The resurgence of Codling Moth in the Hudson Valley

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The codling moth remains a key pest of tree fruit since its early introduction into the US. Recent reports of significant fruit injury caused by codling moth have become an increasing concern to a number of commercial tree fruit growers in the mid-Hudson Valley. Fruit infestations have ranged from 0% to over 20% in commercially grown fresh market fruit over the past few years. When we consider the many factors that can contribute to codling moth injury to apple, we should include the nature of the pest and its capacity to acquire and develop resistance to insecticides, along with the myriad of variables that can influence management success or failure in commercial tree fruit production.

Biology

In New York’s Hudson Valley, the codling moth, *Cydia pomonella* (L.), can have as many as 3 generations per year based on the region’s seasonal weather patterns. Full-grown larvae overwinter within a cocoon under loose bark scales, in leaf litter, apple bins, and other field shelters. As apple bud development nears the pink stage, the codling moth larvae begin pupation, with the first adult flight often beginning during bloom. Eggs are deposited on foliage and developing fruit, and, depending on temperature, hatch occurs 6–10 days later. As the larvae hatch, they will move from foliage to fruit. Eggs laid on the fruit can emerge or directly burrow down into the fruit to begin tunneling (Figure 1).

Larvae have adopted a feeding and fruit burrowing behavior of expelling skin and shallow pulp during their entry into the fruit (Figure 2). This behavior significantly reduces ingestion of both naturally occurring toxins and insecticide residue, increasing the insect’s rate of survival by 25–30% (Gilmer 1933). This behavior appears to contribute to reduced intake of the insecticide’s active ingredient, which likely plays an important role in the development of insecticide resistance that has been occurring since the advent of insecticide use.

The codling moth is in the lepidopteran family Tortricidae, one of the largest families of moths, with approximately 950 species in North America. The codling moth has a host of relatives in this group, including a number of important tree fruit pests such as oriental fruit moth, and the variegated, tufted, redbanded and obliquebanded leafrollers. The ecology and behavior of the tortricid group promotes establishment and continued endemic presence of this pest within the orchard if not completely con-
trolled year after year. Continued exposure of resident insects to control measures has led to the development of resistance to many of the materials applied to reduce fruit injury over the past 150 years.

History

The codling moth is an invasive lepidopteran pest of tree fruit. The first historical record of this species dates back to 371 B.C., at which time the moth was first described by Theophrastus. According to Slingerland (1898), codling moth was introduced into the United States from its European origins in the mid-1700s, likely from early European shipments of pears and apples delivered to the growing colonies. The broad host range of codling moth includes pome fruits such as apple, pear, and quince, while rosaceous species, such as hawthorn and crabapple fruit, along with walnut, are utilized by the larva as a resource throughout the world.

Early apple and pear codling moth management dates back to the period of colonial agricultural production, using oils and organic minerals and metals. In the 1882 report by Lintner to the N.Y. State Legislature, he lists the discovery and uses of valuable insecticides for use in insect pest management. Recommended in this report were Paris Green (arsenic and copper) and London Purple (calcium arsenite), a byproduct of aniline dyes consisting of rose aniline, arsenic acid, lime, iron oxide, and water, for control of codling moth. From 1900 to 1920, the average number of arsenical-type sprays per season for the control of codling moth in the United States was 1–3, in the 1920s 4–5, in the 1930s 4–8, and in the 1940s 6–10 applications. The increase in application frequency was due to the development of resistance against lead arsenate, the primary agent used for codling moth control during this period (Hough 1928; Croft and Riedl 1991). By 1946, DDT had largely replaced lead arsenate for codling moth control, but failures using DDT began occurring by the early 1950s in the US (Jenkins 1952; Glass and Fiori 1955). Development and use of organophosphates began in the early 1950s, with the first detection of resistance to azinphos-methyl in the early 1990s (Varela 1993). Since that time, OP-resistant codling moth has been shown to exhibit cross-resistance to insect growth regulators such as Confirm (tebufenozide) and Dimilin (diflubenzuron), direct resistance through multiple resistance mechanisms to pyrethroids, and, within the past decade, resistance to granulosis virus (Germany), with reduced susceptibility to the neonicotinoid thiacloprid (Calypso) recently observed in Greece and Israel.

Mid-Hudson Valley Codling Moth Concerns

The Marlboro Mountains, including the Illinois Ridge, rises to 1100 ft, spanning 25 miles from Newburgh to south Kingston, while meandering parallel to the Hudson River. The sloping elevation, alluvial soil, and favorable air drainage, provides excellent fruit growing conditions that make this region home to over 3000 acres of tree fruit.

In recent surveys of 10 orchards along the Marlboro Mountains comprising 3100 acres, pheromone trap captures have verified the presence of codling moth adults in at least one block in each orchard. The highest trap captures were closest to packing facilities containing stored bins. In 6 of the 10 orchards, codling moth injury to fruit has been documented (Figure-3), with two orchards reporting over 20% injury in apple blocks in 2016. In contrast to these are the >60% of orchards that have had no signs of codling moth injury, despite relatively high numbers of adult trap captures exceeding a 5 adult per trap threshold.

Causes of Control Failures

Hudson Valley apple orchards tend to have smaller blocks that are bounded by woodland and hedgerows, wild and abandoned apples, and with considerably less contiguous acreage than...
most other growing regions in New York State. This ecology provides alternate hosts for tree fruit pests, many of which supply the genetic diversity to maintain continued insecticide susceptibility. Although there is continued cause for concern regarding regional levels of reduced susceptibility of the codling moth to insecticides, the recent failure to obtain complete control of this insect does not appear to be related to widespread insecticide resistance, considering the very effective tools at our disposal to control the internal worm complex. In part, this can be stated with a fair degree of confidence, as over 60% of the mid-Hudson regional orchards experience less than 1% fruit injury by the internal worm complex on over 50% of the acreage, providing strong evidence of successful control of this pest in the Hudson Valley. That said, it can be asked what are the weak links in the system.

In considering the variables that can have a negative impact on codling moth management, there are a number of factors that contribute to control failure. These are:

- **Weather**
- **Application timing**
- **Shift in insecticide use to less effective insecticides**
- **Low insecticide rates**
- **Incomplete spray coverage**
- **Extended application intervals**
- **A third generation of codling moth in September**

**Weather.** Warm temperatures during the growing season can have a dramatic impact on insecticide efficacy. Generally, the pyrethroидs are more readily detoxified by lepidopterans during post-treatment temperature increases, which can cause outright pest management failures. A bioassay found that, as the temperatures after application rose from 75 to 95°F, the toxicity of Warrior (lambda-cyhalothrin) was seen to have a 9.5-fold decrease in efficacy, Brigade (bifenthrin) a 13.6-fold decrease, and the spinosyn Entrust (spinosad), a 3.8-fold decrease in insect mortality. Yet, there was no change in efficacy of the carbamate Lannate against the European corn borer (Musser and Shelton 2005). In a bioassay efficacy study done at the HVRL, similar results were also demonstrated in codling moth populations exposed to lambda-cyhalothrin. Warrior was topically applied using micro-applications of 1 μl to newly emerged codling moth larvae at a constant rate of 0.16 fl oz/A. A 62% reduction in larval mortality was observed when larvae held at 40°F were compared with those held at 70°F (Figure 4). Choosing insecticide classes based on post-application temperature throughout the season could provide a significant improvement in codling moth pest management.

**Rain.** Dr. John Wise, Department of Entomology at Michigan State University, published a paper, “Rainfall influences performance of insecticides on the codling moth (Lepidoptera: Tortricidae) in apples,” that reports the impact of rainfall over time to assist growers in re-application interval decision-making. The link to the study can be accessed at: [http://msue.anr.msu.edu/news/rainfast_characteristics_of_insecticides_on_fruit](http://msue.anr.msu.edu/news/rainfast_characteristics_of_insecticides_on_fruit)

The study assessed six different chemical classes used to control codling moth, evaluating the effects of rainfall and field aging on their performance. The different classes exhibited different patterns after rain events, both 1 and 7 days post-application, that can produce dramatic results in codling moth management (Tables 1a, 1b). For example, the mode of action as a contact or feeding insecticide (carbamates, organophosphates and pyrethroids) differ in surface retention in comparison to the systemic activity of the neonicotinoid insecticides, demonstrating unique patterns of residue efficacy. Using the residual retention model for re-application decision-making can improve codling moth management during seasons with significant rain events.

**Application timing.** Many seasoned growers are beginning to see codling moth larvae in fruit for the first time. Determining the presence of codling moth larvae and injury to fruit during 1st generation emergence (early July) and at pack-out are good indicators to use in developing pest management strategies for codling moth during the subsequent season. Monitoring of the adult codling moth provides a simple and accurate on-farm assessment of insect presence and population pressure during the growing season. Pheromone traps placed in orchard blocks will detect the first sustained flight of codling moth, which is referred to as the Biofix (Figure 5). This start date is used to initiate the accumulation of temperature units, or degree-days, to effectively calculate and predict when codling moth egg hatch begins. Daily temperatures are then calculated using the base developmental temperature for this insect (50°F). The accumulation of 200–250 degree-days is considered the trigger to begin insecticide management using conventional insecticides. Entering the biofix date into the NEWA codling moth model, using a NEWA station nearest to your location, will provide you with accurate degree day accumulations and recommendations for application timing ([http://newa.cornell.edu/index.php?page=apple-insects](http://newa.cornell.edu/index.php?page=apple-insects)).

The past ten years of codling moth emergence in Highland, NY, shows the dramatic differences in moth emergence and larval emergence dates, reinforcing the importance of applying timely
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applications based on the science behind degree-day predictive modeling, instead of using calendar-based sprays (Table 2).

**Shift in insecticide use** to a less effective insecticide against the 1st generation codling moth occurred during petal fall and 1st cover with the recent loss of Calypso (thiacloprid). Many growers using this neonicotinoid were faced with the decision to select either an old standard or new insecticide chemistry to control plum curculio (PC). Since Calypso had excellent PC and codling moth efficacy, it provided the backbone for management of the internal worm complex, while at the same time reducing the aphid and leafhopper complex. A switch to pyrethroids during very warm conditions, or to the exclusive use of Actara, would not have provided the needed level of lepidopteran management during the onset of 1st generation codling moth activity.

**Low rates** of materials such as Imidan, used for apple maggot (AM) at, e.g., 1 lb/A, would provide the needed control of AM from late June through to harvest, yet this tactic fell short in efficacy against the 2nd or 3rd generation of codling moth in 2016. The same holds true for reduced rates of effective materials such as Assail, Delegate or Altacor, and also pyrethroids when used under temperature extremes.

**Incomplete spray coverage** is an additional variable that should be considered in determining the weak link in codling moth management. The use of alternate row applications on a 5- to 7-day program to manage very mobile insects such as AM late in the season may be effective for apple maggot, yet the codling moth, as previously noted, can burrow into fruit with minimal feeding exposure. Increased tractor and sprayer speed, especially under windy conditions, will reduce spray penetration into the tree canopy, with wind gusts reducing coverage in the tops of trees, where codling moth populations are often greatest.

**Extended application intervals** that reach beyond the residual efficacy of the insecticide will provide a window for the larvae to gain entry into the fruit. This is especially important during the later emergence of the 1st generation of codling moth. If the 1st generation gets a foothold in fruit, the grower will face an uphill battle that will not be easily won, as harvest of early and mid-season apples, such as Ginger Gold, may prevent effective applications from reaching every block on the farm. This will in turn provide for overwintering survival of high endemic populations in the orchard the following season.

**Table 1.** * Number of days after insecticide application that the precipitation event occurred. Insufficient insecticide residue = Insufficient insecticide residue remains to provide significant activity on the target pest, and thus re-application is recommended. Sufficient insecticide residue = Sufficient insecticide residue remaining to provide significant activity on the target pest, although residual activity may be reduced.
Third generation: In years in which there are suitable weather conditions, including degree-day accumulation of heat units, and ample sunlight and moisture, the codling moth may develop a third generation. This occurred in 2016, with CM larval emergence predicted for September 17th (Table 2). For apples harvested after this date, fruit infestation in late season varieties beginning with Red Delicious may have occurred in orchards experiencing threshold trap captures and codling moth infestations earlier in the season.

In closing, effective control options for codling moth are available using products in 10 IRAC insecticide classes, allowing a comprehensive resistance management program to be implemented. Orchardists should also consider beginning to incorporate CM/OFM mating disruption into their programs during coming seasons, as this tactic needs to be implemented prior to bloom. This activity can easily include the placement of dogwood borer mating disruption dispensers in young high-density orchards, where tree decline appears to be a growing concern.

The use of mating disruption in blocks greater than 5–10 acres over multiple years will effectively provide management of the codling moth while reducing the selection pressure on our effective insecticides, ultimately reducing the potential for development of insecticide resistance to these tools. Along with this approach, the use of granulosis virus (Cydia pomonella granulosis virus [CpGV]), should be considered as a rotational tool. The virus is specific to the codling moth, highly pathogenic and fast-acting, and is a tool that will kill its host in the same instar stage as at the onset of infection. It must be ingested to be effective, as viral occlusion bodies dissolve in the larval midgut and release infectious virions. These enter the cells lining the digestive tract, where they replicate and infect other tissue. The larva stops feeding, and within 3–7 days the larva dies, disintegrates, and releases billions of new occlusion bodies that can infect other codling moth larvae via ingestion. There is no adverse effect on fish, wildlife or beneficial organisms, it has a low bee-poisoning hazard, and is non-toxic to humans. The virus has a 0-day pre-harvest interval (PHI) and a 4-hour re-entry interval (REI).

References
Gilmer, P. M. 1933. The entrance of codling moth larvae into fruit, with special reference to the ingestion of poison. J. Kansas Entomol. Soc. 6: (1) 19–25.

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