Ag Innovations Series

FEBRUARY 2015

TECHNICAL BULLETIN

Peer-reviewed research findings and practical strategies for advancing sustainable agriculture systems

CONTENTS

SARE Sustainable Agriculture Research & Education

Ecological Management of Key Arthropod Pests in Northeast Apple Orchards

Geographic Adaptability: *Northeast, mid-Atlantic, and most other eastern fruit growing states, although the specifics of pest biology/behavior may differ by state and region.*

Introduction

Apples are an important crop in the Northeast, grown for both fresh market and processing. In 2012, there were about 89,000 acres of apples in the northeastern and mid-Atlantic states with a farm-gate value of $580 million (USDA NASS, 2012). The list of top apple-producing states nationwide includes two Northeast states: New York, ranked second (1,066 growers and 41,000 bearing acres), and Pennsylvania, ranked fourth (1,239 growers and 19,000 bearing acres).

Northeast apple operations are diverse, with orchards ranging from several hundred acres to less than an acre. Regardless of the orchard's size, however, growers have a challenging task managing insects, mites and diseases. By some estimates, growers may spend up to 25 percent of their production costs on pest management (Penn State University, 2012).

Pest management challenges are compounded by three factors:

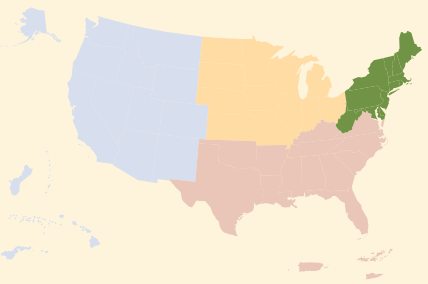
- high cosmetic standards and low tolerance for damage in fruit marketed for fresh consumption;
- regulatory pressures and health concerns regarding organophosphate insecticides;
- the changing nature of the pest complex due to: 1) adaptations of existing pests, and 2) the emergence of new pests, resulting from climatic variation and shifts in host preference.

In response to these challenges, SARE funded three projects, one in Massachusetts and two in Pennsylvania, to help develop alternative management strategies for apple pests in northeastern orchards. This technical bulletin outlines strategies developed from these projects, including biologically based pest control, orchard architecture and development of materials approved for organic production.

At the time of funding (2000-2009), the key arthropod pests in Northeast apple orchards were: European red mite (*Panonychus ulmi*), plum curculio (*Conotrachelus nenuphar*), apple maggot (*Rhagoletis pomonella*) and leafroller complex including obliquebanded leafroller (*Choristoneura rosaceana*) and tufted apple bud moth (*Platynota idaeusalis*). Today, apple maggot, plum curculio and European red mite continue to be important problems for northeastern growers while a number of new arthropod pests have also emerged, including codling moth (*Cydia pomonella*) and Oriental fruit moth (*Grapholita molesta*). This bulletin focuses on these five pests.

The brown marmorated stink bug (*Halyomorpha halys*), though currently a major pest, is not included in this publication because it is a new pest in the United States. SARE is currently funding work on using pheromones, border sprays and other Integrated Pest Management (IPM) methods to manage the brown marmorated stink bug. Results will be published as more research is completed. For more information, visit www.fruit.cornell.edu/berry/pestalerts/bmsbpestalert.html.

SARE Funding for this Project



This technical bulletin is based on three SARE projects, LNE00-135, LNE02-159 and LNE06-248.

For more information, go to www.sare.org/project-reports and search by project number.

Authors: David Chaney, Dan Cooley, Greg Krawczyk, Tracy Leskey, Arthur Tuttle

Managing the Orchard: an Ecosystem Perspective

The field of insect management is rapidly evolving from the use of single, silver-bullet tactics to control pests, to a multi-pronged approach known as ecological pest management, which mimics and augments the functioning of natural systems in order to suppress pests. The SARE research described in this bulletin, along with a plethora of other research efforts around the world, are based on innovative and successful alternative insect management strategies that use the principles of ecological pest management in orchard ecosystems.

In orchard systems, ecological pest management works by:

- creating optimal conditions in the orchard for crop growth;
- stressing and confusing pests by creating conditions that limit their growth or that interfere with their movement or reproduction;
- enhancing populations of beneficial organisms that keep pests in check;
- using IPM practices such as host resistance, cultural control, pest monitoring, field scouting, biological control, economic thresholds and as-needed applications of pesticides rather than preventative sprays.

For the arthropod pests described in this technical bulletin, recommended IPM practices range from pest scouting for properly timed insecticide sprays to more advanced strategies such as monitoring, combinations of multiple tactics (e.g., mating disruption and biocontrol agents and traps), and use of bio-pesticides.

Whether starting a new orchard or adapting an existing orchard, consider implementing the following ecological pest management strategies that take advantage of natural ecosystem processes:

- Create a basic orchard architecture to allow for more sunlight and air circulation within the canopy. An open arrangement captures sunlight, minimizes interior shading and results in healthier trees. *Tree Training and Planting Systems in Vermont Apple Orchards* (Bradshaw, 2011) provides an overview of the main types of systems currently being used.
- Manage the orchard perimeter to confuse and stress pests. For example, use baited traps around the perimeter to monitor and destroy pests with targeted rather than broadcast pesticide applications.
- Manage borders or surrounding farmland using specific crops to attract beneficial predators and parasites.
- Remove alternate hosts from surrounding farmland. For example, codling moth females are capable of moving up to 100 meters within a single generation. So be sure to remove principal host trees of codling moth (e.g., apple, pear, hawthorn and quince) within 200 meters of the orchard perimeter (Prokopy, 2003).

Plum Curculio

Plum curculio (*Conotrachelus nenuphar*) is a weevil native to North America, primarily east of the Rocky Mountains. It is a major pest of apples, blueberries and stone fruits. In most areas within its range, the plum curculio has a single generation, but in the mid-Atlantic and southern United States it may have a partial second generation. Most commercial orchards do not have resident populations of the plum curculio. Infestations are largely a result of adults moving in from adjoining hedgerows and woodlands.

FIG 1. Adult plum curculio. *Photo courtesy Clemson University, Bugwood.org #UGA2912075*

Description and Life Cycle

Adult plum curculio are snout beetles, about one-quarter of an inch long (Fig. 1). They are dark brown, mottled with white or gray patches and have four humps on their wing covers. The snout is about one-third of its body length. Plum curculio larvae are yellowish or grayish white with a brown head and reach about one-quarter of an inch in length.

Plum curculio adults overwinter in the ground or leaf litter found in woods, hedgerows and abandoned fields. Adults begin to emerge as temperatures warm in the spring (several days of mean temperatures above 60 degrees F or maximum temperatures above 75 degrees F). This usually coincides with the blossom period of apples. If temperatures drop and conditions become unfavorable, the adults may return to overwintering sites. Although the emergence period for plum curculio lasts several weeks, 40-60 percent of the total emergence can occur on a single day. As adults emerge in the spring, they walk and fly to trees where they feed on the buds, flowers and newly set fruit. Feeding on early stage fruit results in fruit damage because the adults cut a hole in the skin of the fruit and hollow out a cavity about one-tenth of an inch deep.

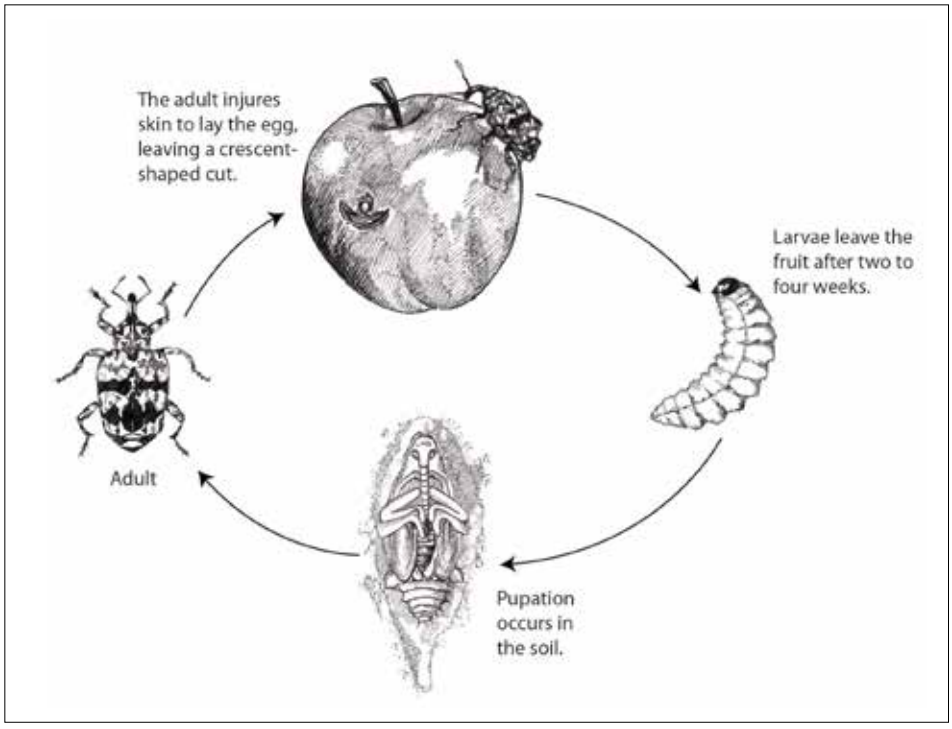


FIG 2. Life cycle diagram of the plum curculio. *Artwork by Ariel Hsu*

Plum curculio eggs are laid singly in small cavities just beneath the skin of the fruit. Females carve a space just under the fruit's skin. In front of the holes in which females lay their eggs, crescent-shaped slits are cut that extend beneath the egg cavities, so that each egg is left in a tiny flap (Fig. 3). This behavior protects the egg from being crushed by the rapidly developing fruit. Each female usually lays about 60-150 eggs. The small, white, oval eggs hatch in two to 12 days. The small wounds resulting from feeding and egg laying exude sap that dries to a white crust. Upon hatching, the young larvae bore into the fruit. If the apple stays on the tree, the larvae are usually killed by the pressure of the growing fruit, but not before damaging the fruit so it becomes unmarketable (Fig. 4). Most larvae continue to develop to the next stage of growth in the damaged fruit that has dropped to the ground. After two to three weeks in the fruit, the full-grown larvae burrow an inch or two into the soil where they pupate and eventually emerge as adults. The entire process from egg to adult takes from six to 10 weeks depending on temperature and weather conditions (Fig. 2).

In summary, plum curculio damage apples in the following ways: surface feeding and wounds from egg laying that scar or deform the fruit by harvest; internal injury produced by burrowing larvae; premature drop of the fruit; and feeding punctures made by new adults in the late summer and fall.

FIG 3. Fresh egg-laying wounds by adult plum curculio on a young fruit. *Photo by Ric Bessin, University of Kentucky Entomology*

FIG 4. Late-season fruit scarring by plum curculio larvae. *Photo by Ric Bessin, University of Kentucky Entomology*

Management of Plum Curculio

For decades, the standard practice for controlling the plum curculio has been to treat the entire orchard two to five times after bloom with applications of organophosphate insecticides. The first application in the spring is timed to keep populations in check before they start laying eggs. Subsequent applications during the remainder of the growing season are based on monitoring plum curculio levels in the orchard. The trap that seems most effective is a pyramid shaped trap baited with a plum curculio pheromone lure and benzaldehyde, placed in a collecting container at the top of the trap (Fig. 5).

SARE research demonstrates viable alternatives to this pesticide-intensive strategy. The University of Massachusetts project found that a single application of insecticide over the whole orchard at petal fall can be followed by more targeted treatment of perimeter trees near the source of overwintering adults based on counts from odor-baited trap trees. New recommendations suggest timing perimeter row applications of effective products based on a threshold of one freshly injured fruit out of 25 fruit sampled on the baited trap tree (Piñero et al., 2011). In this study, localizing and monitoring injury to fruit in the perimeter row led to a 74 percent reduction in insecticide use. Other studies showed similar or higher levels of effectiveness using baited trap trees (Leskey et al., 2008; Piñero and Prokopy, 2006; Leskey and Wright, 2004; Prokopy, 2002).

> SARE-funded research from the University of Massachusetts and Penn State demonstrate viable alternatives to a pesticide-intensive strategy.

The SARE-funded mite management project at Penn State University evaluated Kaolin clay as an organically acceptable control option for plum curculio. Kaolin (Surround®) is a specialized clay mineral used as an insecticide on many fruit crops which can reduce the level of injury caused by plum curculio. Kaolin clay works as a repellant and therefore should be applied before plum curculio begins laying eggs. Additional applications are also needed to maintain the coating as the fruit grows, especially after it rains. In a comparison of organic transitional and conventional blocks, plum curculio was monitored using pyramid traps and branch traps. Seasonal and harvest fruit evaluations were conducted in all monitored orchards. Throughout the period of the project, no excessive numbers of plum curculio were observed in any of the organically treated orchards.

FIG 5. The black pyramid trap is used to monitor the plum curculio. *Photo by Tracy Leskey, USDA Agricultural Research Service*

Apple Maggot

The apple maggot is native to eastern North America. Originally it was associated mainly with large-fruited hawthorns, but it later adopted apple as another host and has become a major pest in the northeastern United States and Canada. During the early 1980s, apple maggot also became established in the West, although it has yet to become a serious pest there.

Description and Life Cycle

The adult apple maggot fly is similar in size to a house fly. Females are black and have a pointed abdomen with four white cross bands. Males are smaller and have three cross bands on a rounded abdomen. The wings are clear, with four black bands shaped like the letter "W" (Fig. 6).

Apple maggot adults begin to emerge from the soil in the middle of June, with peak emergence from mid- to late July. The pattern of emergence varies by geographic location and depends largely on the host and environmental factors such as temperature, soil type and rainfall. Newly emerged flies mature seven to 10 days after emergence and congregate on the fruit, where mating occurs. After mating, females puncture the apple skin with their ovipositors to lay eggs, which are deposited singly, just beneath the skin of the apple. Over their 30-day life span, females will lay an average of about 300 eggs.

Eggs hatch after two to 10 days, depending on the ambient temperature. The legless, cream-colored maggots are about one-quarter of an inch long at maturity and have a blunt posterior that tapers down to a rounded point containing two black mouth hooks. They spend from 20 to 30 days feeding within the fruit, going through three instars—developmental stages between malts—in the process. After reaching their final growth stage in the apple fruit, maggots drop to the ground, burrow into the soil and go through two more molting stages to become a pupa. The brownish-yellow pupae are about one-eighth of an inch long and overwinter in the soil, usually within two inches of the surface (Fig. 7).

FIG 6. Adult apple maggot. *Photo courtesy New York State Agricultural Experiment Station, Cornell University*

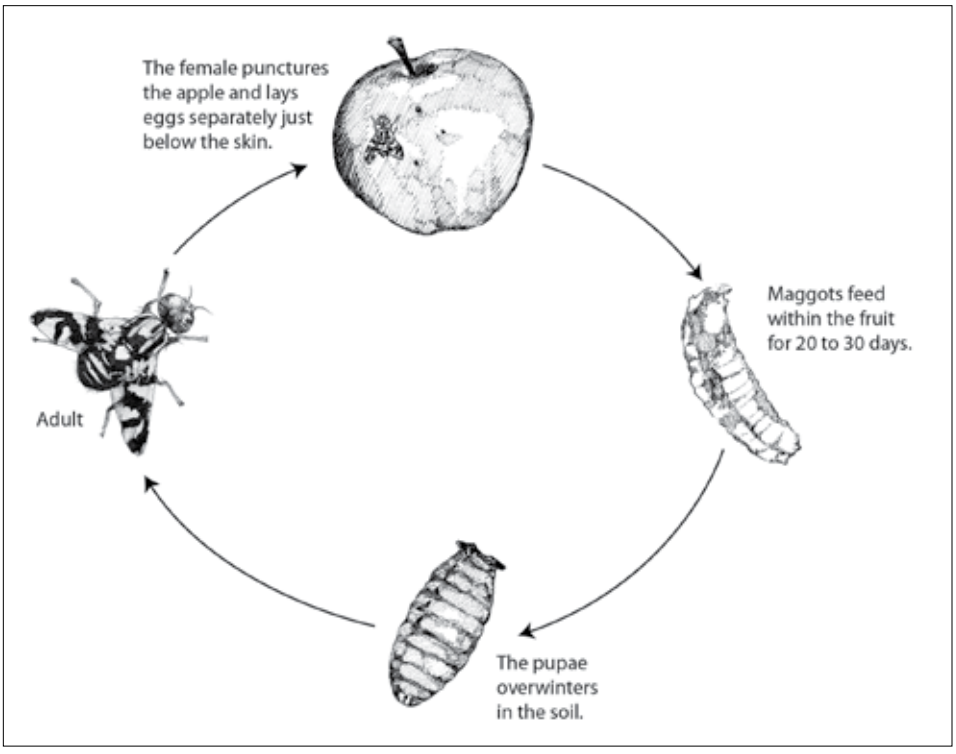


FIG 7. Life cycle diagram of the apple maggot. *Artwork by Ariel Hsu*

Young larvae feeding within the fruit leave brown, winding, threadlike trails. As the larvae grow, feeding tunnels become more conspicuous as they are prone to bacterial decay. Eventually, the apple becomes soft and rotten and drops prematurely from the tree. This internal breakdown proceeds more rapidly and is more severe in softer-fleshed, earlier-maturing cultivars.

Egg laying by adult females may also cause some damage characterized by pitting and dimpling on the apple surface (Fig. 8).

Management of Apple Maggot

The standard practice for apple maggot management has been broad-spectrum insecticides applied at regular intervals

FIG 8. Damage from apple maggot oviposition. *Photo courtesy New York State Agricultural Experiment Station, Cornell University*

FIG 9. Apple maggot red sticky sphere trap with bait. *Photo by Greg Krawczyk, Pennsylvania State University*

in July and August to prevent adult flies from laying eggs. To reduce costs and negative environmental impacts, monitor adult apple maggot fly populations and apply insecticide, only when threshold levels have been met. The most effective traps for monitoring apple maggots are sticky red spheres baited with apple volatile compounds (e.g., Tanglefoot® red sphere traps and lures) (Fig. 9).

To implement an effective apple maggot monitoring program:

- Place a single trap in each three-acre block, with traps placed one to two rows in from the orchard border.
- Place traps by early to mid-June, about head height, and positioned so they are surrounded by fruit and foliage, but without the foliage touching or obstructing them.
- Inspect and clean traps weekly from initial placement through early September.
- Apply insecticide when an average of five flies per trap are captured. (Due to pesticide residues, fly capture for the week or two following an insecticide application can be discounted.)

Pesticide use can also be reduced by using good orchard sanitation practices:

- Pick up and destroy apples that have dropped to the ground. This will reduce habitat for apple maggot populations for the following year.
- Remove abandoned apple trees and other adjacent apple maggot host plants (e.g., hawthorn) within 100 yards of the orchard.

SARE-funded research at University of Massachusetts has also advanced another non-pesticide control of apple maggots: sticky red spheres. Spheres baited with a blend of five components of synthetic fruit odor (butyl hexanoate plus hexyl butanoate, butyl butanoate, pentyl hexanoate, and propyl hexanoate) turned out to be more effective for trapping apple maggot flies than spheres baited with a single component (butyl hexanoate) for all cultivars except Gala, Jonagold and Fuji, which were particularly susceptible to apple maggots in years one and two of the project.

> To reduce costs and negative environmental impacts, monitor apple maggot fly populations and apply insecticide only when threshold levels have been met.

In these first two years, sphere traps were placed 10 meters apart on perimeter-row apple trees and ultimately proved to be as effective as grower sprays in controlling apple maggot flies. In the third and final year of the project, spheres were placed five to 15 meters apart on perimeter trees depending on tree size, extent of pruning, cultivar and nature of adjacent habitat. For example, in blocks with smaller trees and low to moderate maggot pressure, traps placed about 10 meters apart provided effective control when using the recommended apple volatile compound. This new approach led to a 100 percent reduction in insecticide use for apple maggots and a 37 percent reduction in the number of traps needed to achieve direct control (Prokopy et al., 2000; Prokopy et al., 2004).

The SARE-funded mite management project at Penn State University evaluated Kaolin clay as an organically acceptable control option for apple maggots (and plum curculio as described above). Kaolin clay works as a repellent and therefore should be applied before apple maggots begin laying eggs. Additional applications are needed to maintain the coating as the fruit grows, especially after it rains. In the comparison of organic transitional and conventional blocks, seasonal and harvest fruit evaluations were conducted in all monitored orchards to assess the efficacy of the Kaolin spray; apple maggot was monitored using yellow sticky traps. Throughout the project no excessive numbers of apple maggots were observed in any of the organically treated orchards. Perfect coverage by Kaolin clay of fruit and foliage is crucial for the efficacy of this method. Although excessive use of Kaolin clay can result in white residue (Kaolin dust) on fruit during harvest, it is easily washable and poses no health risk.

Codling Moth

The codling moth occurs throughout North America. Introduced from Europe, it attacks a wide range of plants including apples, pears, walnuts and other fruits. For many years it was considered to be more of a problem in the western United States than on the East Coast, but that situation has changed in the last decade. Increased pressure from the codling moth now makes it one of the most important apple pests in the Northeast. Codling moths can infest 95 percent of the apples in an orchard if left unmanaged. Given the codling moth's ability to adapt to various fruiting periods of the crops it infests, and to develop resistance to insecticides, fruit growers must continually be on guard against a resurgence of this pest.

FIG 10. Adult codling moth. *Photo by Todd M. Gilligan and Marc E. Epstein, Bugwood.org #5482427*

Description and Life Cycle

Codling moths overwinter as full-grown larvae within cocoons under leaf litter, loose bark or any other sheltered place they may find. As the weather begins to warm in the spring, the larvae pupate and the first flight of adult moths emerges about the time of full bloom in apples. Adult moths are an iridescent gray color with a chocolate-brown patch, containing copper to gold markings, located at the tip of each forewing. The hind wings, which are not visible when the moth is at rest, are a lighter, copper brown color (Fig. 10). Adult female moths are approximately three-eighths of an inch long, while males are slightly smaller and have a grouping of hair-like scales near the wing base.

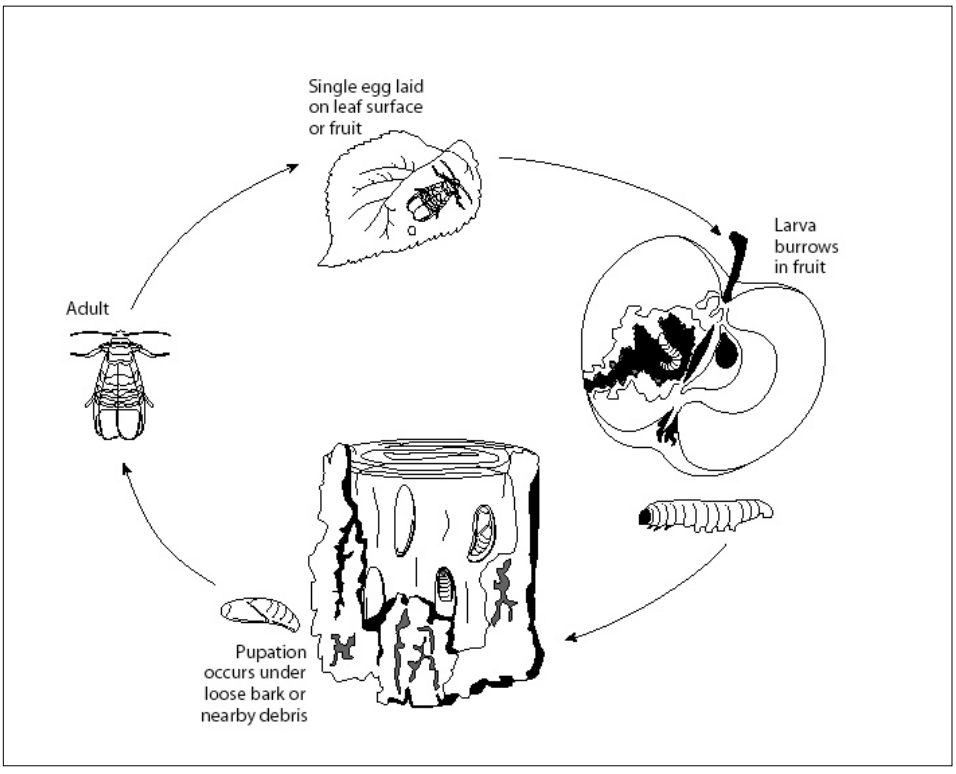


FIG 11. Life cycle diagram of the codling moth. *Artwork by Valerie Winemiller.*

During the day, codling moth adults are inactive and remain camouflaged on the bark of trees. When evening temperatures go above 60 degrees F, the moths become active and mate, and the females lay their eggs. Females may lay up to 100 eggs. Eggs are laid mostly on fruit or on the leaves near fruit and hatch in six to 20 days depending on weather and temperature. Codling moth eggs are laid singly and at first appear as slightly flat, oval discs. They are translucent and tiny. As eggs mature, they become reddish in color and finally enter a stage where the dark head capsule of the larvae can be seen. After hatching, young larvae briefly feed under the surface at the side of the fruit before boring into the core. They then feed on the seeds and surrounding flesh until they are fully grown in three to four weeks, at which time they exit the fruit and seek shelter where they spin a cocoon. At maturity, codling moth larvae are about one-half to five-eighths of an inch long, pinkish white in color, with a brown head marked with dark speckles (Fig. 11).

Codling moths go through one and a half to three and a half generations annually, depending on location, weather and length of the growing season. Some first-generation larvae can pupate and emerge as adults in two to three weeks and produce a second codling moth generation. The majority of this second generation overwinters as mature larvae. The other part of the first-generation larvae do not pupate but instead enter a dia-

FIG 12. Internal injury by codling moth larvae. *Photo courtesy USDA Agricultural Research Service*

FIG 13. Exit tunnel by codling moth larvae. *Photo courtesy New York State Agricultural Experiment Station, Cornell University*

To reduce costs, improve efficacy and reduce the environmental impacts of insecticides, use pheromone monitoring traps to determine if and when sprays are necessary.

pause phase and overwinter as last instar. All overwintering larvae contribute to the first-generation adults the following year. Under an extended growing season (mostly in the mid-Atlantic region), some larvae of the second generation may also pupate and attempt to produce a third generation. This final generation of larvae generally does not survive the winter, but is capable of producing significant late-season fruit injury. Second and third generations may overlap, resulting in the presence of adults from mid-July through the remainder of the growing season (Fig 12).

Codling moth larvae are direct internal fruit feeders. Damage is evident either as a feeding tunnel bored into the seed chamber of the fruit, or in the presence of surface "stings," small shallow holes the size of pin pricks with a little dead tissue on the cavity walls (Fig. 13 and 14). Fruit with sting-type damage usually remains on the tree, while those with deep tunneled entries usually fall during the "June drop." The fruit injuries from subsequent generations may or may not cause premature fruit drop, depending on the variety. Stings lower the value of the fruit for both fresh market and processing apples. Tunneling causes the fruit to be rejected completely.

Management of Codling Moth

The standard practice for managing codling moth has been the use of broad-spectrum insecticides such as organophosphates or carbamates similar to products used for plum curculio or apple maggot. Widespread use of these broad-spectrum materials severely limited the effectiveness of any available biological control agents. To reduce costs, improve efficacy and reduce the environmental impacts of insecticides, use pheromone monitoring traps as an indicator to determine if and when sprays are necessary (Fig 15).

To monitor and treat properly:

- Place at least one trap per five acres by the pink bud stage.

FIG 14. Large plastic delta trap commonly used for monitoring all lepidopteran species in an orchard. *Photo by Greg Krawczyk, Pennsylvania State University*

FIG 15. Isomate twin tube mating disruption dispenser, used for both codling moth and Oriental fruit moth. *Photo by Greg Krawczyk, Pennsylvania State University*

Mating disruption offers an effective management alternative to insecticides for large fruit blocks or smaller orchards in isolated areas with relatively low codling moth populations.

- Set traps on the outside of the tree in the upper part of the canopy. The higher the trap placement, the better codling moths are monitored.
- Check traps daily until the first adults are caught and then weekly thereafter, to establish biofix (the beginning of sustained flight of moths in the spring).

If moths are present in the orchard, use an egg hatch degree-day model to determine the best timing of insecticide applications. First capture of adults in a pheromone trap is used as a biofix, and degree-days (heat unit accumulation) are calculated thereafter. Degree-days are calculated based on the daily minimum and maximum temperatures, and calculated based on the developmental threshold for an insect. If you want to time sprays based on egg development and hatch, time the first insecticide application at 250 degree-days (base 50 degrees F) after the first capture of males in the sex pheromone traps. If needed, make a second application at 550 degree-days (usually 14 to 21 days following the initial application). Additional insecticide treatments may also be necessary after the second application due to extended codling moth flight observed in many orchards.

New-generation materials such as insect growth regulators, viruses and botanicals offer alternatives to broad-spectrum insecticides, although these newer treatments can vary in their effectiveness. Codling moth granulosis virus (CpGV) is a particularly promising control alternative. In the SARE-funded organic systems project at Penn State University, codling moth granulosis virus in the form of commercial products Cyd-X or Carpovirusine CpGV provided excellent control of codling moth and some suppression of Oriental fruit moth.

Mating disruption, a method using insect sex pheromones to disrupt the process of finding a mate, offers an effective codling moth management alternative to insecticide sprays for large fruit blocks, or smaller orchards in isolated areas with relatively low codling moth populations. Pheromone dispensers of various types are placed in the upper part of the tree canopy and emit sex pheromones that confuse male moths and prevent them from finding females (Fig. 15). If the Oriental fruit moth is also present in the same orchard, then dispensers with the combination of two sex pheromones (for codling moth and Oriental fruit moth) can be used for simultaneous management of both species (Isomate CM/OFM CTT or CheckMate Duel). A combination of mating disruption and codling moth granulosis virus can be particularly useful.

In the SARE Penn State University organic systems project, mating disruption used in combination with the granulosis virus was very effective at controlling both the Oriental fruit moth and codling moth. Mating disruption was used throughout the season, but when codling moth adults were observed in pheromone traps during the late part of the season, additional applications of CpGV were needed to keep the population in check. Ultimately, the combination of CpGV and mating disruption kept codling moth and Oriental fruit moth damage at a very low level during the entire project.

FIG 16. Entomologists assess codling moth damage on Red Delicious apples. *Photo by Scott Bauer, USDA Agricultural Research Service, Bugwood.org #1323009*

Oriental Fruit Moth

The Oriental fruit moth was introduced to the United States from Japan in the early 1900s, probably on infested nursery stock. Now found in all regions of North America, it is a pest of most stone and pome fruits. In apples and pears, its appearance and damage are similar to that of the codling moth. In northern-tier states, the Oriental fruit moth has three to four generations per year. In areas with a longer growing season, it may have up to five generations per year.

FIG 17. Adult Oriental fruit moth. *Photo courtesy New York State Agricultural Experiment Station, Cornell University*

Description and Life Cycle

Oriental fruit moth larvae overwinter in cocoons on the trunk or in leaf litter beneath the tree. As with codling moths, Oriental fruit moths overwinter as last instar larvae and pupate in the spring. As the weather begins to warm in the spring, the larvae complete their development and emerge as adult moths at the time apple orchards are in bloom. Male and female moths are similar in appearance—grayish, with a wing spread of one-quarter to one-half of an inch. After mating, females lay eggs singly on the upper or lower leaf surface, often on the terminal leaf of a young shoot. Each female moth can lay up to 200 eggs over a seven- to 10-day period. The eggs appear initially as flat, whitish ovals, changing to an amber color as they mature. Eggs may take up to 14 days to hatch early in the season, and as little as five days during the warm summer months. Just before the larva hatches, the dark head capsule can be seen through the egg. After hatching, young larvae enter young terminal shoots or fruit and begin to feed. They pass through four to five instars, reaching about one-half of an inch when mature. Mature larvae are pink in color, with a reddish brown head capsule.

In the Northeast, the Oriental fruit moth completes three to four generations over the growing season. Mature larvae leave their feeding sites to spin cocoons in which they pupate, later to emerge as adult moths. Cocoons are constructed of silk and are covered with particles of the surface on which they are spun. The pupal stage lasts 12 to 15 days in the summer, somewhat longer in the spring when temperatures are cooler. Early in the season, nearly all of the larvae pupate soon after spinning a cocoon; later in the season, as day length decreases, an increasing proportion of larvae enter diapause to overwinter. Diapausing larvae pupate and emerge the following spring (Fig. 18).

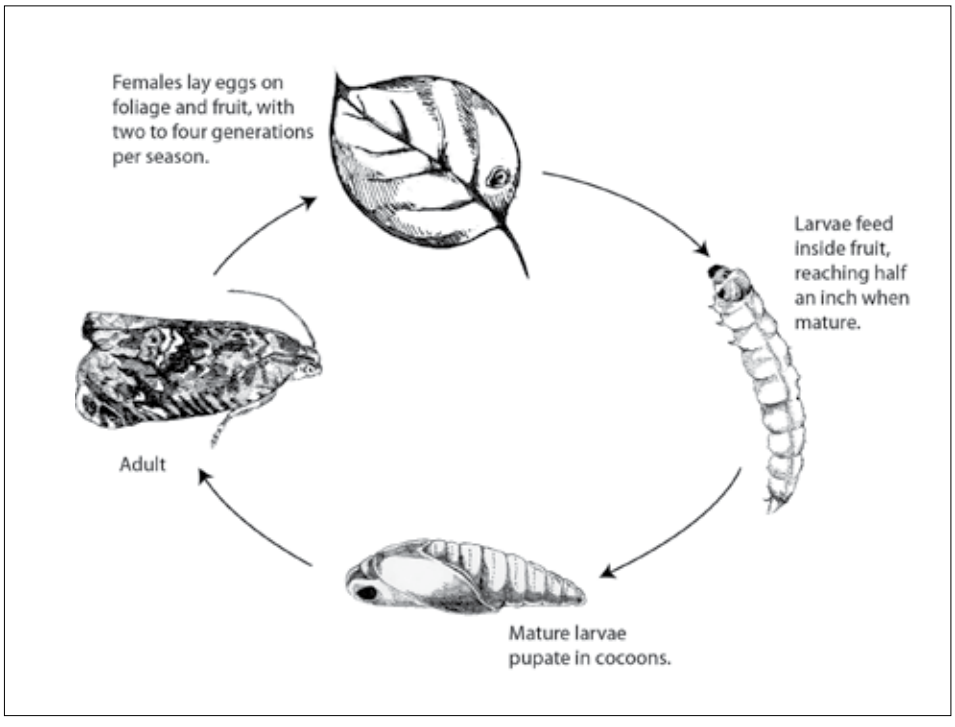


FIG 18. Life cycle diagram of the Oriental fruit moth. *Artwork by Ariel Hsu*

FIG 19. Oriental fruit moth shoot strike on apple tree. *Photo by Jim Walgenbach, North Carolina State University*

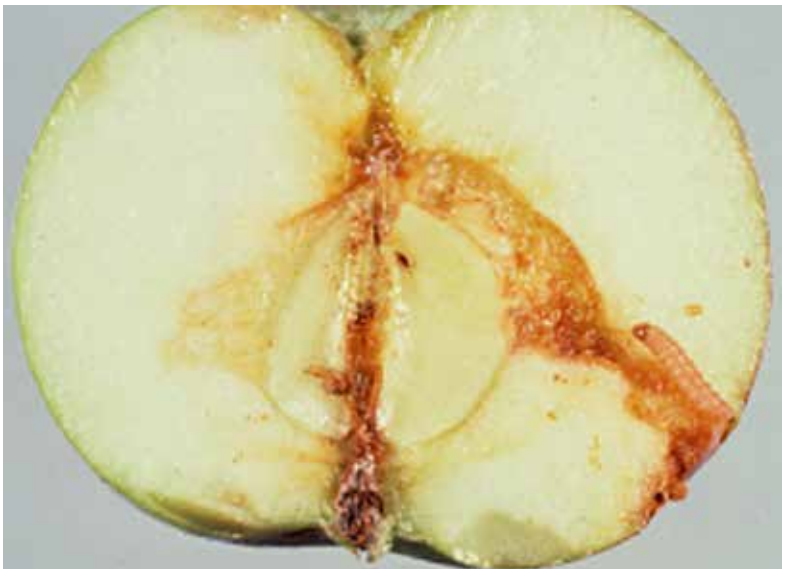


FIG 20. Internal injury by an Oriental fruit moth larva. *Photo courtesy New York State Agricultural Experiment Station, Cornell University*

FIG 21. Exit hole by Oriental fruit moth larvae. *Photo courtesy New York State Agricultural Experiment Station, Cornell University*

Oriental fruit moths feed on both shoots and fruit. The first generation, which is feeding when terminals are succulent and tender, develops almost exclusively in the vegetative growth, so the earliest indication of injury is a dying back of the new growth of twigs in spring (Fig. 19). Later generation larvae also feed on fruit, entering near the stem end and burrowing in toward the core (Fig 20). Infested apples have a collection of frass at the exit hole of the insect's feeding tunnel, or at the calyx end (Fig. 21). It is difficult to distinguish between Oriental fruit moth damage and codling moth damage. Oriental fruit moth larvae tend to feed mostly around the calyx and stem ends of the apple fruit and usually do not feed on the seeds, while codling moth larvae usually tunnel directly to the core of the apple and feed on the seeds.

Management of Oriental Fruit Moth

Similar to the codling moth, growers have relied on broad spectrum insecticides to control the Oriental fruit moth. To lower costs and reduce adverse impacts, use trapping and degree-day models to determine if and when management activities are necessary. Place pheromone traps in the orchard in early April and check daily until a biofix is established. From that point on, calculate and record degree days to determine spray timing or other control tactics. The differences in larval development due to feeding on various food sources (e.g., shoots versus fruit) and possible adult movement between adjacent orchards contribute to significant overlap between generations late in the season. Use pheromone traps to monitor the Oriental fruit moth population in each block to assess the potential problems caused by this pest.

The use of Oriental fruit moth mating disruption has proved to be a very effective alternative to broad spectrum insecticides (Fig. 22). Mating disruption products can either be distributed throughout the orchard as a direct spray material (e.g., Checkmate OFM-F) or by the use of hand-applied dispensers such as Isomate M-100, Isomate Rosso, Cidetrak OFM or Disrupt OFM. If codling moths are also a problem in the same block, then Isomate CM/OFM TT or Checkmate CM-OFM Duel should be used for the control of both species. At the pink bud stage, hand-applied dispensers should be placed in the upper level of the tree canopy at the label rate. The effective pheromone release time for most products available is 90 to 150 days. Ideally, for mating disruption to be effective orchards should be at least five to 10 acres in size. Moreover, pheromone trap monitoring should proceed as usual to check the effectiveness of the disruption program. As indicated above for the codling moth, the SARE organic systems project at Penn State University showed that mating disruption used in combination with the granulosis virus was very effective at controlling both the Oriental fruit moth and codling moth.

FIG 22. CheckMate mating disruption dispenser, used for both codling moth and Oriental fruit moth. *Photo by Greg Krawczyk, Pennsylvania State University*

European Red Mite

The European red mite was introduced into North America from Europe in the early 1900s. It is now established in most fruit growing areas across the country and is considered to be an important pest in apple, pear and stone fruit orchards. European red mite is a secondary pest, which means it does not cause direct injury to fruit and it is usually held in check by natural enemies. Only when those natural enemy populations are disrupted, for example through the use of particular pesticides, are outbreaks of the European red mite likely to occur and cause premature defoliation of affected trees. Predators of the European red mite include several species of phytoseiid mites, stigmaeid mites and Stethorus beetles. Phytoseiid mites are the most effective of these predators in the Northeast and occur naturally in commercial orchards. Although the European red mite is not currently a major pest of apples in the Northeast, it is important to revisit what practices have contributed to its control, particularly for new growers who may not be as familiar with its biology and history.

FIG 23. European red mite adult female. *Photo courtesy New York State Agricultural Experiment Station, Cornell University*

FIG 24. European red mite adult male. *Photo courtesy New York State Agricultural Experiment Station, Cornell University*

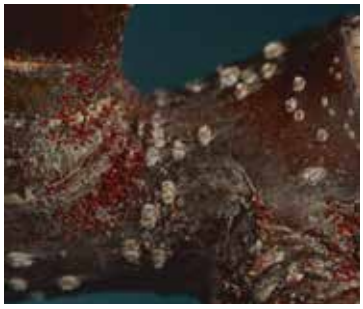


FIG 25. Overwintered European red mite eggs on bark. *Photo courtesy New York State Agricultural Experiment Station, Cornell University*

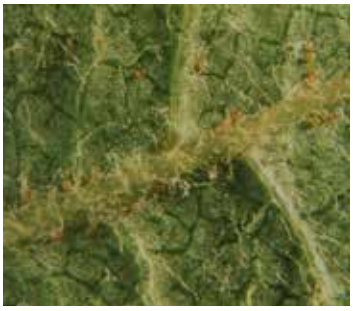


FIG 26. Summer European red mite eggs. *Photo courtesy New York State Agricultural Experiment Station, Cornell University*

Description and Life Cycle

European red mite females are one-sixty-fourth of an inch long, bright red and have four rows of white hairs on their backs (Fig. 23). Males are smaller, lighter in color and have pointed abdomens (Fig. 24). Late in the season, females lay overwintering eggs in groups on roughened bark, in crevices and cracks, and around bud scales on twigs and branches (Fig. 25). Overwintering eggs are round, bright red and have a small stalk, approximately the length of the diameter of the egg, arising from the top. Eggs begin to hatch at pre-pink bud stages and continue throughout bloom. Young mites move to newly opened leaves where they feed, mature and reproduce. Eggs laid during the growing season are pale and translucent (Fig. 26). Mite development and the number of generations that occur during a season depend on weather conditions and temperature; hot, dry weather favors devel-

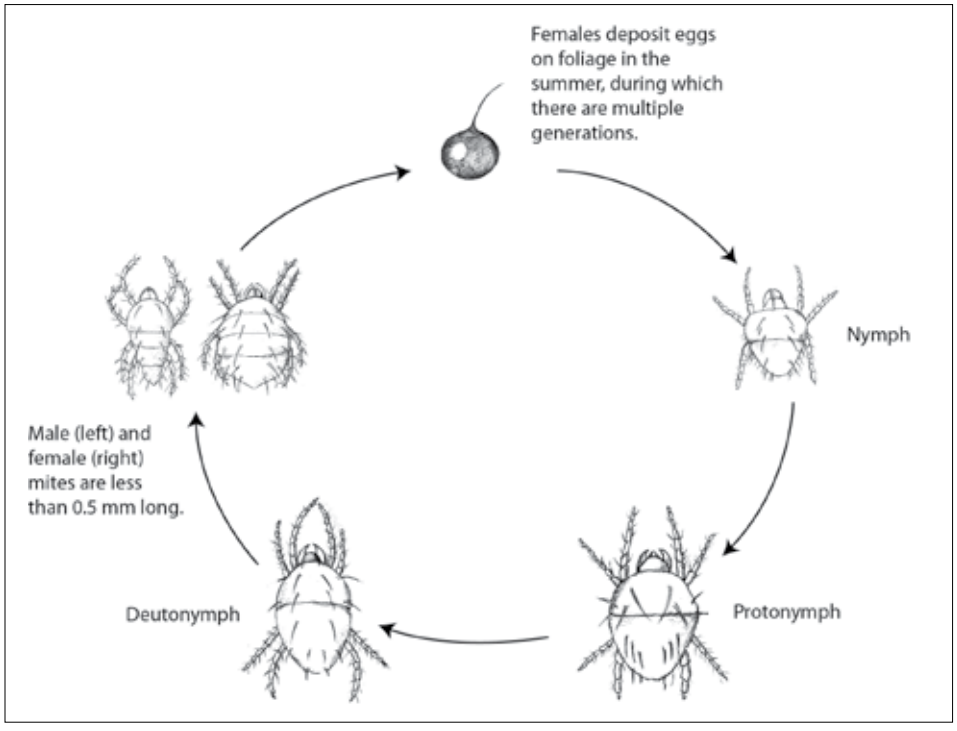


FIG 27. Life cycle diagram of the European red mite. *Artwork by Ariel Hsu*

FIG 28. Comparison of healthy foliage to foliage damaged by the European red mite. *Photo courtesy New York State Agricultural Experiment Station, Cornell University*

The use of miticides to control the European red mite should be considered the last resort as they may continue to suppress populations of beneficial natural enemies, contribute to problems with pesticide resistance and are expensive.

opment, while cool, wet weather delays development. In the Northeast, depending on environmental conditions, eight to 10 generations of European red mites may occur during the season (Fig. 27).

European red mites feed on the leaves of apple trees, hindering photosynthesis and causing injury to the tree (Fig. 28). This is particularly problematic in early summer when trees are producing fruit buds for the following season: Moderate to heavily infested trees produce fewer and less vigorous fruit buds. Since feeding by mites reduces carbohydrate production by the plant, an outbreak can also result in smaller fruit size. Other symptoms include a characteristic brown/bronze foliage, poor fruit color and premature fruit drop. According to Cornell University guidelines, keeping European red mite numbers below 2.5 per leaf before July, below five per leaf in July and below 7.5 per leaf in August should prevent economic losses from this pest (Breth et al., 1998).

Management of European Red Mite

The use of miticides to control the European red mite should be considered the last resort as they may suppress populations of beneficial natural enemies, contribute to problems with pesticide resistance and are expensive. Instead, encourage populations of natural enemies in the orchard and use less toxic options such as summer horticultural oil sprays if European red mite numbers begin to increase beyond established thresholds. These ecologically based strategies have been shown to be effective, either singly or in combination, in commercial orchards.

Biological Control / Natural Enemies

European red mites usually do not become problematic in areas where beneficial mites and mite predators are present. In the Northeast, the most effective predators against European red mites are the phytoseiid mites, including *Amblyseius fallacis, A. cucumeris, Typhlodromus pyri, T. occidentalis,* and *T. vulgaris.* These mites cannot be distinguished in the field and can only be identified by microscopic examination of the arrangement of the setae (hairs) on their bodies. *T. pyri* and *A. fallacis* are the two most common predator mites in Northeast orchards and of the two, *T. pyri* seems more effective at controlling European red mite populations. For the mid-Atlantic region, the Stethorus beetle (*Stethorus punctum*) is also a very effective mite predator, able to provide excellent mite control in apple orchards.

SARE-funded research shows that predatory mites can be introduced and established in commercial orchards, and provide excellent suppression of pest mites. In the SARE University of Massachusetts study, beneficial mites were established in all study locations during the first two years of the study. (*T. pyri* were introduced in burlap bands that were placed at the base of trees.) Populations of both predator mites (*T. pyri* and *A. fallacis*) and pest mites (European red mite) were counted in all blocks. The predator mite *T. pyri*, released in 2000, continued to provide excellent suppression of pest mites in most orchards in 2003, regardless of tree cultivar and nature of border habitat.

How to Introduce Beneficial Mites into an Orchard

When collecting and releasing beneficial mites, first have an expert identify and confirm the presence of *T. pyri* and/or *A. fallacis* in the orchard. Once their presence has been established, there are three possible methods to introduce beneficial mites into another orchard (Breth et al., 1998):

1. Transfer flower clusters from a source orchard to a recipient site during the bloom period. At least 20 flower clusters should be placed in each tree, attached with paper clips, staples or twist ties.
2. During the summer growing season, collect leaves where *T. pyri* are abundant and place them in trees of the target orchard. Stapling leaves to the tree works well. The number of leaves to use depends on the density of *T. pyri* in the source orchard. As a guide, at least 50 predators should be released in each target tree.
3. Create artificial overwintering sites for *T. pyri* using burlap and tree wrap. In early December, collect these bundles and place them in cold storage. The following spring, place the burlap around recipient trees at approximately the half-inch green bud growth stage. As many as 400 predator mites can be transferred in each band with this method.

After beneficial mites have been introduced into an orchard, an environment must be created that allows the population to survive and flourish. First and foremost, this means that no pesticides toxic to the beneficial mites should be applied to the orchard. And even with the right environmental conditions, it may take several seasons for the predator population to become abundant enough to regulate European red mites. During this period additional control measures may be needed to keep European red mites (and/or other pests) below damaging levels. An early-season oil spray can be used to reduce European red mite populations in the spring without damaging the beneficial mite population (see the following section). As a last resort, if European red mite densities continue to rise and exceed threshold levels, a miticide that is not toxic to beneficial mites can be applied. Having some European red mites in the orchard after introducing the beneficial mites is useful, as the pest mites provide a food source for the predators, thus increasing the population of beneficial mites.

Horticultural Oil for Control of Mites

In situations where the European red mite's natural enemies have been reduced, researchers have found horticultural oil sprays provide some effective control of phytophagous mites. In the SARE mite management project at Penn State University, JMS Stylet oil (JMS Flower Farms, Inc.), Mite E-oil (Helena Chemical Company and BioCover LS (UAP Platte Chemical Company) were evaluated for their effectiveness in controlling European red mites in three commercial orchards with high European red mite populations. While one of the growers had used summer oils for mite control in the past, other growers never had. During a two-year period, researchers evaluated oils using two different methods of application—complete coverage versus alternate row applications, where only every other row of trees was treated with the product. In some orchards multiple applications of horticultural oils were compared with the grower's standard miticide program while at other sites the horticultural oils were evaluated side-by-side to compare their efficacy for mite control. Both pest and predator mites were counted over the entire growing season and trees were visually evaluated and rated during harvest for phytotoxicity symptoms on fruit and foliage.

Evaluated in side-by-side comparisons, all three summer oils provided effective control of mites with the JMS Stylet oil treatment, providing the best seasonal mite control when applied as complete sprays with full volume of water (100-150 gallons per acre).

At all test sites, the pre-bloom oil application kept European red mite populations in check through mid-summer. Beyond that point in both years, pest mite populations increased enough that emergency summer oil or acaricide applications were added to the program.

Evaluated in side-by-side comparisons, all three summer oils provided effective control of mites with the JMS Stylet oil treatment, providing the best seasonal mite control when applied as complete sprays with full volume of water (100-150 gallons per acre). As expected, an increase in predatory mites (*A. fallacis* and *Zetzelia mali*) during later parts of the season was observed in all treated blocks. However, applications of horticultural oils using the alternate row method with reduced water volume did not provide adequate mite control. After significant mite build–up, despite alternate row middle applications during the early part of the season, even an increase in water volume and oil concentration did not reduce the mite population to below damaging levels. The increase in the number of European red mites later in the season resulted in visible bronzing of leaves, and acaricide applications were necessary to avert crop loss. No negative effects (phytotoxicity) on fruit finish were observed with any of the oil sprays. Oils should not be used in conjunction with, or within 30 days of, a sulfur application (or captan in conventional orchards), since a combination of the two can cause phytotoxicity, in this case leaf "burning."

In organically managed apple orchards, during each year of the project, no special treatment was necessary to manage European red mite and aphid populations except for the application of oil during tree dormancy (Organic JMS Stylet Oil). Regular in-season mite and mite predator observations consistently revealed a steady although low presence of phytophagous mites such as *A. fallacis*, *T. pyri* and *Z. mali.*

Future Directions

Biological control of the European red mite is a success story in the Northeast. With greater awareness of its status as a secondary pest, and implementation of the management strategies described in this technical bulletin, apple growers have generally been able to avoid damaging levels of the mite in orchards. Maintaining this situation will require continued vigilance on the part of the grower community and educating the next generation about ecologically based approaches to managing the pest.

Much progress has been made in developing integrated strategies to control the pests addressed in this technical bulletin. Tactics such as mating disruption for the management of direct fruit pests, combined with the widespread use of selective, less disruptive pesticides such as codling moth granulosis virus or Kaolin clay, greatly enhance the effectiveness of beneficial organisms. The development of safer, more selective products should similarly enhance the importance of beneficial insects for pest control.

Despite the advances in IPM during the past two decades, when looking at data for the industry as a whole, the number of pesticide applications on apples in the region has not decreased significantly in recent years, and in fact it may be increasing. This trend is possibly the result of several factors, including removal of older pesticides, their replacement with more specific and less broad spectrum products, resistance to pesticides, increased global competition and increased labor costs associated with some IPM tactics (Cooley, 2008). Recently, the introduction of an invasive pest, the brown marmorated stink bug, poses an additional challenge to established IPM practices in the mid-Atlantic and northeastern apple growing regions. The necessity for broad-spectrum insecticides to control this new pest, combined with almost ineffective (or non-existent) biological control, shifts the whole system toward increased use of pesticides. Although intensive research is underway to develop more sustainable methods to manage this invasive stink bug, at the moment only broad spectrum insecticides are effective, which are not compatible with the ecological strategies addressed here.

As apple growers progress towards their goal of economically and ecologically sustainable production, they need new information and continuing support to help them implement and adapt ecologically based pest management practices in their orchards. As demonstrated by this research, many effective options are available. By taking advantage of them, growers will be in a position to sell to markets that demand and pay a premium for fruit grown in a more ecologically friendly manner (e.g., local markets, organic certification, eco-marketing certification programs and other integrated fruit production standards). In turn, this will enhance the economic viability of northeastern apple growers while decreasing the environmental impacts of their production practices.

SARE Research Synopsis

This technical bulletin is based on the following three SARE-funded projects.

Toward Sustainability in Northeastern Apple Production: Orchard Ecosystem Architecture, Key Pests, and Cultivar Selection

Project Number: LNE00-135
Project Year: 2000-2004
SARE Region: Northeast
Grant Type: Research and Education
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For more information, go to www.sare.org/project-reports and search by project number.

[Identified in the text as the SARE University of Massachusetts project.] This three-year project looked at the effect of perimeter-row apple tree cultivars and the composition of the border area habitat on management of several apple pests: flyspeck (*Schizothyrium pomi*), European red mite (*Panonychus ulmi*), plum curculio (*Conotrachelus nenuphar)* and apple maggot (*Rhagoletis pomonella*). The main objectives were to: 1) reduce reliance on pesticides in the region, and 2) enhance sustainability of northeastern apple production through evaluation of new cultivars. University of Massachusetts researchers worked with growers to set up the study in 12 commercial orchards. At each orchard site, four plots were identified, each measuring 30-45 meters in perimeter-row length and seven rows wide. In six of the 12 orchards, perimeter rows were comprised of the cultivars Gala, Jonagold or Fuji. Perimeter-row trees in the other six orchards were comprised of McIntosh or Empire cultivars. Habitat adjacent to perimeter rows consisted of woods, hedgerows or open field. The research methodology for each of the pests addressed in this technical bulletin was:

Plum curculio. In year one, three types of traps were tested: wire-mesh circle traps wrapped around trunks of perimeter-row trees, trunk-mimicking pyramid traps, and branch-mimicking cylinder traps. Three types of odor bait were tested in each type of trap: benzaldehyde+grandosoic acid (GA), limonene+GA or ethyl isovalerate+GA. In year two, similarly baited, sticky clear-plexiglass panel traps were tested against black pyramid traps and wire mesh circle traps. In addition, a new "trap tree" approach, was introduced, which involved baiting branches of one perimeter-row tree per plot with benzaldehyde+GA. The significant aggregation (15-fold) of fresh ovipositional plum curculio injury on trap trees was designed to facilitate monitoring of the seasonal course of plum curculio injury to apples and to provide a new approach for determining need and timing of insecticide applications against the pest. In year three, a trap tree baited with benzaldehyde+GA was established as the central tree of the perimeter row of each of three perimeter plots in the orchard. Each plot was randomly assigned a threshold of either 1, 2 or 4 percent freshly injured fruit on the trap tree. Trap trees were sampled for freshly injured fruit three times per week beginning seven days after a petal-fall spray of insecticide to the entire plot. Thereafter, insecticide against plum curculio was applied only to perimeter and second rows and only when the proportion of trap-tree sampled fruit showing fresh injury had reached the pre-established threshold of 1, 2 or 4 percent for that plot.

Apple maggot. In years one and two, sticky red sphere traps were baited with a five-component blend of attractive synthetic fruit odor and placed 10 meters apart on perimeter-row apple trees. They were compared with similar traps baited with a single component of synthetic fruit odor (*butyl hexanoate*) placed in similar positions. Trap captures and damage were related to border structure and composition, and apple cultivar composition in the blocks. In year three, distances between spheres (range five to 15 meters) on perimeter trees were based on a newly developed formula that incorporated tree size, extent of pruning, tree cultivar and nature of adjacent habitat as distance-determining factors. Performance was assessed on the basis of captures of apple maggot fly on unbaited monitoring spheres at interiors of plots and on the percent of fruit injured by apple maggot flies.

European red mite. Populations of both predator mites (*Typhlodromus pyri* and *Amblyseius fallacis*) and pest mites (European red mite) were counted in all blocks and related to border structure and apple cultivars.

Use of Horticultural Oil for Mite Management in Fruit Orchards

Project Number: LNE02-159
Project Year: 2002-2004
SARE Region: Northeast
Grant Type: Research and Education
Project Coordinators:
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For more information, go to www.sare.org/project-reports and search by project number.

[Identified in the text as the SARE mite management project.] The main objective of this project was to provide information and recommendations to Pennsylvania fruit growers that was both practical and feasible.

Seasonal and harvest fruit evaluations were conducted in all monitored orchards to assess the efficacy of employed practices. Three highly refined horticultural summer oils [JMS Stylet oil (JMS Flower Farms, Inc.), Mite E-oil (Helena Chemical Company) and BioCover LS (UAP Platte Chemical Company)] and two methods of application (complete sprays versus alternate row middle applications) were evaluated for European red mite control in Pennsylvania commercial apple orchards during a two-year period. In some orchards multiple applications of Stylet oil were compared with the grower's standard mite management program while in other orchards the horticultural oils were evaluated side-by-side to compare their efficacy for mite control.

The experimental blocks were located in three commercial apple orchards in Franklin and Adams counties. Only orchards with a historically high, established European red mite population were designated for use in the study. The one Franklin County orchard had been using summer oils for mite control for a few years prior to the project, while the two Adams County sites had not used summer oils for mite control before. Blocks on grower A's farm consisted of one apple cultivar, Red delicious (more than 15 years old). On grower B's farm, a 10-acre orchard with Yorking and Golden delicious was divided into two similar blocks and the oil program was applied in one block. The experiment at grower C's site involved four separate apple bocks, with three of the blocks treated with different horticultural oils and the fourth block used as a control. Each block had two apple varieties, Yorking and Golden delicious.

All three growers used JMS Stylet oil. While the dormant oil application was applied in each orchard as a standard, the later in-season applications varied among orchards:

Grower A: JMS Stylet oil was applied on May 11 and 29, June 10 and 20, and July 10. The standard block received an application of clofentezine on May 11 and an application of pyridaben on June 20.

Grower B: In the standard block no conventional acaricides were applied the entire season, while the JMS Stylet oil block had applications of the oil on May 30, and June 13 and 27.

Grower C: Clofentezine was applied on May 6, and then the oil-program blocks received various treatments on June 3, 13 and 18. No conventional acaricides were needed in the standard block during the season.

All oil applications by growers A and B were done as complete sprays using 100 gallon of water per acre, except for grower A's July 10 application, when 200 gallons of water per acre was used. Grower C applied tested oils as alternate row applications using 50 gallons of water per acre. At each farm, blocks used for oil efficacy evaluations were treated with the same insecticide and fungicide programs as the standard blocks.

Mite and mite predator densities were evaluated on a weekly basis and compared to mite populations in blocks where the standard program was used. During each observation, leaves were collected from eight trees scattered throughout each block for counts. At least 25 leaves per tree (200 leaves per block) were evaluated using a leaf brush machine for the presence of phytophagous mites, predatory mites (*Amblyseius fallacis* and *Zetzellia mali*) and mite eggs. Each variety was also visually evaluated and rated during the harvest for phytotoxicity of oils on fruit and foliage.

Pennsylvania Regional Organic Fruit Industry Transition

Project Number: LNE06-248
Project Year: 2006-2009
SARE Region: Northeast
Grant Type: Research and Education

Project Coordinators:
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For more information, go to www.sare.org/project-reports and search by project number.

[Identified in the text as the SARE organic systems project.] This two-year project was carried out in three transitional organic orchards located on commercial farms in Pennsylvania and an organically certified block located at the Penn State University Fruit Research and Extension Center in Biglerville. Two main entomological aspects of organic apple production were evaluated in comparison to a conventionally managed orchard in this project: 1) efficacy of an organic arthropod pest management program, and 2) the influence of OMRI-approved pesticides of all types (including fruit thinners) on beneficial arthropods. The organically approved products evaluated in this study were: spinosad, for control of leafrollers and leafminers; azadirachtin, for control or suppression of apple aphids, spotted tentiform leafminers, codling moths and Oriental fruit moths; horticultural oils for control of mites and aphids; Kaolin clay for control of plum curculio and apple maggot flies; and various mating disruption techniques. These tactics were integrated into specific pest management programs designed to be most appropriate for the observed insect pest complex. The range of potential tactics applied during each season was selected based on site-specific sampling observations.

All transitional organic and conventional blocks were extensively monitored to determine the need and timing for control tactics against insect and mite pests throughout the season. Pheromone traps for monitoring various lepidopteran species were deployed at each site before the beginning of flight activity for each species and monitored on a weekly basis during the entire season. Plum curculio was monitored using pyramid traps and branch traps. Seasonal and harvest fruit evaluations were conducted in all monitored orchards to assess the efficacy of employed practices. Overall, results from this project showed that high-quality organic apples can be grown in the eastern United States with existing and alternative management tools currently available for organic fruit production.

References

General

Bradshaw, T. 2011. *Tree Training and Planting Systems in Vermont Apple Orchards.* University of Vermont. http://orchard.uvm.edu/uvmapple/hort/AppleHortBasics/plantingsystems.htm

Cooley, D. 2008. *Biointensive Apple IPM in New England.* Presentation at SARE's New American Farm Conference. www.sare.org/Learning-Center/Conference-Materials/The-New-American-Farm-Conference/Breakout-Sessions/Apples-and-Winegrapes-Integrated-Farming-Practices

Cooley, D. and W. Autio. 2011. Summer pruning of apple: Impacts on disease management. *Advances in Horticulture Science* 25: 19-24.

National Agricultural Statistics Service. 2012. USDA NASS Quick Stats. http://quickstats.nass.usda.gov

Kogan, M. and R. Hilton. 2009. Conceptual framework for Integrated Pest Management (IPM) of tree-fruit pests. *In Biorational Tree-Fruit Pest Management*, eds Aluja, M., T. Leskey, and C. Vincent. CAB International: Cambridge, MA.

Penn State University. 2012. *Pennsylvania 2012-2013 Tree Fruit Production Guide.* The Penn State University. http://agsci.psu.edu/tfpg

Peck, G. and I. Merwin. 2009. *A Grower's Guide to Organic Apples.* Cornell University, Department of Horticulture. www.nysipm.cornell.edu/organic_guide/apples.pdf

Prokopy, R. 2003. Two decades of bottom-up, ecologically based pest management in a small commercial apple orchard in Massachusetts. *Agriculture Ecosystems and Environment* 94: 299-309.

Robinson, T., S. Hoying, A. DeMaree, K. Iungerman and M. Fargione. 2007. The evolution towards more competitive apple orchard systems in New York. *New York Fruit Quarterly* 15(1): 3-9.

Hinman, T. and G. Ames. 2011. *Organic Apple Production Guide.* ATTRA. https://attra.ncat.org/attra-pub/summaries/summary.php?pub=4

Plum Curculio

Leskey, T. and S. Wright. 2004. Influence of host tree proximity on adult plum curculio (Coleoptera: Curculionidae) responses to monitoring traps. *Environmental Entomology* 33: 389-396.

Leskey, T. C., J. C. Piñero, S. Wood, and R. J. Prokopy. 2008. Odor baited trap trees: a potential management tool for the plum curculio. *Journal of Economic Entomology* 101: 1302-1309.

Lienk, S. 1980. *Plum Curculio IPM Fact Sheet.* New York State Integrated Pest Management Program. www.nysipm.cornell.edu/factsheets/treefruit/pests/pc/pc.asp

Piñero, J. and R. Prokopy. 2006. Temporal dynamics of plum curculio, Conotrachelus nenuphar (Herbst.) (Coleoptera: Curculionidae) immigration into an apple orchard in Massachusetts. *Environmental Entomology* 35: 413–422.

Piñero. J. C., A. Agnello, A. Tuttle, T. C. Leskey, H. Faubert, G. Koehler , G. Morin, K. Leahy, L. Loss, D. Cooley and R. J. Prokopy. 2011. Effectiveness of odor-baited trap trees for plum curculio (Coleoptera: Curculionidae) monitoring in commercial apple orchards in the Northeast. *Journal of Economic Entomology*. 104: 1613-1621.

Plum Curculio. Tree Fruit Insect and Mite Pest Fact Sheets. Penn State college of Agricultural Sciences. http://extension.psu.edu/plants/tree-fruit/insects-mites/factsheets/plum-curculio

Prokopy, R. 2002. An odor-baited 'trap-tree' approach to monitoring plum curculio. *Fruit Notes* 67(1): 23-24.

Apple Maggot

Apple Maggot. Tree Fruit Insect and Mite Pest Fact Sheets. Penn State College of Agricultural Sciences. http://extension.psu.edu/plants/tree-fruit/insects-mites/factsheets/apple-maggot

Hoffmann, S., R. Mittenthal, B. Chandler, G. Lafleur, S. Wright, P. Appleton, M. Becker, S. Dyynok, and R. Prokopy. 2002. Influence of odor-bait, cultivar type, and adjacent habitat composition on performance of perimeter traps for controlling apple maggot flies. *Fruit Notes* 67(1): 20-24.

Prokopy, R., S. Wright, J. Black, X. Hu, and M. McGuire. 2000. Attracticidal spheres for controlling apple maggot flies: commercial orchard trials. *Entomologia Experimentalis et Applicata* 97: 293-299.

Prokopy, R., I. Jácome, E. Bigurra, M. Blanco, B. Chandler, and S. Wright. 2004. Evaluation of pesticide-treated spheres for control of apple maggot flies in 2003. *Fruit Notes* 69(2): 21-25.

Reissig, W. 1991. *Apple Maggot IPM Fact Sheet.* New York State Integrated Pest Management Program. www.nysipm.cornell.edu/factsheets/treefruit/pests/am/am.asp

Codling Moth

Agnello, A. and D. Kain. 1996. *Codling Moth IPM Fact Sheet.* New York State Integrated Pest Management Program. www.nysipm.cornell.edu/factsheets/treefruit/pests/cm/cm.asp

Codling Moth. Tree Fruit Insect and Mite Pest Fact Sheets. Penn State college of Agricultural Sciences. http://extension.psu.edu/plants/tree-fruit/insects-mites/factsheets/codling-moth

Oriental Fruit Moth

Oriental Fruit Moth. Tree Fruit Insect and Mite Pest Fact Sheets. Penn State college of Agricultural Sciences. http://extension.psu.edu/plants/tree-fruit/insects-mites/factsheets/oriental-fruit-moth

Seaman, A. and H. Riedl. 1988. *Oriental Fruit Moth IPM Fact Sheet*. New York State Integrated Pest Management Program. www.nysipm.cornell.edu/factsheets/treefruit/pests/ofm/ofm.asp

European Red Mite

Beers, E. and S. Hoyt. 2007. European Red Mite. Orchard Pest Management Online. Washington State University, Tree Fruit Research and Extension Center. Wenatchee, WA. http://jenny.tfrec.wsu.edu/opm/displaySpecies.php?pn=290

Breth, D., J. Nyrop and J. Kovach. 1998. *Biological Control of European Red Mite in Northeast Apples: An Implementation Guide for Growers*. Achieving IPM Pub. #215. New York State Integrated Pest Management Program. Cornell University, Ithaca, NY. http://nysipm.cornell.edu/factsheets/treefruit/pests/erm/erm.asp

European Red Mite. Tree Fruit Insect and Mite Pest Fact Sheets. Penn State college of Agricultural Sciences. http://extension.psu.edu/plants/tree-fruit/insects-mites/factsheets/european-red-mite

Lienk, S. 1980. *European Red Mite IPM Fact Sheet*. New York State Integrated Pest Management Program. www.nysipm.cornell.edu/factsheets/treefruit/pests/erm80/erm80.asp

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This publication was developed by the Sustainable Agriculture Research and Education (SARE) program with funding from National Institute of Food and Agriculture, USDA. Any opinions, findings, conclusions or recommendations expressed here do not necessarily reflect the view of the U.S. Department of Agriculture.