BIOCONTROL

IMPROVING APPLE IPM

by Maximizing Opportunities for Biological Control

Vincent P. Jones[1], Thomas R. Unruh[2], David R. Horton[2], Jay F. Brunner[1]

[1]Washington State University, Tree Fruit Research and Extension Center, Wenatchee, Washington

[2]USDA-ARS, Yakima Agricultural Research Lab, Wapato, Washington

Published by Good Fruit Grower
December 2006

An era of opportunity for biological control in Washington apples

Historically, Integrated Pest Management (IPM) programs in apples have been dominated by pesticides. The importance of pesticides in our management programs is mostly a result of the overwhelming need to control codling moth, but it is also related to simplicity of use, speed of action, and the possibility for prophylactic control. While pesticides will remain a major component of IPM, we feel that biological control needs to be fostered to reduce the need for many insecticide applications, especially those targeted against secondary pests.

The changes occurring in pesticide chemistry and availability, the broad use of mating disruption, and the growing use of codling moth granulovirus all herald an era of opportunity for restructuring our IPM program in apples. Rebuilding our IPM system to better incorporate biological control should enhance stability, reduce the costs of IPM, and reduce environmental impacts and worker safety issues, while reducing crop damage.

The two best examples of integrated biological control in apples are:

—Control of McDaniel and twospotted spider mites by the western orchard predatory mite; and

—Control of the western tentiform leafminer by the wasp *Pnigalio flavipes*.

In the first example, the dose of Guthion (azinphos-methyl) was reduced to allow survival of the predatory mite, while still giving control of codling moth. In the case of *P. flavipes*, it became resistant to Guthion in the early 1990s. The value of tentiform leafminer control by *P. flavipes* is estimated to be roughly $1.5 million annually for the last decade. The annual benefits from biocontrol of spider mites have been estimated at roughly $3 million for the past 35 years, based only on reduced miticide costs, and ignoring improvements in crop quality. These improvements include:

—Fewer mites overwintering in the calyx end of the apples, which avoids potential export problems;

—Less reduction of grade from direct fruit damage; and

—Less risk of loss of miticides because of resistance development, which otherwise can happen in as little as two years.

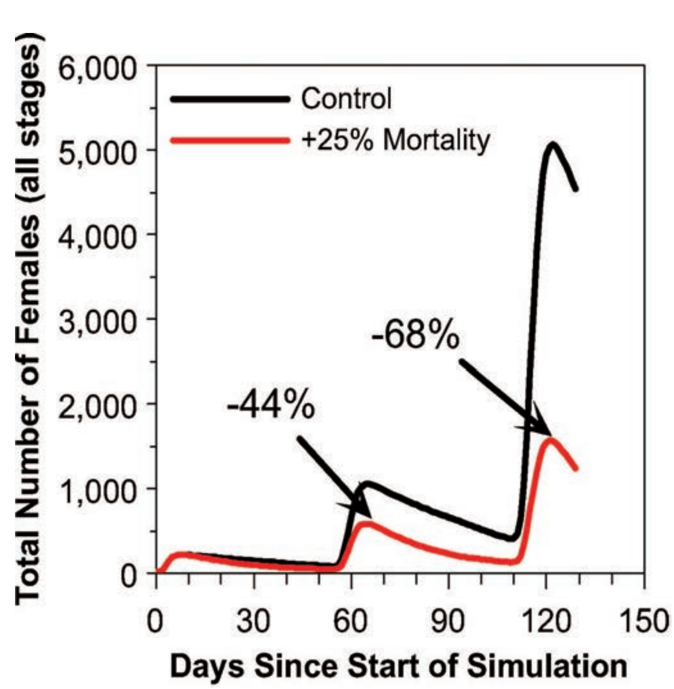
Clearly, biological control has the potential to greatly reduce management costs as well as minimize environmental impacts and worker safety concerns.

FIGURE 1 The effect of low levels of mortality on population growth

The population model is started using 16 fertile female codling moths. We ran the model twice, the first time using mortality rates observed in the laboratory (the control) and the second time using the same mortality rates but with an additional 25 percent mortality at the larval stage, to simulate natural-enemy induced mortality. We then plotted the size of the control population and the one with the additional larval mortality.

Both populations increase rapidly, but the one with 25% morality added increases slower than the control population. After a single generation, there are 44% fewer individuals in the population and after two generations 68% fewer in the 25% mortality treatment compared with the control.

The effect in each generation is the result of not only killing the additional 25% of larvae, but also eliminating all the progeny of those individuals. Another way to think of this is that the additional mortality acts similarly to compound interest in a savings account. As the savings grow because of interest paid, the greater the interest earned the following period.



The parasitoid *Colpoclypeus florus* attacking a late instar obliquebanded leafroller larva. The adult parasitoids lay multiple eggs per caterpillar. The hatched parasitoids feed externally and devour the caterpillar before it can pupate. *Image courtesy of USDA-ARS.*

Despite the successes mentioned, biological control is often not viewed as a critical part of apple IPM programs. This perception has led in many instances to unnecessary reliance on pesticides. In fact, it is our experience that biological control is most often discussed by IPM professionals when management programs appear to be breaking down. We believe this attitude is an outgrowth of our poor understanding of which natural enemies are important, our limited knowledge of their biology and ecology, a lack of information on how to measure their abundance and impact, their relative invisibility compared to pest insects, and our poor understanding of the extent to which they are disrupted by pesticide use.

Given the number of things we do not know, and the complexity of the system, it is understandable that we generally see a lack of appreciation for biological control in apple IPM programs.

Understanding the potential of biological control

A simple population model for codling moth can help us appreciate the potential contribution of biological control to the stability of IPM programs. This model allows us to arbitrarily set codling moth mortality at any life stage and then observe population levels one or two generations later. For example, if the average percentage mortality of codling moth larvae were increased by 25%, population levels after one generation would be 44% lower than a population without increased larval mortality and 68% lower after a second generation (*see Figure 1 at left*).

The decreases in the pest population are a result of not only killing larvae, but also eliminating the progeny that would have been produced by those individuals had they survived to reproduce. Clearly, even a small amount of mortality at the right time, such as might occur by a predator attacking larvae, can produce very significant differences in the pest pressure we face in the orchard.

What are the levels of natural enemy induced pest mortality that we see in Washington apple orchards? That depends greatly on the pesticides used, the dose they are applied at, the timing of the applications, and the natural enemies and pests in question.

Parasite: ***An organism that lives on or in another species, from which it derives sustenance or protection. It usually does not benefit the host, and often does it harm. It may complete its life cycle without killing the host.***

Parasitoid: ***An organism that requires and eats only one animal in its life span, but may be responsible for killing many (primarily as an adult). The immature stage is typically rigidly associated with the host insect.***

Predator: ***An organism that kills and consumes many animal food items during its life span.***

Codling moth

In the case of codling moth, which is often assumed to have few effective natural enemies, we have seen that 2 to 40% of overwintering larvae collected from fruit or tree bands can be parasitized by the widely established

Obliquebanded leafroller with two tachinid eggs on the outside. Tachinid flies are among the most important parasitoids of leafrollers (and other caterpillars). Very little is known about their ecology, but alternate host caterpillars are likely important in both overwintering and synchronization with leafrollers in the orchard. *Photo courtesy of Nik Wiman, WSU-TFREC.*

egg-larval parasitoid *Ascogaster quadridentata*. In orchards where the parasitoid *Mastrus ridibundus* is established, it might parasitize more than 50% of cocooned codling moth larvae. In addition to parasitism, generalist predators can cause extensive mortality of cocooned codling moth larvae.

FIGURE 2 Effect of natural enemies on codling moth

Parasitism and predation of codling moth at two conventional orchards, as estimated using sentinel cocooned larvae. The graph demonstrates that predators are the dominant natural enemies of codling moth.

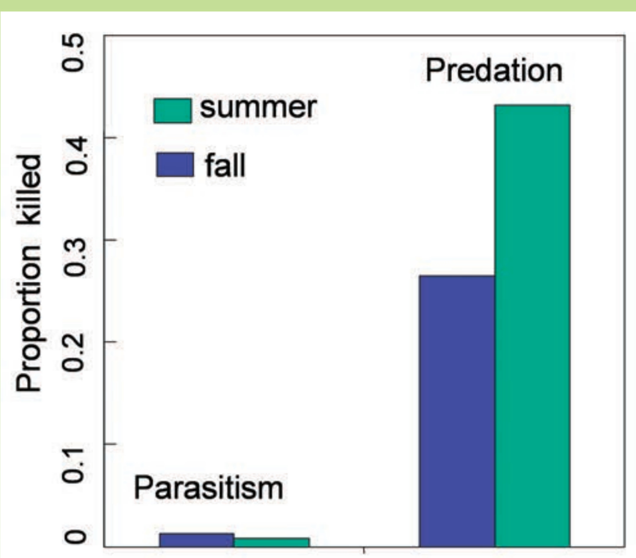


Figure 2 summarizes predation and parasitism of codling moth from two conventional orchards. In both organic and conventional orchards, we have seen predation exceeding 50% at times. The average for an entire generation of the moth has approached the 25% example used in the population model described in Figure 1.

Leafroller

In studies with the obliquebanded leafroller over a range of orchards and times, we found parasitism averaged 12% over the first generation (34.5% maximum) and 21% over the second generation (39.5% maximum). Orchards with low percentages of parasitism were typically treated with insecticides in the first generation when large leafroller larvae were present. Unfortunately, this also corresponds to the time that leafroller parasitoids are present. Thus, spray timing affects levels of biological control for leafroller.

A summary of parasitism levels measured in one life stage taken from 102 sites across 1,500 acres of orchard in the Yakima area is also summarized in Figure 3 (*see page 5*). A key point is that at a number of sites, parasitism rates by tachinid flies or parasitic wasps were quite high, suggesting that management practices and/or environmental factors play a key role in parasitism rates.

Parasitoids are usually easy to detect in samples because their immature stages must develop directly in or on the host and they usually leave behind a telltale sign of their activity (like a pupal case or damage to a host stage that is distinctive). This allows us to readily measure parasitism in the field. However, predation is much more difficult to detect because predators leave few, if any telltale signs. They may in fact eat the evidence!

Often, the only clue we have as to a predator's importance is indirect: the predator may be observed at high densities and be commonly associated with high pest populations that eventually decline.

Difficulties in detecting predator impact mean that basing our measure of the importance of biological control using parasitism values alone is likely to dramatically underestimate the overall importance of the total mortality caused by natural enemies. However, new DNA-based technology is available that can help us determine which natural enemies are feeding on different pests by examining the predator gut contents.

Predation is difficult to detect: predators eat the evidence!

How biological control differs from the pesticide approach

To better understand how important biological control can be, it is important to introduce the concept of "replaceable mortality." This concept is used in biological control to help explain the effect of multiple natural enemies attacking a particular pest species at different times in the pest's life cycle.

Let's suppose that two predators are present in an orchard. The first is a predator of the late larval stages of the pest, and the second is a predator of the egg stage of the pest. The larval predator can only eat those individuals that escaped the egg predator during the egg stage. Thus, a portion of the potential impact caused by the predator of larvae is "replaced" by the egg predator, and if the egg predator were suppressed by some factor, a portion of its mortality would be "replaced" by the larval predator, making the system more stable than if only a single type of predator were present.

In most situations, multiple natural enemies attack at different points in the life cycle of the pest, which helps reduce the potential population growth of the pest and leads to more stable pest population levels. The advantages of biological control are that it occurs naturally (free!), and over the entire life history of the pest. While a specific natural enemy may only attack a single stage or even a specific larval instar, typically other natural enemies attack different stages or even multiple stages of the pest, and all increase the stability of the system.

To demonstrate the diversity of natural enemies that can attack different stages, we have summarized in Figure 4 (*see page 6*), some of the natural enemies attacking codling moth at different points in its life history. Another facet of biological control is that generalist predators can often build up on one pest and move to another, so that they affect population growth of several species, which tends to increase stability of the system even further, unless they are accidentally destroyed by poor management timing or tactics.

Pesticides replace mortality that would be caused by natural enemies, *but only for a limited time* (depending on the pesticide's residue characteristics). The problem is that the application of a pesticide may greatly reduce the natural enemy complex through either direct mortality or indirect effects.

These indirect effects can be lower egg production or sterility, shift of sex ratios to more males, or simple starvation because the predators have nothing to eat. Harm to the natural enemy population results in pest levels that require additional pesticide applications to keep them below economic

FIGURE 3 Parasitism of leafroller larvae

Parasitism of third- and fourth-instar obliquebanded leafroller larvae after exposure on potted trees placed in conventional orchards during the summer of 2000. The green areas are apple orchards; the yellow areas are pears; and the red areas are cherry orchards. Parasitism is shown as colored pies. Black represents tachinid flies; red represents *Colpolclypeus* wasps; yellow represents *Oncophanes* wasps; and white represents no parasitism. At these 45 sites, parasitism averaged 42%. The Yakima River is shown in blue at left.

levels. Thus, pesticides destabilize the system, with the result that they may become a self-perpetuating control tactic. In the past, this was referred to as the "pesticide treadmill."

The effects of pesticides on the natural enemies are multiplied if the pesticides have a broad spectrum of activity, as they may kill natural enemies of pests other than the targeted pest. In such situations, pesticides targeted at these secondary pests are then required to prevent damage. This harkens back to our introductory statement that the use of Guthion at high rates in the late 1950s and early 1960s for codling moth control caused problems with the biological control of spider mites due to suppression of the western orchard predatory mite. It is important to note that many new pesticide chemistries and biorational methods make properly designed pest management programs potentially much less disruptive of biological control than previously possible.

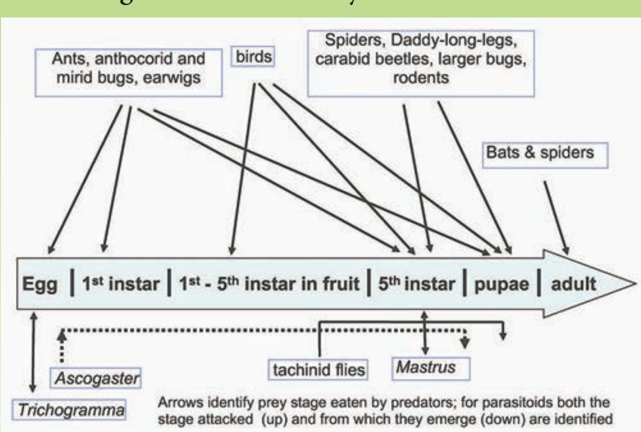
Integrating pesticides and biological control into an IPM program

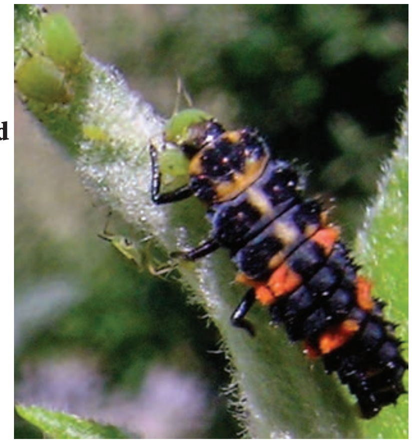
While biological control has many advantages, it is unlikely to be a stand-alone solution for apple IPM programs, except in a few special circumstances. However, we suggest that biological control should be better integrated into current management programs to avoid killing natural enemies with pesticides. This will allow the industry to take advantage of biological control's ability to limit pest populations, thus minimizing the control actions needed to produce undamaged fruit. In Washington apples, we feel the key to integrating biological control and pesticides is to focus on four factors:

1) Identification of the key natural enemies for each pest and estimates of their impact on pest population growth. In particular, it is critical that we improve our understanding of the role and impact of predators in pest suppression.

FIGURE 4 Predators and parasitoids

This figure shows the most likely predators (above the arrow) and parasitoids (below the arrow) of codling moth throughout its life history.





Lady beetle larva feeding on aphids. Lady beetles feed extensively on a variety of aphids and other soft-bodied insects in Washington orchards. *Stethorus* species are predators of spider mites. Another species, *Cryptolaemus montrouzieri*, is known as the mealybug destroyer. *Photo courtesy of Jay F. Brunner, WSU-TFREC).*

2) Understanding the phenology of key natural enemies as well as the pests. This will allow growers to limit, as much as possible, insecticide applications at times when natural enemies are most vulnerable.
3) Understanding the direct and indirect effects of pesticides on key natural enemies. This will permit us to assess the potential effects of specific chemicals on natural enemy populations.
4) Development of recommendations that integrate behavioral, chemical, and biological controls.

Now is a good time to invest in biological control

We feel that the Washington apple industry is at a crucial period for integrating biological control into IPM programs. Pest control programs are in transition from organophosphate-dominated systems to programs based on behavioral control of codling moth (mating disruption) combined with new pesticide chemistries and insect pathogens that address worker safety and environmental concerns.

The use of mating disruption, now used in roughly 75% of Washington apple acreage, has reduced the average number of insecticide sprays required for codling moth and increased the possibility of natural enemy survival. The newer pesticide chemistries typically:

—Have a narrower spectrum of activity (for codling moth granulovirus, the effects are almost completely restricted to that pest);
—Are in general slightly less efficacious on the target pests;
—Act primarily upon ingestion (*i.e.*, greatly reduced or no contact activity); and
—Last a shorter time in the environment.

The attributes of these new pesticides have made pest management programs more complex, and require more precise timing and better coverage for acceptable results.

In addition to requiring better timing and improved coverage, the switch to new pesticide chemistries causes other potential problems. Several entomologists working on the

Areawide Codling Moth Control Program II (AWII)—Tom Unruh, Dave Horton (USDA-ARS, Wapato), Nick Mills (UC Berkeley), Helmut Riedl and Rick Hilton (Oregon State University)—clearly demonstrated that even in the absence of a significant direct toxicity, sublethal pesticide effects can dramatically reduce the effectiveness of natural enemies (*Figure 5*). In some cases, the materials sterilized the females, skewed the sex ratio to mostly males, or delayed mortality beyond the 24-or 48-hour evaluation period traditionally used to determine the negative effects of insecticides. While this paints a somewhat dark picture for the possibility of integrating biological control into our management programs, some of these problems can be eliminated using ecological selectivity—that is, only applying them at certain times, locations (*e.g.*, not on tree trunks), or at reduced dosages. Clearly, we need to understand the effects of these pesticides on the population dynamics of our key natural enemies so that we can optimize IPM programs.

Pesticides destabilize the system, with the result that they may become a self-perpetuating control tactic.

Finally, one factor that should contribute significantly to the use of biological control in apples is Washington State University's Decision Aid System. That system has taken the phenology models for seven pests of apples (with more coming on-line) and integrated them with real-time weather data from the WSU-Ag Weather Net, weather forecasts, and pesticide recommendations. The system provides the user with an estimate of not only the current pest conditions, but also those predicted by 10-day weather forecasts. More importantly, it provides the industry with management recommendations that consider pest phenology, sampling times, and (at least for leafrollers) times when pesticide applications should not be applied in order to minimize impact on parasitoids. We also provide information on which pests are controlled by each material and information on the acute toxicity of each material to certain natural enemies.

The major goal of the Decision Aid System is to provide a strong framework upon which IPM programs can be based. These programs should be simpler to understand and use, less expensive, more stable, and should reduce the number of surprises that occur when managing such a complex system.

By incorporating new information about the susceptibility of natural enemies to pesticides and phenology models for natural enemies, we might be able to change management programs to be more natural enemy friendly, while still providing excellent suppression of pest populations.

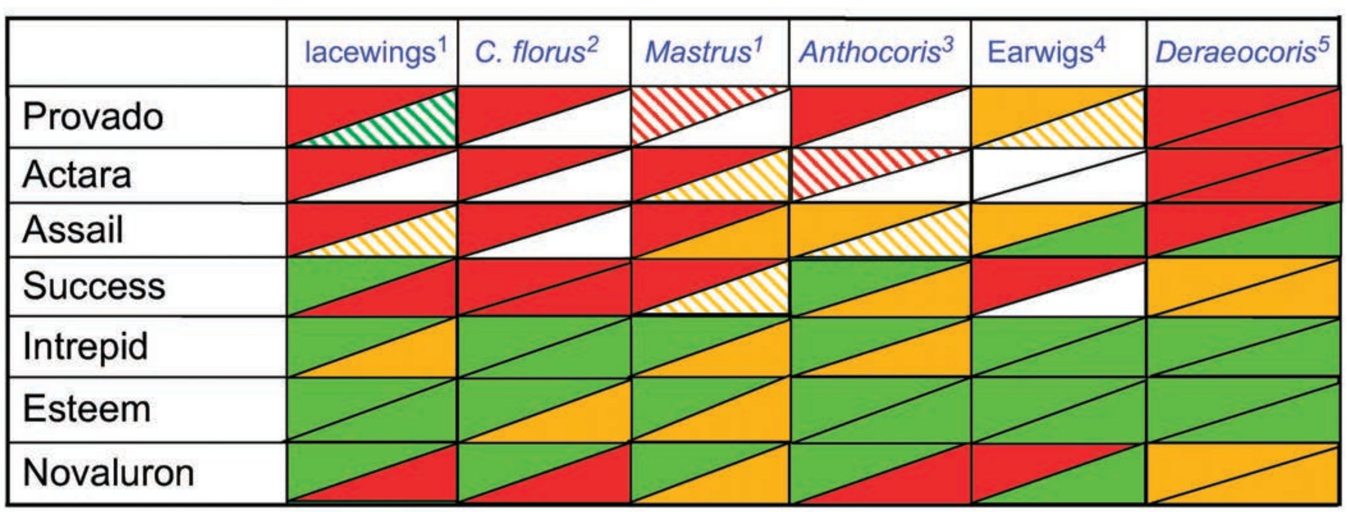
A timely opportunity

By supplementing mating disruption and softer chemicals with improved biological control, apple growers have the

FIGURE 5 New, "kinder" pesticides still affect natural enemies

In the chart, acute effects are shown above the diagonal, and sublethal effects below. Green indicates little or no effect; orange indicates modest effects; and red indicates strong effects (little or no survival).

The solid colors represent results using field rates. If acute effects were high, sublethal effects were tested at 10% field rate, and are shown as hatched colored areas. If the area below the diagonal is white, it was not tested.



[1]Nick Mills UC Berkeley, [2]Tom Unruh, [3]Dave Horton, [4]Rick Hilton, Oregon State University, [5]Helmut Riedl, Oregon State University

On-line help in decision making

The Washington State University Decision Aid System (WSU-DAS) is a Web-based program for tree fruits that integrates phenology models for insects and diseases with management recommendations.

The system currently has models for codling moth, obliquebanded leafroller, Pandemis leafroller, Western cherry fruit fly, apple maggot, San Jose Scale, *Campylomma* bug, *Lacanobia* fruit worm, fireblight, and storage scald. We will soon be adding peach twig borer, cherry powdery mildew, apple scab, and shot hole of stone fruits.

The decision aids are based on weather data collected by the Washington State University AgWeather Net system that is a wireless network of weather stations scattered distributed throughout the state. It can be accessed at *http://fruit.wsu.edu/AWN/Site%20Folder/index.html.*

The data from this system are collected in near real-time and used to run the phenology models for the insects and the temperature- or temperature/wetness-driven models for the diseases mentioned above.

The output consists of the current status of the population and management recommendations for activities critical for IPM. There is also a prediction of the near future (up to 10 days out, depending on the model), based on weather predictions from the U.S. Weather Service.

Both graphical and tabular output are available. In addition, we have integrated into the system a pesticide database that indicates the materials available for the target pest, other pests controlled by the materials, and effects on natural enemies (if known). The choices are presented in an easy-to-compare table that also includes information on the reentry time, preharvest intervals, rates, and general use recommendations and restrictions.

The Decision Aid Web site is currently restricted, but will be available on a general basis in the early spring. Details will be at *http://entomology.tfrec.wsu.edu/das.* More information on this system will be published soon.

opportunity to reduce pesticide use and associated costs while maintaining high fruit quality and yield. The public's increasing preference for fruit grown with minimal insecticide use suggests that it is timely for apple growers to invest in improving biological control, which benefits both organic and conventionally grown fruit. New technologies, such as the DNA-gut content analysis and the WSU Decision Aid System, will help us address previously intractable problems and allow us to then deliver state-of-the-art pest-control information to growers. The information will ultimately provide growers with a prescription for strategies leading to improved pest control that actively integrate biological control without significantly increasing the complexity of the management program.

A green lacewing larva feeding on a woolly apple aphid nymph. Lacewing larvae are voracious predators of soft-bodied insects, including aphids, mealybugs, thrips, leafhoppers, scale crawlers, and insect eggs of all types. There are several species in Washington orchards, and the species composition likely varies between orchards depending on spray programs and environmental variables. *Photo courtesy of Betsy Beers, WSU-TFREC*

Acknowledgements

We wish to thank Stan Hoyt and Callie Baker (Washington State University), Nick Mills (UC Berkeley), Diane Alston (Utah State University), Larry Hull and David Biddinger (Penn State University), and Mark Brown (USDA-ARS Kearneysville, WV) for comments on earlier drafts of the manuscript. We also thank Nick Mills, Rick Hilton, and Helmut Riedl for allowing us to use their data on pesticide effects on natural enemies.

Washington State University Tree Fruit Research and Extension Center
1100 N. Western Avenue, Wenatchee, WA 98801
Jay Brunner: *jfb@wsu.edu* • Vince Jones: *vpjones@wsu.edu*

U.S. Department of Agriculture Yakima Agricultural Research Laboratory
5230 Konnowac Pass Road, Wapato, WA, 98951
Tom Unruh: *unruh@yarl.ars.usda.gov* • Dave Horton: *horton@yarl.ars.usda.gov*