Codling Moth Management with New Insecticides

Mike Doerr and Jay Brunner
Washington State University
Tree Fruit Research and Extension Center
Wenatchee, WA

Codling moth (CM) is the "key" pest of pome fruit in Washington. Recently, CM densities have begun to increase in most growing areas of the state. A CM control program that is reliant on one tactic is inherently less stable than one using multiple tactics. This is especially true as increasing pest pressure threatens a grower's ability to produce a marketable crop. If a grower is using an insecticide-based program it is wise to consider using products with differing modes-of-action. If using mating disruption then supplemental insecticides should be applied when needed.

A continued reliance upon the organophosphate (OP) class of insecticides (e.g. Guthion or Imidan) as the primary chemical control tactic is becoming more difficult under the current regulatory environment. Past research has documented that CM have developed resistance to OPs, which threatens the excellent level of control growers have come to expect. It is likely, though not proven yet, that recent control problems with CM stem from increased levels of OP resistance. The registration of new insecticides with different modes-of-action and with high selectivity provide management options that can be used in conjunction with either an insecticide- or mating disruption-based CM management program. The knowledge level required to manage CM increases as growers move away from a strategy reliant only on OP sprays. A careful and thoughtful approach to incorporating new insecticides into the management program will ensure the best possible control of CM, improve control of some other pests, e.g. leafrollers, and conserve more natural enemies.

Bringing new insecticides to market: Although the Food Quality Protection Act of 1996 (FQPA) has resulted in restrictions on the use of OP insecticides in pome fruit production, it has allowed for expedited registration of new insecticides under the "reduced risk" and "OP alternative" programs. An unanticipated consequence of this action is that new insecticides often receive registration before researchers have had the opportunity to fully understand their role in the orchard environment. It is our hope that growers appreciate the measured steps researchers take before recommending a new insecticide for a specific pest.

Four methods are used to evaluate the potential of new insecticides:

- Laboratory bioassays
- Field-Aged bioassays
- Small-plot field trials
- Large-plot field trials

Laboratory bioassays: Using a variety of techniques (e.g. direct sprays, apple-dip or leaf-dip bioassays) the toxicity of candidate insecticides is evaluated in the laboratory. These bioassays provide a means of determining relative toxicity and whether further testing is warranted. Insecticide manufacturers have a general idea as to which group of insects are affected by their experimental product, but local researchers have the ability to test new insecticides against the pests common to a specific region. Laboratory bioassays can also be used to screen new insecticides against a variety of beneficial insects. Further, these bioassays form the basis of resistance monitoring. A concentration of an insecticide that kills 50% of the pest is called the LC_{50}. These LC_{50} values are determined for new insecticides using a susceptible laboratory maintained population and provide "base-line" data on the pest's susceptibility. This information can then be compared to LC_{50} values obtained from field-collected populations of the pest to see if resistance to the new insecticide is present or has changed over time. Any significant shift in toxicity noted in field-collected populations suggests that tolerance or resistance could limit the efficacy of a new insecticide in commercial orchards.

Field-aged bioassays: This technique involves spraying a candidate insecticide onto individual trees and then collecting and returning foliage or fruit to the laboratory at regular intervals to assess residual toxicity. Field-aged bioassays are used to identify the best rates and treatment intervals to use.

Small-plot field trials: Once a good idea of an insecticides rate range is determined from field-aged residue bioassays field-trails are initiated. In these trials the insecticide is applied to replicated, single-tree plots using a handgun sprayer. A relatively large and uniformly distributed pest population is needed for this type of trial. To maintain standardization among all treatments they are applied at full dilute rates to ensure excellent coverage of foliage and fruit. Thus, confounding factors of coverage or concentration are eliminated and the results tend to be consistent and repeatable. An effort is made to evaluate candidate insecticides in a number of different locations under a variety of pest pressures. This allows researchers to adjust rates and modify timing intervals gaining an understanding of how the insecticides perform in different situations. Small-plot field trials targeted for one pest allows a glimpse at the selectivity of the insecticide. It can take three years or more of testing before researchers are confident of recommending a use pattern that best fits the conditions and pest complexes of the region.

Large-plot field trials: Large-plot field trials are an important step in understanding how a new insecticide will fit into a pest management program. The small-plot trials can determine rate and interval information for a particular pest but are not robust in identifying other positive or negative effects on the orchard ecology. In these tests an insecticide is applied by an air-blast sprayer at rates and volumes used commercially. The effect of a new treatment program is then evaluated by carefully sampling all pest and beneficial arthropods. These trials are labor intensive and costly but reveal the full impact of a new insecticide implemented as a grower would. These kinds of trials need to be evaluated at the same location for more than one year to gain a true understanding of any long-term changes in orchard ecology.

A consequence of rule changes under FQPA is that pesticide companies no longer obtain Experimental Use Permits (EUP) to allow for large plot field testing prior to final registration. That is because they would have to give up a position in the EPA registration cue, replacing another insecticide they want registered, and the data required for an EUP is essentially the same as for full registration. The result has been to limit the ability of researcher to evaluate new insecticides using typical grower practices. Due to this limitation, the impact of a new insecticide is typically not fully understood at the time of registration. Therefore, large-plot field trials are generally conducted after an insecticide is registered delaying the optimized recommendations on how to use them coming from unbiased sources.

Alternative insecticides for CM: We would like to explore use patterns for a select number of insecticides that have the potential to be substitutes or supplements in insecticide-based or mating disruption control programs. By definition, the use of these products should be considered alternative or supplemental control measures within a pest management strategy targeting codling moth. A grower needs to utilize the specific modes-of-action of these products to help protect against high-risk situations. It is expected that a grower will select portions and/or combinations of the programs detailed below to establish a successful, site-specific, CM management program.

An educated approach to utilizing these insecticides requires an understanding of the targeted life-stage that is based on specific modes-of-action of these products. The insecticides that will be covered in this paper are:

- Horticultural oil
- Granulosis virus
- Entrust/Success
- Intrepid
- Assail

Horticultural oil: WSU-TFREC has conducted an extensive evaluation of the summer use of oil and has established that repeated applications of highly refined horticultural oils can be made safely under most circumstances. It is thought that the repeated use of oil during the summer has the potential to affect fruit quality and even tree vigor, but solid data demonstrating this under our conditions has yet to be fully documented. A grower must balance the use of oil for codling moth control with possibility of enhanced fruit maturity (mainly in pear), a greasy coating that may inhibit wax deposition, an increase in sunburn, and possible long-term horticultural effects.

The oil we have the most experience with is Orchex 796. This product forms the base for many oil products that are reformulated by agricultural chemical distributors. The life-stage targeted by oil is the egg and the mode-of-action is as an oxygen barrier, which suffocates the egg (Table 1). Oil is primarily effective when it is applied on top of eggs, thus any egg laying activity of adult moths after an oil application should be considered unaffected. Issues affecting the level of CM control are:

- Water volume/coverage
- Concentration of oil (v:v)
- Frequency of application
- Rate (gallons) of oil/acre

It is essential that the volume of water used assure complete coverage of the foliage and fruiting surfaces. However, too much water can result in oil running and pooling on foliage and fruit where it is concentrated during drying. It is under these conditions that fruit marking of foliage burn is most often observed. Laboratory and field trials have demonstrated a concentration-based effect with oil. While there is some effect of concentrations above 0.25%, the most consistent results have been noted with at least a 1% v:v concentration. Increasing rates above 1% can increase efficacy slightly but the risk of phytotoxicity on foliage or fruit also increases. Under high pressure, an increased frequency of applications is necessary to ensure that eggs deposited after one application do not hatch prior to the next spray. Water volume, concentration and frequency of application all affect the amount of oil/acre that is applied to trees. It is likely that the amount of oil/acre has the most influence on undesirable horticultural responses.

Granulosis virus: CM Granulosis virus occurs naturally. It is relatively easy to perpetuate in a colony but becomes considerably more difficult to formulate into an insecticide. Many virus products have been introduced into the marketplace, but the virulence (potency) of these products has varied. Quality control of the virus and its formulation by the manufacturer is critical. The best results can be expected from a product that has a proven history. Calliope of France produces Carpovirusine. We have experience with Carpovirusine that dates back to 1995, and this product has been used extensively in Europe since that time. This product is now available for use in North America. Other virus formulations that are also being introduced into the market place may have good qualities but unless we have tested them we cannot and will not recommend their use.

The target of CM granulosis virus is the neonate (newly hatched) larva. Active CM granulosis virus is very specific, affecting only CM, and it is highly lethal. Virus particles must be ingested prior to the larva entering the fruit to be effective and have the maximum crop protection value (Table 1). Granulosis viral DNA is released in the alkaline environment of the insect gut. The viral DNA attacks cells of the insect, thereby disrupting normal physiology. Infected CM larvae turn milky white prior to dying. Dead larvae appear to "melt", releasing an oozing substance that is full of virus particles. While mortality can occur rapidly in neonate larvae if enough virus particles are ingested it is often delayed and under high-pressure situations there is little reduction in fruit injury. The virus continues to work on CM larvae even after they enter the fruit or even if they complete development and move to a pupation site. The full effect of the virus is not noted until subsequent generations when the population does not increase as expected.

There are issues remaining to be investigated regarding the long-term effect of granulosis virus on the CM populations where delayed mortality and sublethal effects may be common. In addition, the natural persistence of the viral DNA in the CM population needs to be explored. Research on the use of Carpovirusine in Washington is limited and thus fine-tuning of rates and treatment intervals is still necessary. However, this product does offer the organic grower another tool in combating their more serious insect threat.

Entrust/Success: Growers have been using Success (spinosad) to successfully manage leafroller and Lacanobia fruitworm for several years. The use of Success against CM in conventional orchards has not been recommended, though we have known it has activity, in order to preserve its use for these other pests. An organic formulation with the same active ingredient as in Success, spinosad, has recently been registered and is marketed under the name Entrust. This opens the door to the possible use of spinosad against CM in organic orchards where there are few other alternatives.

The target of Entrust is the neonate larva. Entrust must be ingested to be effective, that is, prior to or as the larva enters a fruit (Table 1). Entrust is a nervous system toxicant acting at the synapse. All research on the efficacy of spinosad against CM has been done with the Success formulation. We will assume for sake of this discussion that the Entrust formulation will work similarly. Our research with Success shows that the residual activity is the limiting factor in CM control. Therefore, more frequent applications at lowered rates should enhance efficacy. We feel that control with Entrust will be improved if combined with an oil program that would utilize two modes of action attacking two life stages.

Intrepid: Intrepid (methoxyfenozide) is an insect growth regulator (IGR) that mimics a hormone specific to lepidopteran insects. This IGR is an insecticide that is very active against two life stages; against eggs as an ovicide and larvae as a larvicide (Table 1). A common term to describe this class of IGR is Molt Accelerating Compound. As this name suggests, ingestion of the chemical by larvae stimulates a molt. Since this hormone mimic is not perfect, the larva is not able to complete the molt and dies. The mode of action against the egg stage is not as well understood but it does stop the egg from developing completely.

The length of residual control of Intrepid appears to be longer than Success, thus treatment intervals of 14 days should be effective. Delayed mortality is not uncommon and neonate CM larvae may enter under the fruit skin before dying. If this occurs during the first generation the injury will likely scar-over and not result in a downgrading of the fruit at harvest. However, if populations are high in the second generation these “stings” may result in significant fruit injury. While “stings” might not be acceptable if populations of CM are too high they are not a true reflection of Intrepid’s effect on the population. The shallow stings produced by larvae that eventually die will does not mean that the orchard will have a serious carry over problem the following year.

Assail: Assail (acetamiprid) belongs to a new class of chemistry called chloronicotinyl. Assail has performed consistently and with a high degree of efficacy in several trials, and is the most active of the new insecticides now registered for CM control. The target of Assail is the neonate larva. Assail must be ingested prior to the larva entering a fruit (Table 1). Assail is a neuro-active insecticide that works at the synapse to paralyze an intoxicated insect.

The chloronicotinyls have been implicated in disruption of integrated mite control. The exact cause of mite flare-ups with this class of chemistry is not well understood, but as a precaution the manufacturer recommends the addition of 1% oil to an Assail spray to assist with spider mite suppression.

A review of the products available to manage CM (Table 1) shows that there are viable options to attack all life stages. It will be the proper combination of these insecticides with the old reliable tools of Guthion (azinphos-methyl) or Imidan (phosmet) and mating disruption that will be the key to a successful management of CM in 2003, even when faced with situations of high pressure.

Codling moth phenology: The insecticide alternatives to OPs described above have very specific modes of action, and vary in their residual activity. Thus a thorough understanding of the CM life cycle is necessary to accurately time their applications to assure control of the targeted life stage and eliminate waste.

The life cycle graphs presented below (Fig. 1) are developed from predictions generated by the widely used CM degree-day (DD) model. Model predictions are based on normal CM development and in no way replace a sound monitoring program.

Table 1. Summary of viable supplemental codling moth insecticides.

Insecticide	Target life stage	Mode of action
Orchex 796	Egg	Asphyxiation
Carpovirusine	Larva	Disrupt cell physiology
Entrust	Larva	Disrupt nerve transmission at the synapse
Intrepid	Egg Larva	Disrupt normal cell division Molt Accelerating Compound
Assail	Larva	Disrupt nerve transmission at the synapse

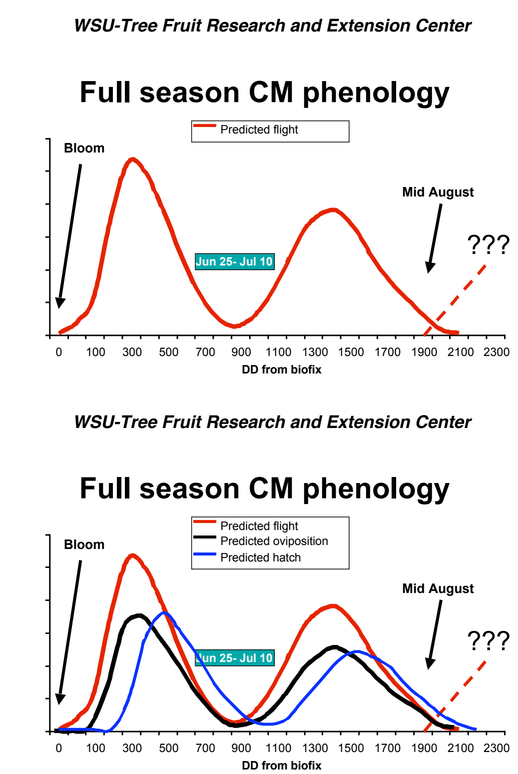

Figure 1: Codling moth model predictions for the adult flight (A), oviposition (B) and hatch (B).

The CM "season" begins with adult flight, which traditionally has occurred at the same time as full bloom in

Delicious apples. The flight lasts about 800 DD (Fig. 1A). The second flight begins at approximately 850 DD and ends near 2000 DD. CM responds to shortening day length, a signal to mature larvae to enter diapause. In our area this trigger occurs about August 15 each year. Only those larvae that pupate prior to mid-August will continue their development and emerge as a partial 3rd generation. The size of this 3rd generation is dependent on how quickly the first and second generations develop, or in other words how many DD are accumulated prior to mid-August. As we get closer to mid-August it is possible to estimate the amount of 3rd generation activity that might occur within a region. If a large 3rd generation is predicted and control of the proceeding generations was not good, growers will need to respond appropriately to protect their fruit.

CM females emerge slightly after the males (50 DD) and begin laying eggs around 70-80 DD. Eggs require approximately 150 DD to hatch. The predicted oviposition and hatch curves are offset from the male flight curve accordingly (Fig 1B). These predicted curves will be used to demonstrate appropriate use patterns for different insecticides in CM control.

Optimizing insecticide treatments
Horticultural oil: To review, oil is applied over the CM eggs to smother the developing embryo. In order to optimize use, oil sprays need to begin prior to egg hatch (230-250 DD) and repeated at regular intervals to cover the entire oviposition period. In a typical scenario the first spray is applied at 200 DD, and repeated at 400 and 600 DD (Fig. 2). These timings generally cover the majority (90%) of the first oviposition period. Abnormal moth activity, such as late flights in a generation, is not uncommon and would leave fruit unprotected using this protocol.

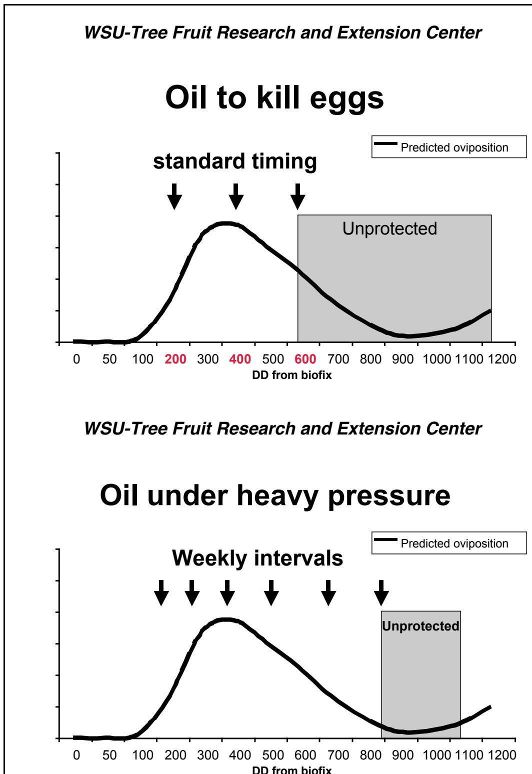

Figure 2: Timing of oil to control codling moth eggs during the 1st generation using the standard timing (A) or weekly under high pressure (B).

In orchards under high-pressure the frequency of applications must increase to maintain control of CM eggs and assure significant hatch doesn't occur in the interval between applications. The most aggressive program utilizes as many as 6 sprays during the 1st generation alone (Fig. 2B). Plotting these weekly applications on a DD scale shows that oil may be applied relatively more frequently earlier in the generation due to fewer DDs accumulated during the cooler days. This can be considered beneficial, though, as the majority of oviposition generally occurs during the early part of the generation. The more intensive oil program leaves a smaller portion of the period between generations unprotected.

Entrust: Entrust (Success) is a larvicide that must be ingested by young larvae prior to entering the fruit to be effective (Fig. 3). This product has not ovicidal activity. Entrust applications must be timed to coincide with egg hatch as the length of residual control is relatively short (10 to 14 days). The level of control expected from Entrust is modest and combining it with an oil program should maximize control and therefore fruit protection. The combination with an oil program enlists two different modes of action targeting two life-stages. The spray program detailed in Fig. 3 shows oil applied at one-week intervals (black arrows) with Entrust added combined with the oil every other week (red arrows) to cover the entire hatch period.

Codling moth granulosis virus: The same strategy used for controlling CM with Entrust could be used for the granulosis virus (Fig. 3). Young CM larvae must ingest virus prior to entering fruit to be effective. Granulosis virus is extremely toxic to CM, but larvae generally ingest only a small amount and it may take several days for viral DNA to replicate to the point that death occurs. Therefore, it is important to realize that injury in the form of "stings" will likely occur but that is not necessarily an accurate measure of the efficacy of granulosis virus. Often the full effect is not noted until the following generation. To maximize fruit protection granulosis virus should be combined with an oil program. Entrust and granulosis virus are best suited for organic orchards where other viable control alternatives are limited.

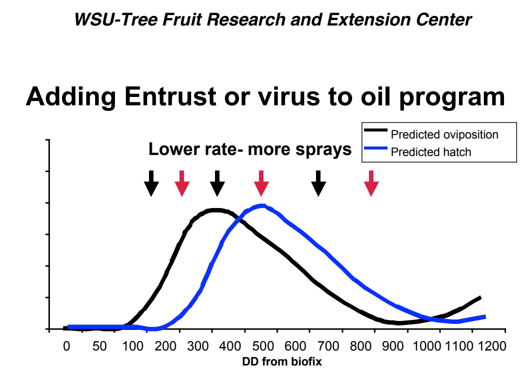

Figure 3: Adding Entrust or Granulosis virus to an oil program during the first generation. Red arrows designate a combination oil/Entrust (virus) spray.

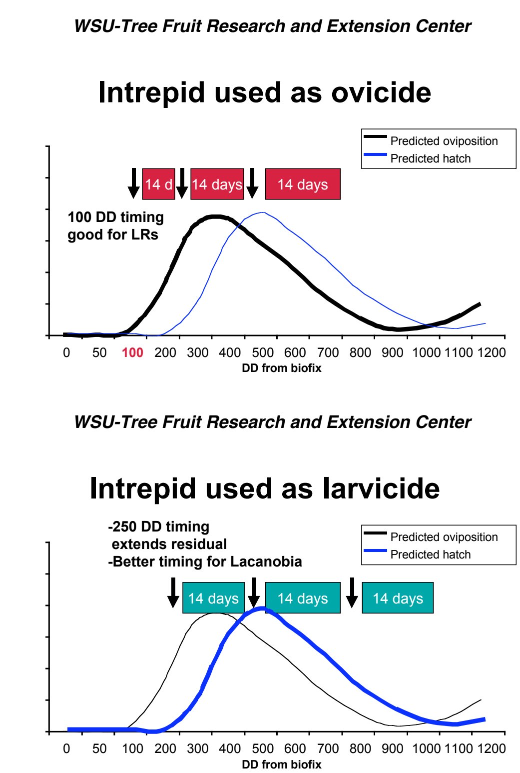

Figure 4: Two Intrepid programs starting at an ovicide timing, 100 DD (A) or larvicide timing, 250 DD (B).

Intrepid: Intrepid has a unique mode of action that makes it active against both eggs and larvae. Laboratory bioassays and field-trial data suggest that there is little difference between starting Intrepid sprays at the traditional ovicidal (50-100 DD) or larvicidal (250 DD) timings (Fig. 4).

The decision of how to incorporate Intrepid into a pest management program should be based on expected pressure from secondary pests. The 50-100 DD timing is right around the petal fall period, which is the optimal timing for spring leafroller control. Delaying the first application to 250 DD may be the best option if noctuid pests such as *Lacanobia subjuncta* or Bertha Armyworm are the main concern. In order to maximize fruit protection Intrepid should be sprayed at 14-day intervals.

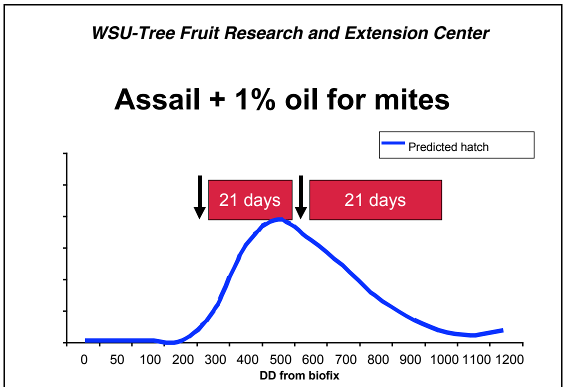

Figure 5: Timing Assail to control codling moth larvae of the 1st generation.

Assail: Assail is a larvicide that must be ingested prior to larvae entering the fruit to be effective. Of all the new chemistries Assail behaves most like the traditional CM insecticides (e.g. Guthion and Imidan). Assail is a fast acting insecticide with a relatively long residual period. An Assail use pattern will be very similar to a Guthion program (Fig. 5). The manufacturer of Assail recommends that its use be combined with 1% oil. The oil is added to suppress the resident mite population. Assail, as well as other chloronicotinyl insecticides has been implicated in causing increased spider mite densities. Therefore, the use of Assail should be limited to a role as one of different products used to control CM rather than a strict Guthion replacement.

Creative combinations employing different modes of action: IPM practitioners can use their creativity to optimize spray timings. Creating new spray programs requires a sound understanding of the CM lifecycle, insecticide mode of action, and a reliable monitoring program. The example detailed in Fig. 6 illustrates the use of a tank mix of Intrepid/Assail applied at 250 DD to control CM during the first generation. Assail residues will control hatching CM larvae for about 21 days (300-400 DD) after application. Which will cover most, ca. 70% of the predicted egg hatch period. Intrepid will suppress hatch of eggs deposited prior to application if coverage is sufficient. Further, it will kill CM eggs deposited on top of residues for 14 days (200-250 DD). These are eggs that would have started hatching at 450 DD or after most of the Assail residue had worn off. In addition the larvicidal activity of Intrepid residues will help with the control of larvae. This strategy manages the CM population with a single spray by combining the different modes of action. However, the orchard is susceptible to late activity so special care should be made to monitor during that time period.

Second Generation: Spray programs targeting the second CM generation must take into account a longer emergence pattern (Fig. 7). It is probably more important to monitor orchards in the second generation to see if the activity in the orchard is agreeing with the model predictions. Model predications are not as reliable for the second generation. Spray timings based on the CM degree-day model may be further confounded by the presence of a partial third generation. The size of this generation is variable and based on how quickly the first two generations develop.

Ovicidal sprays: The standard oil timing of 1200, 1400 and 1600 DD cover less than 70% of the oviposition period (Fig. 7A). This leaves a large portion of the 2nd generation, as well as any 3rd generation activity, uncontrolled.

Larvicidal sprays: The extended hatch period of the second generation challenges the residual limits of a two cover spray program (Fig. 7B). Assuming 21 days of residual control, this program covers most of the 2nd generation and the beginning of the 3rd generation. If 21 days of residual control cannot be expected, further control decisions must take into account relative CM pressure, as well as preharvest and re-entry intervals.

What level of control can be expected?
Codling moth has the capacity to increase population levels quickly in the absence of chemical control, even if we assume a very high level (80%) of natural mortality (Table 2). A CM management program needs to suppress the population by an additional 90% just to maintain the same number of CM. If a management program is not able to provide this level of suppression the population will grow exponentially. It is common for us to see the damage level of CM in our untreated plots increase from 0.5% at harvest the previous year, to between 5-10% after the first generation the next year and at harvest of that year fruit damage could easily be between 30-50%.

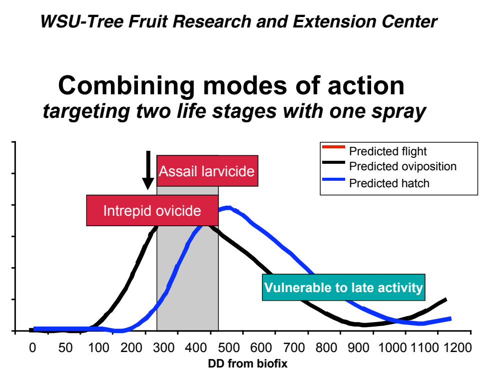

Figure 6: Employing different modes of action into one well-timed spray.

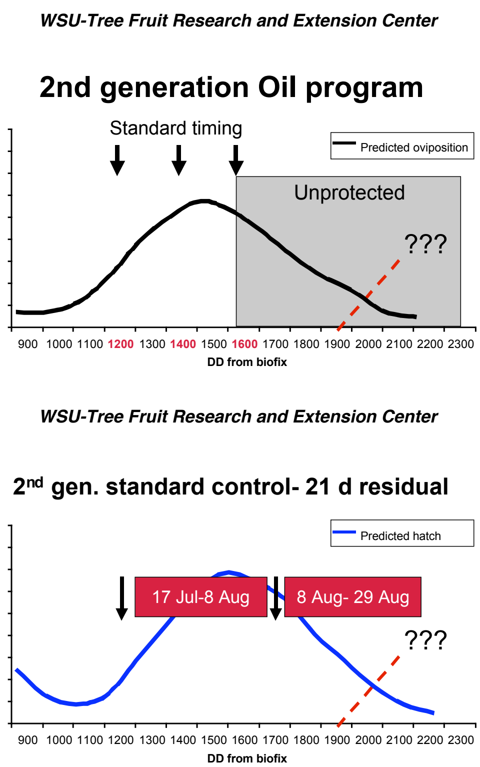

Figure 7: Spray programs targeting oviposition (A) and hatching larvae (B) during the 2nd CM generation.

Table 2: Exponential CM growth under a variety of insecticide control programs.

Year/ Generat^n	Total number of CM adults* (Control from IPM program) 0%	50%	75%	90%
2000-1st	1	1	1	1
2000-2nd	10	5	3	1
2001-1st	100	25	6	1
2001-2nd	1,000	125	16	1
2002-1st	10,000	625	40	1
2002-2nd	100,000	3,125	100	1
2003-1st	1 mil	15,625	250	1

* Assumptions: 100 eggs/female, 50% sex ratio, 80% natural mortality.

Mating disruption: It is difficult to assess the level of control that can be expected from mating disruption. The level of suppression is dependent on the population pressure within an orchard. As the pressure increases, the level of control can be expected to decrease. However, the use of mating disruption does provide some suppression even under high-pressure situations and that could be critical to the success of an insecticide-based program.

Organophosphates: Guthion remains the industry standard for CM control. This insecticide can be relied upon to consistently provide 95+% control of a <u>susceptible</u> population in a four cover spray program (Fig. 8). However, as CM populations develop higher tolerances to azinphos-methyl, the level of control will decrease and additional cover sprays or supplemental treatments will be needed.

Results from Imidan (phosmet) trials were more variable than with Guthion (Fig. 8). On average, Imidan resulted in control near the critical limit of 90%. However, the range of suppression dipped to a low of 75% in some tests. An insecticide program based solely on Imidan as a Guthion replacement would likely prove less stable in the long-term, especially if the CM population had already developed elevated tolerance for Guthion.

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What level of control can be expected?

Chemical	Rate/a	# Apps/gen	Level of control
Guthion	**2-3 lbs**	**2**	**32 trials**
			Range 85-100%
			Avg 94.8% (±0.1)
Imidan	**4.5 lbs**	**2**	**4 trials**
			Range 75-99%
			Avg 91.8%(±5.6)

Figure 8: Summaries of field trials using organophosphates to control codling moth in season-long trials.

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Softest organic products

Chemical	Rate/a	# Apps/gen	Level of control
Oil	**1%**	**3**	**9 trials**
			Range 32-76%
			Avg 52.9% (±5.7)
Carpovirusine	**900 ml**	**3**	**45.8%**
	450 ml	**3**	**50.0%**

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Spinosad (Entrust)

Chemical	Rate/a	# Apps/gen	Level of control
Success	**4 fl oz**	**6**	**78%**
	8 fl oz	**3**	**78%**
	8 fl oz	**6**	**98%**
	6 fl oz	**3**	**61, 61%**
Success +oil	**6 oz+1%**	**3**	**77, 78,88%**
		6	**100, 95%**

Figure 9: Summaries of field trials using organically derived products to control codling moth in season-long trials.

Organically derived products: The level of control that can be expected from the use of horticultural oil varies depending on the number of applications. The range of suppression observed in a 6-spray program is 32-76% with an average of about 50% (Fig. 9). This is a wide range of expected control and can be influenced by the amount of injury that develops in the second generation or from a late flight/3rd generation activity. Eggs laid after the last oil spray is applied are not affected.

Carpovirusine used in a 6-spray program has provided about 50% control with no difference in control noted at the rates tested (Fig. 9). These data suggest that the treatment interval may be more important than the rate. In other words, more frequent applications of the lower rate might be needed to further reduce CM injury. We have limited experience with this product though it does look to have some promise for our area.

Several tests with Success were conducted using different rates and combinations of oil (Fig. 9). A couple treatment programs show exceptional control of CM with Success. These were trials where Success was applied at weekly intervals for a total of 12 applications at 8 fl oz/acre, or 12 applications at 6 fl oz/acre in combination with oil. Both of these programs, if maintained for an entire season, would be above label rates for the active ingredient in the Entrust formulation. However, frequent applications at lower rates in combination with oil would provide effective control for a single generation. A grower must balance the need for more applications that use the season's allotment of Success/Entrust in one generation, or use the insecticide less frequently over the entire season.

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Intrepid and Assail

Chemical	Rate/a	# Apps/gen	Level of control
Intrepid	16 fl oz	3	73, 73, 78% Injured fruit
Assail	3.3 oz	2	12 trials Range 78-98% Avg 85.8 (±2.0)
Warrior	3.4 fl oz	3	90%

Figure 10: Summaries of field trials using Intrepid, Assail and Warrior to control codling moth in season-long trials.

Intrepid applied at 14-day intervals for a total of 6 applications consistently reduced fruit injury by 70-80% (Fig. 10). It is not uncommon for larvae that ingest Intrepid to enter the fruit and die sometime later. If larvae were dissected out of the fruit and survival was assessed, the actual impact on the CM population may be somewhat greater. The level of CM control from Intrepid was statistically the same when used as an ovicide or as a larvicide.

Assail performs consistently well when used in a four cover spray program (Fig. 10). The range of control and performance of Assail is similar to what would be expected with Imidan. It is not likely that a CM management program would be based only on Assail for reasons detailed above, but certainly it could be used to replace a specific OP spray without any notable loss in efficacy.

The synthetic pyrethroid, Warrior performed well when applied at 14-day intervals for a total of 6 applications (Fig. 10). However, the use of this product is not encouraged except in specific emergency situations as pyrethroids have historically been implicated with disruption of integrated mite control.

Possible causes of failure

Gaps in residual control: The level of control observed by a control program can fall short of expectations for many reasons (Fig 11). Shortened residual control due to poor coverage or insecticide resistance can leave gaps in the program. If the gap in control occurs after the first cover spray (Fig. 11A) as much as 25% of the population could hatch and be left uncontrolled in a one-week period. If the second cover spray provides only 14 days of residual activity another 10% of the population could potentially be left uncontrolled.

The data presented in Table 3 shows that regardless of the chemistry and mode of action, initial activity of an insecticide is high when coverage is not ideal, but residual control is reduced. While these data are from a leafroller test the concepts of coverage versus efficacy are important for CM as well. It should be noted that all of the insecticides presented in Table 3 need to be ingested to be effective.

An initial sign that a population is developing resistance is shortened residual control from a particular insecticide. It is reasonable to assume that many CM populations in Washington have some level of tolerance to azinphos-methyl, thus a full 21 days of residual control may not be realistic. Unfortunately, the actual amount of residual control from azinphos-methyl is difficult to assess on an orchard-by-orchard basis.

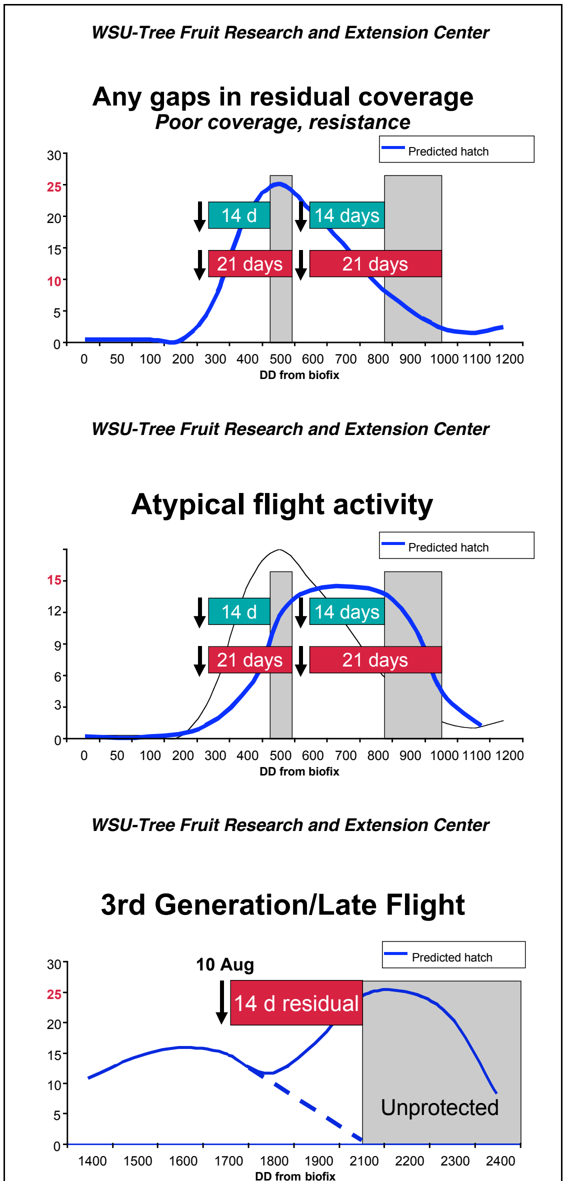

Figure 11: Possible sources of error due to gaps in residual control (A), atypical phenology (B) and 3rd generation (C). Expected control shown in red bars and observed control shown in green (A, B only).

Atypical phenology: It is not uncommon to observe CM population development that varies from model predictions (Figs. 11B-C). Developmental models are mathematical explanations of normal or average development. There are many reasons that what really happens can vary from model predictions, for example:

- Immigration from an outside source (dirty neighbor)
- Introducing individuals into an orchard that are not developmentally in-sync with natives (e.g. bin piles)
- The more generations that occur in a season the less precise models work (e.g. 3^{rd} CM generation)
- Insecticide use eliminates the earliest emerging individuals thereby selecting for a late emerging population
- Choosing a mating disruption product that stops releasing pheromone before second generation is completed

Any combination of the events listed above can result in a change to a management program that was planned around timing sprays with a model. Any period of observed adult activity should be treated as "real" and managed appropriately.

Atypical flights can constitute the largest percentage of observed captures in some orchards and thus have the potential to cause the most injury. The sources of error associated with residual control and unexpected adult activity can all lead to variable control results, especially if a grower depends on a single control tactic. The most stable CM management program is one based on a control strategy that will maintain populations at low levels using a variety of tactics targeting as many life stages as possible. A sound monitoring program is crucial if an IPM practitioner is to fully utilize the available tools.

Table 3: Residual control of leafroller by various insecticides in a leaf-disk bioassay, 1999.

Insecticide	Canopy Location	Mortality- Days after trt		
		7 d	14 d	21 d
Success	Periphery	100	95	100
	Interior	100	95	80
B.t.	Periphery	88	66	50
	Interior	71	41	34
Confirm	Periphery	98	97	96
	Interior	100	100	75

B.t., *Bacillus thuringiensis*, organically registered bacterial stomach poison.
Confirm, growth regulator analog to Intrepid.