pests have been accidentally introduced from other parts of the world. It is also based on the fact that the most efficient natural enemies of a pest are often found in the native home of the pest, or in the home of a closely related insect species. "Exotic" natural enemies are then sought out by USDA and university scientists, evaluated for their potential benefits and risks, and then imported, released, and, hopefully, permanently established in the area of the non-native pest. There are many examples of outstanding success using this approach, such as the complex of imported parasites which controls alfalfa weevil. Unfortunately, there are also many cases where effective exotic natural enemies simply haven't been found or haven't been successfully established in the target area. When fully successful, this method of biological control approaches natural control in that once the new natural enemy is established it can be sufficiently effective so that further human inputs may be unnecessary, other than assuring that the activities of the natural enemy are not hampered. Although importation of exotic natural enemies will not solve all pest problems, there are still many pest species that could be subjects for this approach. USDA and university scientists are on continuous exploration in foreign lands for potentially useful beneficial natural enemies. However, federal and state funds for these activities are limited and major successes are relatively slow in coming.

CONSERVATION of existing natural enemies.

Natural enemies, like all other organisms, are subject to biotic and abiotic environmental factors that influence their populations. Negative influences should be reduced and positive influences should be encouraged. When humans are actively involved in improving environmental conditions to favor natural enemies, this is referred to as **conservation** of natural enemies. Probably the single most important factor in conservation of natural enemies is to avoid utilization of broad spectrum insecticides that are known to kill them. Not all pesticides are equally harmful to natural enemies. Some beneficial insects are naturally tolerant of certain pesticides, while other natural enemies have, through many generations of repeated exposure, developed resistance to certain pesticides. In some situations it will be necessary to utilize pesticides for pest control, especially where no other methods are effective and the pest numbers are so great that serious economic damage will result if chemical controls are not applied. In many such cases it will be possible to use chemical controls in conjunction with natural enemies, and this fact gave rise to the concept of "integrated control" or **Integrated Pest Management** (IPM). But in these situations, proper choice of materials and correct timing and method of application are usually very important to conserve natural enemies.

AUGMENTATION of natural enemies.

Because of various environmental factors, some natural and others created by humans, natural enemies often occur in inadequate numbers to provide satisfactory pest control. In these situations, there are two options: (1) do nothing and suffer significant losses, or (2) provide human input in the form of some control method. One of the possible control methods is to artificially increase the natural enemy population by releasing additional natural enemies that have been raised at insect farms called **insectaries.** (Actually, insectaries are fairly sophisticated indoor laboratories and some of the natural enemy rearing techniques are quite advanced.) The natural enemies that are released may be the same species that already exist at the site, or they may be other species that may have greater or lesser effectiveness than those occurring there naturally. This type of artificial input of natural enemies is called **augmentation.**

Generally, plant communities with greater complexity (more species of plants) have greater numbers of plant-feeding insects, which, in turn, support a greater number of species of generalist and specialist natural enemies. By growing our crops in a monoculture (even on a relatively small scale, such as in cranberry beds), and by eliminating competing weeds, we reduce the numbers of plant feeders with a resulting reduction in the number of types of natural enemies. Under these conditions, there are often inappropriate types or inadequate numbers of natural enemies to suppress an increasing pest population. Disruption of the agroecosystem also can have a negative impact on natural enemies. Therefore, we see more natural enemies and a greater diversity in a perennial crop, such as a cranberry bed, Christmas tree plantation, orchard, vineyard, or alfalfa field than we do in an annual crop such as corn, soybeans, or cabbage, where the entire field is completely cultivated or cleared at least once each year. These factors have formed the basis for the augmentation approach to biological control.

Augmentation of natural enemies can be subdivided into two approaches: (1) **inundative releases** and (2) **inoculative releases.** Inundation involves releasing massive numbers of natural enemies for immediate reduction of a damaging or near-damaging pest population. In this way it is analogous to a corrective insecticide application; the expected outcome is for immediate pest control. Because of the nature of natural enemy activity, and the cost of purchasing them, this approach using predaceous and parasitic insects is rarely recommended. However, the utilization of microbial insecticides (such as *Bacillus thuringiensis)* and insect parasitic nematodes are excellent examples of inundative releases of natural enemies. **Inoculation** involves releasing small numbers of natural enemies at prescribed intervals throughout the pest period, starting when the pest population is very low. The expected outcome of inoculative releases is to keep the pest at very low numbers, never allowing it to approach an economic injury level. In this way, inoculative releases are analogous to preventive insecticide applications. When using inoculative releases you assume that a pest problem is going to develop. In some ways inoculative releases go against the dictates of integrated pest management programs, which discourage pest management inputs (other than a routine monitoring program) until a pest problem becomes evident. The utilization of inoculative natural enemy releases is neither low input nor sustainable; it requires a relatively high input of time, labor, and money and must be repeated at least annually and usually several times per growing season. However, these negative aspects of the augmentation approach to biological control are fairly minor in comparison to the problems which are sometimes associated with the use of broad spectrum insecticides and other disruptive methods of pest control.

TYPES OF NATURAL ENEMIES COMMERCIALLY AVAILABLE

There are over thirty types of natural enemies commercially available in the United States. Although this seems like a relatively large number, consider that there are over 700 species of serious arthropod pests (insects and mites) in North America; and most of these have a complex of generalist and specialist natural enemies. Commercially available natural enemies fall into two categories: (1) those that are generalists in what they attack (such as ladybird beetles, lacewings, and *Trichogramma)* and therefore have a potentially wide market, and (2) those that are specialist natural enemies (such as predatory mites or the whitefly parasite *Encarsia),* for which there are major markets on high value crops. The production of natural enemies requires highly specialized equipment and methods and is relatively labor intensive. Often, years of university, federal, and private research are necessary to sufficiently understand the biological needs of a natural enemy to be able to mass produce it. Therefore, producers will continue to supply generalist natural enemies of proven abilities, or specialized natural enemies for major markets. It should be realized that many if not most cranberry pests will not be appropriate targets for those natural enemies currently available, and other types of control practices may be necessary, especially against the most damaging pests. However, it is likely that the list of commercially available natural enemies will continue to slowly increase as long as producers have acceptable markets for their new products.

The following is a brief discussion of the major natural enemies currently available that might be considered for use on cranberry.

Predatory insects.

Ladybird beetles. The most commonly available ladybird beetle is the convergent lady beetle, *Hippodamia convergens.* It is native to much of the United States, including throughout the Midwest. The convergent lady beetle is not commercially produced. Instead, it is mass collected, literally by the bucketful, from amazingly large hibernating congregations in the hills and mountains of central and southern California. The natural behavior of the lady beetle in California is to fly out of the coastal and inland valleys in the fall into higher cooler elevations, and then congregate in spectacular masses to spend the winter. In spring, their normal behavior is to fly back down to lower elevations, where aphids and other prey have started to develop, before they start feeding. This has posed problems with the field collected lady beetles because they naturally rapidly disperse some distance after release. Lady beetles now are preconditioned by the commercial suppliers by temperature treatment and feeding to reduce the normal dispersal behavior. However, many users are still somewhat disappointed by the rapid decline in numbers after release.

Another problem related to this is the need for lady beetles to feed. If aphids or other appropriate foods are not abundant, this will also cause rapid dispersal to more productive hunting grounds. For these reasons, release of convergent lady beetle is more efficient when large areas are treated as compared to smaller areas such as home gardens.

Both the adults and the larvae of convergent lady beetles are predaceous. The preferred food is aphids, but in the absence of these they will also feed on other small, slow moving, soft bodied insects and mites.

Because of their limitations, use of convergent lady beetles on cranberry is **not** recommended.

Lacewings. Green lacewings also are somewhat specialized for feeding on aphids, but will also feed on quite an assortment of other small insects and mites. Because they are usually released as eggs or young larvae, they do not fly away. The larval stage, called the aphid lion, is the most important stage for pest control. Although the adults also feed on insects, they require other food sources, and if any necessary type of food is not available, they will fly elsewhere to lay e s. Two species of green lacewings are commercially available. *Chysoperla* (or *Chrysopa) carnea* is usually considered best for row or field crops, while *C. rufilabris* is better adapted for orchards.

We occasionally find green lacewing larvae occurring naturally in cranberry beds, where they probably feed on small caterpillars such as fireworms and spanworms, and other small insects. We suspect that they may also feed on tipworm larvae, but this has not been demonstrated. No research has been conducted on augmentative releases of lacewings in cranberry beds, so any use should be considered experimental.. Typical release rates on other crops are in the range of 10,000-20,000 eggs per acre at a price of about $25-50 per acre. Application to small areas is usually done by hand, but mechanical devices are available for hand, tractor, and even aircraft application.

Spined soldier bug: ***(Podisus maculiventris)*.** This member of the stink bug family feeds on a variety of slow-moving, soft-bodied insects that live on plants, such as caterpillars and the larvae of Colorado potato beetle. It is a native insect which is often very important in natural control and holds promise for augmentative releases. However, it has been in commercial production for only a couple of years and it has yet to be fully evaluated. No research has been done to measure the potential benefit of this predator in cranberries.

Praying mantids. Some suppliers sell mantid egg cases. Each egg case will give rise to many young mantids. Mantids are very general predators which make no distinction between pests and beneficial insects. Their numbers usually decline rapidly after hatching and they provide little if any significant value in pest control. The use of purchased mantid **egg** cases is **not recommended** for commercial agriculture, including cranberry production.

Parasitic insects.

Trichogramma. *Trichogramma* is the most commonly used parasitic insect in augmentation programs world wide. Millions of acres in the former USSR and China are treated annually with this tiny wasp. The entire genus *Trichogramma,* indeed, the entire family *Trichogramma* tidae, consists of insects that parasitize the eggs of other insects. The tiny adult *Ttichogramma* wasp, less than 1 mm long, lays one or more of its own eggs within the egg of its host insect. The *Trichogramma* egg hatches and the larva consumes the inside of the host egg. The *Trichogramma* then pupates, and eventually the next generation adult emerges, leaving the host egg killed. Because the pest is killed in its egg stage, the damaging stages do not develop.

Some species of *Trichogramma* are specialized parasites whereas others are more general in their acceptance of host eggs. Eggs of moths and butterflies are most frequently attacked, although some species also attack eggs of beetles and other insects. There are three or four species commercially available in the United States, all of which are used primarily against the eggs of various types of moths. *T. pretiosum* is most suited for use in field and row crops; *T. minutum* is better suited for use in orchards and other tree crops; and *T. evanescens* is used primarily against European corn borer. A fourth species is used against avocado pests in California. Research is currently being conducted on other species of *Trichogramma* which may be more efficient parasites of the eggs of various types of pests. We have found both *T. minutum* and *T. pretiosum* capable of parasitizing blackheaded fireworm eggs in cranberry beds, where we have found ***T.*** *pretiosum* to also occur naturally.

Release of *Trichogramma* should coincide with the earliest flights of moths of the target pest. For example, releases should be made within a few days of first pheromone trap catches of blackheaded fireworm. Additional releases should be made at one to two week intervals through the flight period.

Although we are not currently able to recommend *Trichogramma* releases on cranberry, typical release rates on other crops are about 50,000-100,000 per acre, at a cost of $1020 per acre. Various manual and mechanical application methods have been developed.

Insect pathogens (microbial insecticides).

Although several insect pathogens have received approval from EPA for use as microbial insecticides, few types are actually commercially available. Most microbial insecticides have several advantages over traditional chemical insecticides in IPM programs. They combine ease of application with human and environmental safety. Also, they tend to be fairly specific, and generally are not directly harmful to beneficial predatory and parasitic insects.

Products containing the bacterium *Bacillus thuringiensis* (“Bt”) are by far the most widely used microbial insecticides. There are several varieties of Bt, each of which has somewhat different properties. *Bacillus thuringiensis* var. *kurstaki* is the variety most frequently used in commercial preparations for caterpillar control. It is exempt from federal residue tolerances and can be used up to the time of harvest. It is registered for use on many types of crops. Bt varieties *tenebrionis* and *san diego* are effective against larvae of certain beetles, including Colorado potato beetle and elm leaf beetle. The variety *israelensis* is effective for control of larvae of mosquitoes, black flies, fungus gnats, and other fly relatives.

Another bacterium, *Bacillus popilliae* causes milky disease of white grubs. It is especially effective against Japanese beetle grubs and is not effective against the larvae of June beetles *(Phyllophaga* sp.), which are the most important white grubs in Wisconsin. Commercial products containing this bacterium **are not recommended** for use on cranberry in Wisconsin. However, research is being conducted on other types of milky disease bacteria, and one may ultimately be found that is effective against *Phyllophaga* grubs.

Nosema locustae is a protozoan which is effective against grasshoppers, crickets, and related groups. It is slow in acting and often decreases vitality of the insect and reduces reproduction rather than outright killing the insects. It has greatest application in rangeland, where some feeding injury can be tolerated. It is sold as a bait formulation which is attractive to, and fed upon by the grasshoppers.

There is much interest in the commercialization of insect parasitic nematodes (also called “entomogenous” nematodes) for biological control. Such nematodes are safe to use and do not affect plants. They are primarily used against soil insects, and they may be detrimental to some groups of beneficial predatory insects that live in the soil, such as predaceous ground beetles. Parasitic nematodes require moisture for survival and movement, and will be most effective in moist habitats, such as moist soil. Nematodes have three advantages in pest management: (1) the living worms move through the habitat and actually seek out their host insects, (2) they reproduce in their hosts and tend to persist in the environment as long as some hosts are present, and (3) they are viewed by EPA to be higher animals, more similar to beneficial insects, and are not currently regulated by federal agencies. *Steinernema carpocapsae* is the most commonly available nematode for biological control. There is also interest in *Heterorhabditis* nematodes and other groups, which may eventually become commercially available. Thus far, production costs are high, and application costs may be as high as $300 per acre. Therefore, current use is restricted to high value crops. However, as mass production technology improves, prices are expected to decline considerably. Storage and application are not as straight forward as other microbial insecticides, but application technology is also improving.

TEE OUTLOOK FOR BIOLOGICAL CONTROL OF CRANBERRY INSECTS IN WISCONSIN

Certain approaches to biological control are already in use by the cranberry industry. There is great potential for the development of many other specific biological control methods.

Outlook for IMPORTATION of new natural enemies of cranberry pests.

Historically, the north central states have been relatively neglected in the area of new natural enemy introductions. No state departments of agriculture or universities in the Midwest have the types of biological control facilities and programs that are sponsored in leading biological control states such as California, Texas, and Hawaii. Furthermore, USDA importation programs in the Midwest have been minor compared to other regions. Many of our biological control successes, such as alfalfa weevil, have resulted from natural enemy introductions into other areas, with resultant spread into the north central states.

This situation is likely to change. There is increased interest by the USDA to cooperate with individual states and regions in finding, evaluating, and introducing new natural enemies. In addition, individual states in the Midwest are making a greater commitment to biological control. Several Department of Entomology faculty at the University of Wisconsin - Madison are actively involved in biological control programs. However, Wisconsin does not have the facilities necessary for natural enemy importation activities, and the state does not fund foreign exploration. Therefore, most activities in our department have focused on the conservation and augmentation approaches to biological control. This situation could easily change if facilities and resources for importation programs became available.

Because cranberry is a native North American crop, and because most cranberry pests are also thought to be native to North America, the importation approach to biological control on cranberry may be somewhat limited. Significant opportunities do exist, however. For example, blackheaded fireworm and some of our spanworm species are also considered to be native to the Old World, especially Europe and Asia, where more efficient natural enemies may exist. Also, there are species of the egg parasite *Trichogramma* which occur in Europe and Asia but not in North America; one of these species may be more effective at killing the eggs of cranberry pests than our native *Trichogramma.* Our recent research on the Wisconsin natural enemies of blackheaded fireworm demonstrated very little native parasitization and it is likely that more effective natural enemies could be found elsewhere. Virtually no research has been conducted to determine potentially important natural enemies of cranberry pests, and this would likely be a productive area of work.

Outlook for CONSERVATION of natural enemies of cranberry pests.

The use of broad spectrum insecticides is one of the greatest impediments to successful biological control. Frequent use of such insecticides in a preventive approach to insect control will never be compatible with most biological controls. Usually, the routine utilization of pest scouting to make decisions about control has significantly reduced the use of insecticides, helping to preserve natural enemies. Pest monitoring should continue to be the cornerstone for IPM programs.

The widespread acceptance by the cranberry industry of the University's IPM program has provided many benefits, including reduced usage of broad spectrum pesticides except where actually needed. There is no doubt that such reduction increases the abundance of native natural enemies. For example, our research has shown that there are over twice as many beneficial natural enemies inhabiting the soil surface under cranberry vines in unsprayed vs. sprayed beds. Further, cranberry girdler egg predation rates were over twice as great in the unsprayed bed. We believe that there have been similar increases in natural enemies of foliage and fruit pests where insecticide usage has declined, although no research has yet been done on this.

IPM is not just using scouting procedures to determine pest levels, and. then spraying accordingly. More importantly, it is the integration of all effective, economic, and environmentally safe pest management procedures. Cultural insect controls, such as sanding and flooding, and biological controls such as the use of *Bacillus thuringiensis* sprays, will be less detrimental to natural enemies than will be traditional insecticides. As the cranberry industry continues to implement IPM practices, more natural enemies will be conserved, resulting in more effective natural pest control.

As biological control becomes more important in cranberry pest management, IPM scouts must learn to identify natural enemies and assess their impact. In a fully developed IPM program, it will be just as important to monitor the natural enemies in a bed as it will to monitor the pests.

Outlook for AUGMENTATION of natural enemies of cranberry pests.

The use of biological control by augmentation of natural enemies has become an accepted and established practice. However, historically and currently relatively few types of natural enemies are commercially available in the United States, and these are targeted against a relatively small number of pests. Natural enemy augmentation programs have had their greatest impact in western Europe in glasshouse crops, and in Eastern Europe and China where *Trichogramma* is used for control of various caterpillar species on millions of acres of field crops, row crops, and orchards.

Specific types of natural enemy releases are currently being developed and evaluated for use on cranberry. At least three companies are marketing *Bacillus thuringiensis* (Bt) formulations: Abbott Labs (DiPel), DuPont (Biobit), and Mycogen (MVP). Although not currently labeled specifically for blackheaded fireworm, laboratory and field studies indicate that Bt can effectively control this pest, but use pattern and timing of applications are critical. Research continues in this area. Bt is also effective against spanworms if properly timed. Currently, Bt is the material of choice for eradicating gypsy moth from forest areas in eastern Wisconsin, and it is already registered for use against this pest on cranberry should this become of concern here. Applications of Bt for all target pests should be made as soon as possible after egg hatch. If the egg hatch period is prolonged, two or three applications at 5-7 day intervals may be necessary for optimum control.

Although Bt is the only microbial insecticide currently available for use on cranberry, there is good potential for others. We recently discovered an insect virus which is quite active against blackheaded fireworm, resulting in as much as 100% natural mortality in some of our 1992 research samples. We will be cooperating with an insect pathologist at the University of Illinois to characterize this virus, and will then determine its potential as a microbial insecticide. We are also conducting laboratory studies of a virus of codling moth that is being registered as a microbial insecticide by the University of California. This virus may also have potential for controlling blackheaded fireworm. Further, there is a variety of *Bacillus thuringiensis* that may be effective against cranberry tipworm larvae; we will be doing laboratory evaluations of this as well. Finally, several agrichemical and genetic engineering companies are working to register other insect pathogens for control of various insects; some of these may have benefit against cranberry pests.

The use of insect parasitic nematodes for cranberry pest control was first seriously studied on the West Coast where black vine weevil is a pest of unflooded cranberry plantings. Studies in Washington showed that these nematodes also gave good control of cranberry girdler larvae and applications have been made for girdler control in

Wisconsin. Most studies on cranberry have been against soil insects, using the nematode *Steinernema carpocapsae.* OceanSpray entomologists have done considerable work trying to kill *Phyllophaga* grubs with this nematode, but without good success. I consider the use of nematodes still somewhat experimental but as more research is developed on production, formulation, and application technologies, I believe the consistency of results will increase and cost per acre will decrease. There are many species of insect parasitic nematodes known but which are not currently available commercially. Some of these may have a future place in cranberry insect management. For example, we will be conducting laboratory studies this year to determine if tipworm may be a potential target of nematodes. Currently, insect parasitic nematodes are not considered by the Environmental Protection Agency to be microbial insecticides. Therefore, they are not regulated, either from the perspective of assuring efficacy, or for the need of establishing pesticide residue tolerances.

Of the commercially available predatory and parasitic insects, only the egg parasites *Trichogramma* currently have potential for use on cranberry, the targets being the egg stages of various moth pests such as blackheaded fireworm, cranberry fruitworm, sparganothis, and spanworms. Limited research in Massachusetts has shown that cranberry fruitworm eggs can be killed by *Trichogramma* releases, but the degree of control was often not sufficient. In small scale caged field studies here in Wisconsin, we have successfully parasitized blackheaded fireworm eggs with two commercial species of *Trichogramma, T. minutum* and *T. pretiosum,* but parasitization rates were too low to be effective. However, large scale, late summer field releases of *T. minutum* conducted by Canadian workers in 1991 resulted in over 60% control of overwintering blackheaded fireworm eggs. Use of *Trichogramma* has great potential on cranberry, but much more research is necessary.

I have one further thought on the use of augmentative releases of natural enemies for control of cranberry insects. Much of my discussion has focused on purchasing natural enemies from commercial suppliers. Such suppliers must be able to make a profit from a given natural enemy or will not be willing to produce it. Further, availability of a particular natural enemy may be subject to production schedules and unpredictable levels of orders from customers. An alternative approach has been taken in the California citrus industry, which heavily (in some cases, exclusively) relies upon biological control. In the Fillmore region north of Los Angeles, a cooperative “citrus protection district” has for many years operated a non-profit insectary for producing and distributing, in a timely manner, natural enemies to its member growers. If, through research, we can find effective natural enemies for use against cranberry pests, I see the potential for the cranberry industry doing something similar in each region of the country. This seems a very logical future step in the evolution of cranberry pest management.

CONCLUSION

The U.S. Department of Agriculture has recently indicated that, where the technology exists and can be used economically, biological control should be the focus of integrated pest management programs. In the past few years, biological control methods have become available for use in cranberry pest control. These methods include the conservation of natural enemies by (1) pest scouting, (2) reduced pesticide use, and (3) use of non-chemical control methods. In addition, specific types of natural enemy augmentation have been used, specifically, the use of microbial insecticides based on *Bacillus thuringiensis* and insect parasitic nematodes. Preliminary research within the Department of Entomology at the University of Wisconsin - Madison shows promising avenues of additional biological control methods for cranberry insect management.

Note: Use of company names or brand names is for convenience only and is not an endorsement of these companies or products over others that are similar. Material provided herein is for informational purposes only; the user of pest control products and practices assumes responsibility for safe, legal, and environmentally sound usage.

ADDITIONAL READING

There are many books in your local libraries that will help you become more familiar with insects in general, and pests and their control. For general insect identification, including natural enemies, there are several excellent and inexpensive field guides available in local bookstores. An excellent source of up-to-date information on alternative pest control measures is the “IPM Practitioner” newsletter; this is also often available in local libraries but is well worth the subscription price. The following books are specific references on biological control. Some of these are out of print and available only through libraries. None of these references include specific information on biological control of cranberry insects.

Non-technical books.

DeBach, Paul. 1974. Biological control by natural enemies. Cambridge Univ. Press. 327 p.

Swan, Lester A. 1964. Beneficial insects. Harper and Row. 429 p.

Technical books.

Burges, H. D., and N. W. Hussey. 1971. Microbial control of insects and mites. Academic Press. 861 p.

Clausen, C. P. 1972. Entomophagous insects. Hafner Publ. Co. 688 p.

Clausen, C. P. 1978. Introduced parasites and predators of arthropod pests and weeds: a world review. USDA Agric. Handbook No. 480. 545 p.

Croft, Brian A. 1990. Arthropod biological control agents and pesticides. Wiley. 723 p.

DeBach, Paul. 1964. Biological control of insect pests and weeds. Reinhold Publ. Co. 844 p.

Hoy, M. A, and D. C. Herzog. 1985. Biological control in agricultural IPM systems. Academic Press. 589 p.

Huffaker, C. B., and P. S. Messenger. 1976. Theory and practice of biological control. Academic Press. 788 p.

Ridgway, R. L., and S. B. Vinson. 1977. Biological control by augmentation of natural enemies. Plenum Press. 480 p.

van den Bosch, R., P. S. Messenger, and A. P. Gutierrez. 1982. An introduction to biological control. Plenum Press. 247 p.

Waage, Jeff, and David Greathead. 1986. Insect parasitoids. Academic Press. 389 p.