The use of pheromones to monitor codling moth has been discussed in an earlier article. This article discusses the use of pheromones in a manner to reduce codling moth populations and therefore damage in orchards. Following are the three ways pheromones have been used to control codling moth: mass trapping, attract-and-kill and mating disruption.

Mass trapping is just as the name suggests, placement of a large number of traps in an area baited with pheromone lures. This works by removing male moths from the population with the result of preventing or delaying mating. This method was used in the past, and when codling moth densities were low there was a reduction in damage. However, results of many mass-trapping studies were variable, and in most cases there was no effect on codling moth damage in orchards. Mass trapping requires a high density of traps in order to remove enough males. The large number of traps makes mass trapping an expensive approach. It is always possible that male moths will mate with female moths before they are trapped, a weakness in the mass trapping technique. An alternative to the mass trapping approach with pheromone lures is to use the pear ester, DA lure, as the attractant. The advantage is that both males and females are trapped. Some studies have been conducted with this technology, but results have not been verified by independent studies.

Attract-and-kill (A&K) is a technique that combines an attractant, usually a pheromone, with a contact toxicant (usually a synthetic pyrethroid), both contained in a matrix. The male moth is attracted to the matrix by the pheromone, and when it contacts the matrix it receives a lethal dose of insecticide. The method works like mass trapping in that it depends on removing males from the population and thus suffers from the same weakness, that is, males might mate prior to being removed (killed). The advantage of the A&K technique is that traps are not required and the matrixes used are relatively inexpensive. The only registered A&K product in the U.S. for codling moth control is Last Call™ CM (IPM Technologies, Portland, Oregon). This product uses a paste-like matrix that is applied to the bark of a tree (Fig. 1). The advantage of the Last Call CM formulation is that it uses very small amounts of both pheromone and insecticide per acre. The company has reported that several growers in Washington have used Last Call CM with good results. Limited trials by WSU have shown variable results. Under moderate to high pressure Last Call CM has not performed well without supplemental controls, something that is true for all products using pheromones to control codling moth. Last Call CM must be applied multiple times during the growing season. This product may prove valuable as a tool to treat borders of orchards where hand applications or other methods of dispensing pheromone are used.

Mating disruption relies on the application of pheromone in relatively high amounts per acre to control codling moth. There are different mechanisms that have been proposed to explain how mating disruption works. In order to understand the mechanisms by which mating might be disrupted it is
important to know how pheromones are used to mediate “normal” mate location and mating. This is depicted in Fig. 2. Here a female moth is “calling,” that is, releasing pheromone from a gland that produces it, creating a plume of pheromone that is carried downwind. The male moth becomes active at a certain time of evening or when it encounters some of the pheromone on its antennae. The male then flies upwind and toward increasing concentration of the pheromone until he finds the location of the female, at which time mating usually occurs. Mechanisms that can disrupt the normal mate location include false trail following, adaptation or habituation, masking and sensory imbalance. I will take a little time to explain how each of these mechanisms might work.

**False trail following** – this mechanism is portrayed in Fig. 3. Here the male moth is attracted by pheromone released from some kind of dispenser. The male moth spends most of his time and energy searching out “false” trails of pheromone. Under ideal situations the male would not find a real female and so no mating would occur.

**Adaptation or habituation** – this mechanism is portrayed in Fig. 4. Here the male moth is exposed to abnormally high levels of pheromone and the sensory apparatus stops functioning, at least for a time. This might be similar to our ability to smell a strong odor in a room upon first entering, then not being able to smell the odor following continuous exposure. In a similar manner, the male moth loses the ability to detect the pheromone coming from a female moth because his “smelling” system is overloaded. Recent research suggests that a codling moth might take a couple of hours to recover from exposure to a high concentration of pheromone. For comparison purposes, a hand-applied dispenser can release more than 100,000 times the amount of pheromone per hour as a female codling moth.

**Masking** – this mechanism is portrayed in Fig. 5. Here the pheromone is in high concentration relative to that released by the calling female. The sensory system of the moth is working well, is not adapted or habituated, but because of the “fog” of pheromone the male cannot locate the female and thus no mating would occur.

**Sensory imbalance** – this mechanism is portrayed in Fig. 6. In most dispensing systems used in mating disruption the pheromone is the same as that released by the insect or is an active component of the insect’s pheromone blend. With sensory imbalance, a chemical is used that is close to the insect’s pheromone but is either not a part of the attractive blend or is a single component of the blend that alone is not normally active in attracting the insect. Here the idea is that the insect’s sensory system is somehow slightly altered so that its ability to detect the “true” pheromone is diminished or blocked.

It is likely that none of these mechanisms alone is responsible for success of mating disruption for any insect. Most likely all of these mechanisms operate to a greater or lesser degree in a mating disruption program against different insects or with different pheromone dispensing systems. That is, false trail following could be important for hand-applied dispensers at some distance and then habituation could come into play as the moth enters a zone of high pheromone concentration.

Does pheromone use actually lead to mating disruption? We know that mating occurs in orchards treated with pheromones even though we commonly refer to the use of pheromones as mating disruption. Many studies have presented information showing that there are high levels of mating (70-80%) in pheromone treated orchards and this level of mating is often not different from that observed in conventional orchards. However, in orchards using pheromones where codling moth densities are low the levels of mating do seem to be suppressed, only 30-35% mating.
So if mating is occurring in pheromone treated orchards why does it work to reduce codling moth populations and prevent fruit injury? All of the mechanisms described above offer an explanation of mating disruption that focuses on the interference of mate locating behavior. Research has shown that if mating of a moth is delayed then its ability to reproduce is diminished. Codling moths can mate the day they emerge or would normally mate within the first two days. If mating is delayed 4 or 6 days then the number of eggs laid can be reduced by 50% or more and the viability of those eggs, that is the number that will hatch, is also reduced. So **reduced fecundity and egg viability** is the result of **delayed mating** which is caused by pheromone treatments interfering with mate location. Therefore, even if mating is occurring in orchards treated with pheromones it can still result in pressure to reduce populations over time. When populations of codling moth are at low densities the dual effect of **reduced mating** and **delayed mating** can have a strong negative impact on the pest, resulting in good crop protection.

**Technologies to deliver pheromone:**

There are four ways to deliver pheromone for control of codling moth. These systems deliver pheromone in different rates of release from the dispensing apparatus and use a different number of point sources per area. The four categories are as follows:

- **Aerosol emitters (aka “puffers”)** – high release rate and few point sources per area.
- **Hand-applied dispensers** – moderate release rate and hundreds of point sources per area.
- **Fiber formulations** – low release rate and thousands of point sources per area.
- **Microencapsulated formulations** – very low release rate and millions of point sources per area.

**Hand-applied dispensers** are the most common methods of applying pheromones for codling moth control in Washington. The main types of dispensers used, Isomate-C Plus, Isomate CTT, NoMate CM and CheckMate CM XL1000, are shown in Fig. 7. All of these dispensers are placed by hand, sometimes using devices to get them into the tops of trees where they need to be placed to get the maximum effect. The pheromone is held in the matrix or some kind of reservoir and evaporates off the surface of the dispensers or through a membrane.

The amount of pheromone released over time can be estimated by analyzing the amount left in the dispensers at different times during the growing season following their placement. For the past two years we have placed different pheromone dispensers in the field and then collected them at different time intervals and analyzed the remaining pheromone. This work has been done at the Food and Environmental Quality Laboratory by the team headed by Dr. Vince Hebert. The dispensers were placed on trees much as a grower would place them and collected every 28 days (Wenatchee, Washington) or every 30 days (Medford, Oregon). Results in Figs. 8 and 9 show the amount of pheromone left in dispensers on different days after placement in the field, estimates of the release rate over the entire season, and the percentage of pheromone released from the dispensers over the summer at Wenatchee and Medford. In these figures the “Lab-Day 0” is an analysis made when the dispensers were first received from manufacturers by the laboratory but before they were placed in the field. The “Day 0” is the samples of dispensers collected on the day they were placed in the field, and subsequent days are the samples of dispensers collected from the field at respective times after placement.
The discussion below is an excerpt from a report on the field-aging study that can be found on the WSU-TFREC web site:

[http://entomology.tfrec.wsu.edu/jfbhome/reports.html](http://entomology.tfrec.wsu.edu/jfbhome/reports.html)

**Results:**

The average loading rate of all dispensers was within the limits indicated by the label for each product (see Lab-Day 0). A drop in codlemone (the main component of codling moth pheromone used in dispensers) levels was noted for all dispenser types on Day 0 for each location, that is, following the placement of the dispensers in the field. It is likely that this drop was due to the codlemone on the exterior of the dispensers volatilizing off after the container in which they were received was opened.

**Isomate-C Plus:** There was a gradual decline in the residual codlemone over the 140- or 150-day period in Wenatchee or Medford, respectively ([Figs. 8 and 9](http://entomology.tfrec.wsu.edu/jfbhome/reports.html)). This dispenser released an average of 75% (Wenatchee) or 96% (Medford) of codlemone over the duration of the test. The average estimated release rate in Wenatchee and Medford over a 140- or 150-day period was 0.7 or 0.9 mg per day, respectively. There was concern about the high variability of residual pheromone remaining in this dispenser on a couple of dates, especially from the Medford samples on days 30 and 60 and Wenatchee on day 84 ([Figs. 8 and 9](http://entomology.tfrec.wsu.edu/jfbhome/reports.html)). On these sample dates the analysis showed that one of the five dispensers sampled had a much lower than expected amount of residual pheromone. This was thought to be due to a compromise in the physical structure of the dispenser associated with twisting used to secure its placement on the tree. However, the dispensers from samples on these dates not yet analyzed were inspected under magnification and were not found to be physically damaged. The high variation in residual pheromone was not noted in 2001 tests; however, the dispensers were not twisted onto foliage in those tests but were hung on a piece of rope. For these reasons the estimated release rate of the Isomate-C Plus dispenser showed a high degree of variability from one period to the next.

**Isomate CTT:** There was a gradual decline in the residual codlemone over the 140- or 150-day period in Wenatchee or Medford, respectively ([Figs. 8 and 9](http://entomology.tfrec.wsu.edu/jfbhome/reports.html)). The average estimated release rate over the 140- or 150-day period in Wenatchee or Medford was 1.6 or 1.4 mg per day, respectively. This dispenser released an average of 81% (Wenatchee) or 77% (Medford) of codlemone over the duration of the test. There was a high degree of consistency of residual codlemone in these dispensers on any sample date over the entire test, and therefore an estimated release rate per day was fairly consistent for every evaluation period.

**NoMate CM:** There was a slow decline in the residual codlemone during the first 28 days at Wenatchee but not at Medford. From day 28 or 30 to day 112 or 120 there was a fairly rapid decline in residual pheromone ([Figs. 8 and 9](http://entomology.tfrec.wsu.edu/jfbhome/reports.html)). In the last 28- or 30-day period at both locations there was a small change in residual pheromone, suggesting a low release during this period. The average estimated release rate over the 140- or 150-day period in Wenatchee and Medford was 0.8 mg per day. This dispenser was efficient in release of codlemone with an average of 93% (Wenatchee) or 97% (Medford) of codlemone expended over the duration of the test. There was a high degree of consistency of residual codlemone in these dispensers on most sample dates except at the end of the test where codlemone content per dispenser was low.

**CheckMate CM:** There was a very gradual decline in the residual codlemone over the 140- or 150-day period in Wenatchee or Medford, respectively ([Figs. 8 and 9](http://entomology.tfrec.wsu.edu/jfbhome/reports.html)). The average estimated release rate over the 140- or 150-day period in Wenatchee or Medford was 0.7 or 1.2 mg per day, respectively. This dispenser released an average of 38% (Wenatchee) or 64% (Medford) of codlemone over the duration of the test. There was some variation from dispenser to dispenser in the residual codlemone
in these dispensers as they aged. This dispenser is not very efficient in releasing pheromone over the season, especially in the cooler area of Wenatchee, a behavior not observed in the similar kind of evaluation conducted in 2001.

Residual pheromone analysis does not indicate how efficacious a pheromone delivery system will be, but it does provide some indication of how the pheromone is being released over time, if it is lasting long enough for the conditions, and how efficient it is in releasing the pheromone load it contains. Most of the hand-applied dispensers released pheromone at a fairly constant rate over the growing season. The Isomate CTT dispenser showed the most consistent release and covered the period of codling moth activity (140-150 days). The Isomate-C Plus dispenser also released pheromone over the entire codling moth activity period, but some dispensers seemed to release too much pheromone and it was unclear how this could affect product performance since sample sizes were small. The CheckMate CM XL-1000 dispenser showed a slow release rate, especially in Wenatchee. This dispenser is designed to be used at a full rate of 200 per acre. It was expected that it would have a release profile similar to that of the Isomate CTT, which is also used at a full rate of 200 per acre, but its release rate was considerably less. The NoMate CM dispenser released all of its pheromone load but in a shorter interval than other dispensers. It had released essentially all of its pheromone by day 112 or 120 which may not be sufficient to cover the entire activity period of codling moth in some locations.

**Placement of pheromone dispensers**: Hand-applied pheromone dispensers should be placed in the upper canopy of the tree. The recommendation of many pheromone dispenser manufacturers is to place them in the upper third of the canopy but we suggest a different perspective. It is better to think of placing dispensers in the upper two feet of the tree canopy; in this way the dispensers are usually placed in the best position. Dispensers should be placed on a spur or stiff shoot of a limb that will not bend down once fruit load develops. It is also important to have a uniform distribution of dispensers throughout the orchard. It might be a good practice to place a few more dispensers on orchard borders, especially at the upper edges of slopes or where external pressures are anticipated. Do not place dispensers on trellis wire where they will be exposed to sunlight because this can heat up the dispensers and cause an abnormally quick release of pheromone.

**Aerosol emitters** – these dispensing systems, also known as “puffers” (Fig. 10a), release very high rates of pheromone from one site for every one or two acres. The advantage of this system is ease of putting up the dispensers since so few are required. The high release rate carries pheromone concentrations from an emitter and affects codling moth behavior over a considerable area. However, a disadvantage of this technique is that there is a lot of distance between dispensers, potentially allowing areas of low pheromone concentration where mating could occur. This is especially true on borders of orchards where aerosol emitters are used. Usually these orchards also use hand-applied dispensers on the borders to reduce the risk of codling moth damage in these areas. Another problem with aerosol emitters has been a failure rate of the individual units. Dr. Steve Welter (University of California, Berkeley) indicated that he experienced a failure rate of approximately 20% (batteries or valves sticking) in aerosol emitters he used in studies (personal communication). Dr. Alan Knight has reported that control in orchards treated with aerosol emitters plus border treatments with hand-applied dispensers has been equal to that in orchards treated with half rates of hand-applied dispensers.

**Microencapsulated formulations** – these formulations include microcapsules that contain pheromone (Fig. 10b). The pheromone is released over time from millions of capsules applied to the orchard. These formulations are easy to apply. They are placed in the spray tank and are compatible with most agricultural chemicals. The main concern about microencapsulated formulations is the amount of pheromone released over time and longevity of release. In addition, there are concerns with
rain fastness and the effects of over-tree sprinklers on retention of microcapsules in the canopy. Results with these sprayable formulations when used against codling moth have been variable. In low-pressure situations results with the Suterra formulation have been good, but when codling moth pressure increases supplemental controls are needed in addition to the sprayable pheromone. It might be better to think of using sprayable pheromones as an addition to an existing codling moth management program relying on insecticides.

What is the best way to use pheromones for codling moth control?

Several experiences over the past decade have pointed to an areawide approach as the best way to implement the use of pheromones for codling moth control. The advantage of treating a larger area is shown in Fig. 11. The larger the area the smaller the border area is relative to the interior. A known weakness of pheromone treatments is damage that occurs on orchard borders so by increasing the area treated the vulnerable area is diminished. This principle was put forth to the USDA as a proposal entitled the Codling Moth Areawide Management Project (CAMP) in the western U.S. The proposal funded five CAMP sites in three states (Washington-3, Oregon-1 and California-1) for a period of five years. Data from one of these sites, Howard Flat near Chelan, Washington, shows the effect of an areawide approach to pheromone treatments over time.

Howard Flat is a 1,200-acre area that has reasonable isolation from other growing areas around Lake Chelan. A total of 36 growers produced primarily apple, dominated by Red Delicious. Prior to the initiation of the CAMP project (1994) crop losses because of codling moth damage at Howard Flat averaged 0.9%, a high level for the Washington fruit industry, and the average number of insecticide applications directed at codling moth control was 2.7 per acre (Fig. 11 – yellow bars). After the first year of CAMP the average number of codling moth captured in traps was about 10 per year but the percentage of traps catching moths was still high, about 80%. The average percent crop loss declined to 0.55%, and average number of insecticides applied per acre was only 1.5. The trend of reduced moth activity, crop loss and insecticide applications continued into the second year (Fig. 11). During the last three years of CAMP at Howard Flat crop losses due to codling moth damage declined to between 0.01 and 0.03%. Only 10-20% of the traps captured even one moth all year long, and the average number of moths per trap was less than one. The number of insecticides applied for codling moth control in the last three years was between 0.7 and 0.5 per acre (Fig. 11). The most interesting thing about the Howard Flat CAMP site was that after two years of pheromone treatments supplemented by insecticides there was virtually no codling moth injury identified in the interior of the project area. This result held true for the last two years of the project even though growers reduced the number of pheromone dispensers from 400 per acre to around 250 per acre. Other CAMP sites in Washington, Oregon and California showed similar trends in reduced crop losses due to codling moth damage while reducing use of broad-spectrum insecticides.

Areawide projects do not have to be organized and run by government agencies or universities. All that is required to organize an areawide codling moth project is a few growers deciding to cooperate! We can help with the technical information necessary to run a successful program. Ted Alway published a guide to establishing an areawide codling moth management project that is on the same web site as this article. Areawide projects do not have to be as large as Howard Flat. Great benefit can be gained by a few growers organizing and coordinating efforts on as few as 300-400 acres.
Best management recommendations:

Based on our experiments and experience, what follows is the best approach to using pheromones for control of codling moth.

1. When starting out, use full rates (200-400 dispensers per acre). Reduce use of dispensers only after codling moth populations and damage have been reduced.
2. Take care to place the dispensers in the proper locations for optimum impact (upper two feet of the tree canopy).
3. Distribute the dispensers uniformly unless using aerosol emitter devices or MOPS.
4. Use pheromones on as large an area as possible. Avoid treating small irregular blocks unless they are part of a larger project (Fig. 12). It is better to cooperate with neighbors to establish an areawide project.
5. Supplement pheromone treatments with insecticides as needed based on monitoring information, especially against the first generation.
6. Establish a good monitoring program.
   - Use high-load type lures and possibly DA lures.
   - Decide on a standard trap type and stick with it.
   - Place traps in the upper canopy, not near a dispenser.
   - Use one trap every 2-3 acres unless experience allows you to reduce this density.

How do you know when to supplement pheromone treatments with insecticides?

Pheromone treatments to control codling moth should not be considered as a “stand-alone” approach. Pheromones can be the most important basis of a “soft” pest management program, but the supplemental use of insecticides for both codling moth control and control of other insects must be considered a part of that program. Knowing when to apply supplemental controls for codling moth should come from a carefully planned and executed monitoring program, something discussed in more detail in a companion article.

Based on codling moth pressure, you can plan on what pheromone rates to use (hand-applied dispensers) and what kind of supplemental insecticide program to anticipate. The guidelines shown in Figs. 13a and 13b are based on experience as a way of categorizing codling moth pressure in an orchard. Low pressure is defined as an orchard that had between 0.1 and 0.5% fruit injury (at harvest) when applying 1-2 insecticides. A moderate pressure situation is defined as an orchard that had fruit injury between 0.5 and 2.0% and achieved this with 2-4 insecticide applications. Any fruit injury over 2% regardless of the number of insecticides applied should be categorized as high pressure (Fig. 13a). The rates of pheromone to use in these various situations are shown in Fig. 13b. We have shown that reduced rates of pheromones are effective against low-pressure codling moth situations. Even in these situations, supplemental insecticides might be needed if monitoring shows more codling moth activity than expected. If codling moth pressure is moderate to high you should use full rates of hand-applied dispensers and plan to use supplemental insecticides.

SUMMARY

The key to a successful mating disruption program for codling moth lies in planning and knowing your situation. Below is a checklist of things that will lead to a successful program.

- Choose a pheromone product and rate that is right for your situation, that is pest pressure and duration of activity.
• Develop a plan of monitoring codling moth and stick to it. The more traps the better unless knowledge of your orchard allows you to use fewer traps. Include visual observations of fruit injury as part of any monitoring program.
• Develop plans to cooperate in an areawide mating disruption program. Growers in these programs do not have to use all the pheromone dispensers but should share information.
• Be prepared to use supplemental insecticides that fit your situation. Consider alternative products to those traditionally used if control has become more difficult and consider control of other pests in these plans.

Codling moth control is the key to a successful insect pest management program in Washington apple and pear orchards. Use of pheromones can form the basis for a long-term stable pest management program that relies less and less on broad-spectrum insecticides and aims at conserving beneficial insects. Our current research shows that most orchards can use pheromones in conjunction with newer and safer insecticides to manage apple and pear pests without increased costs to the grower (see Areawide II report - http://entomology.tfree.wsu.edu/stableipm/current.html ). Any pest management program will work better if you are willing to work with your neighbor and share information on pest development and densities and, most importantly, on using pheromones in an areawide approach.
Figure 5: Mechanism of mating disruption; Masking.

Figure 6: Mechanism of mating disruption; Sensory Imbalance.

Figure 7: Various hand-applied mating disruption dispensers.

Figure 8: Residual analysis of mating disruption dispensers, Wenatchee 2002.

Figure 9: Residual analysis of mating disruption dispensers, Medford 2002.

Figure 10: Alternative pheromone dispensing systems: Puffers (A) and Microencapsulated sprayables (B).
Figure 11: A successful case study of the “Areawide” concept to implementing mating disruption, Howard Flat, WA.

Figure 12: Choosing an appropriate site for implementing mating disruption.

Figure 13: Optimizing your potential for success: Plan on supplementing mating disruption with insecticides (A), Choose the appropriate rate of dispensers (B).