Codling Moth and Leafroller Control with New Insecticide Chemistry

Jay F. Brunner
Washington State University
Tree Fruit Research and Extension Center

The codling moth, *Cydia pomonella* L., is the "key" pest of pome fruit in Washington. An average of nearly 3.5 applications of insecticides is applied per acre each year to manage codling moth. This means that some orchards are using 4 or 5 or more insecticide applications to keep this pest under control. At the same time growers and crop consultants report that fruit damage by codling moth has been increasing. The introduction of codling moth mating disruption has resulted in about 15% of Washington's apple acreage using this selective product, resulting in reduced sprays of broad-spectrum insecticides to control this pest. Often, however, supplemental cover sprays are required in mating disrupted orchards because codling moth densities are too high for pheromones alone to provide adequate control. Currently, broad-spectrum insecticides are the growers' only alternative to supplement codling moth mating disruption. These broad-spectrum insecticides, primarily Guthion and Imidan, have negative impacts on some natural enemies present in orchards. The development of new insecticides with different modes-of-action and with high selectivity promises to provide chemical control tools that can be used in conjunction with mating disruption, or as "stand alone" products, to control codling moth and retain full activity of natural controls.

Leafrollers are the second most important pest of apple in Washington and in some regions exceed codling moth as the "key pest" in orchards. Two leafroller species are important in commercial fruit orchards in eastern Washington, the pandemis leafroller (PLR), *Pandemis pyrusana* Kearfott, and obliquebanded leafroller (OBLR), *Choristoneura rosaceana* (Harris). The life history and identification of leafrollers are given in the book *Orchard pest management: a resource book for the Pacific Northwest,* published by the Good Fruit Grower. Pheromones for each species can be used to monitor their seasonal activity and assist in the timing of summer control applications.

There are two generations of PLR and OBLR per growing season. Both species of leafroller overwinter as young larvae in hibernacula in crevices of bark or pruning cuts on the tree. By half-inch green tip (HIG) most larvae of PLR have left their hibernacula and can be found feeding in buds. The emergence from the overwintering hibernaculum appears to be more extended in the OBLR because older and younger larvae may be found together during bloom. Moth flight varies from year to year and may differ slightly between PLR and OBLR. In general, first moths are detected in late May or early June, with peak flight between June 15 and 25. The start of the second generation flight is often difficult to determine. In most years there is not a clean break in moth activity between the flight of moths of the overwintering generation (May-June) and those of the summer generation (July-September). The beginning of the second flight typically occurs in late July with the peak of moth activity about three weeks later.

Egg hatch of the summer generation begins three to four weeks after the beginning of the moth flight and extends for a period of three to four weeks, longer in cool summers. There are degree day (°D) models for both leafroller species that can help to time treatments against the summer generation. Models for each species use slightly different lower thresholds, 41°F for PLR and 43°F for OBLR. Following Biofix, or the capture of first moths of the overwintering generation in pheromone traps, egg hatch for each species begins after an accumulation of about 400°D. Egg hatch of the overwintering generation begins about mid-August and can extend through much of September, typically beginning about three weeks after the start of the second moth flight. It is difficult to apply controls against leafroller larvae at this time because of the nearness of harvest and because it is often impossible to drive spray equipment through the orchards.

Lorsban continues to provide the best control of overwintering leafroller larvae compared to other registered alternatives, with the possible exception of synthetic pyrethroids, e.g., Asana, which are not recommended because their use can result in mite outbreaks. The level of control with Lorsban has diminished markedly in some orchards since the early 1980s. For example, in the early 1980s when Lorsban was first recommended for leafroller control, the average percent suppression in field tests was nearly 96%. In the period from 1985 to 1990 the average percent control of leafrollers with Lorsban was only about 80%. In recent field tests, control was only about 70% or less. While these data do not prove that leafrollers have developed resistance to Lorsban, they certainly add to the anecdotal data suggesting that this product is not providing the same level of control experienced when first introduced. Penncap-M (encapsulated methyl-parathion), which has been relied upon as a summer control of leafroller populations, has not provided acceptable suppression in many orchards in the past three years. Where this has occurred, consultants should avoid recommending this product. A list of registered insecticides that are not effective for controlling leafrollers is given in Table 1.

Table 1. Insecticides that provide good or poor leafroller control.

Good control		Poor or no control	
Lorsban[2]	Confirm[3]	Guthion	Diazinon
Penncap-M[2]	Comply[3]	Imidan	Dimethoate
Asana[1]	Success[3]	Thiodan	Vydate[1]
Lannate (methomyl)[1]		Sevin[1]	Supracide
Bt products		Agri-Mek	

[1] Use of this product may result in increased mite problems.

[2] Leafroller populations in some orchards resistant or highly tolerant, control questionable.

[3] New insecticides not yet registered for use on apple.

Bts and leafroller control: The softest leafroller control programs relied upon an application of Lorsban in the delayed-dormant period followed by bacterial insecticides (Bt products) applied from pink through petal fall and again in summer when needed. Bt products are stomach poisons and, as such, are highly sensitive to variations in weather and spray coverage (concentrate sprays are a good method of application if foliage is well covered). Bt products have short residual activity, lasting only about 7 days in the spring and even a shorter time in the summer. Figure 1 gives data on the residual activity of Dipel 2X following application in the spring and summer. There were significant declines in leafroller mortality after only 4 days in summer, while mortality in this test remained relatively high through 8 days in the spring. These data are typical of the residual activity of most Bt products. There has been little difference observed in the ability of different Bt products to control leafrollers. Most experience has been gained with Dipel 2X and Javelin, but other products used in appropriate concentrations have provided adequate suppression of leafrollers. Generally, leafroller population suppression with Bt products requires more than one application to achieve desired results (Table 2).

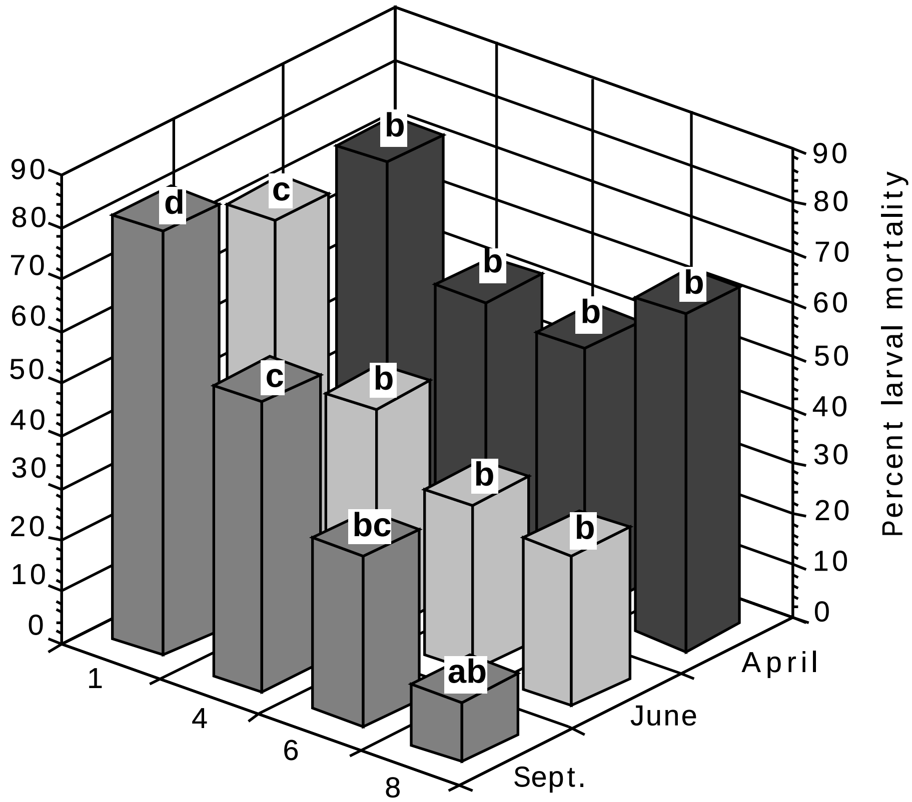


Figure 1. Percent mortality of pandemis leafroller larvae exposed for seven days to aged residues of Dipel applied to apple trees at different times during the growing season, 1994.

Table 2. Control of pandemis leafroller larvae with Bt products and conventional insecticides in the spring of 1993.

Material and form.	Rate form./ 100 gal	Treatment date	Plant growth[1] stage	Larvae per 20 buds/tree 19 Apr	Larvae per tree 17 May
Dipel 2X	4 oz	5/5, 5/10	P, FB	7.2	0.4ab
Dipel 2X	4 oz	5/5, 5/10	P, FB	8.7	0.8ab
Coax	1 qt				
Dipel 2X	6 oz	5/5, 5/10	P, FB	6.2	0.1a
Javelin WG	4 oz	5/5, 5/10	P, FB	7.3	0.6ab
Biobit	4 oz	5/5, 5/10	P, FB	7.7	0.5ab
Lepid Bt	22 ml	5/5, 5/10	P, FB	8.5	1.2abc
Lorsban 4E	1 pt	4/19	HIG	6.3	2.2c
methyl-parathion 4E	1 pt	4/19	HIG	5.9	1.5bc
Untreated	-----	--------	-----	7.1	11.7d

Means in the same column without letters or followed by the same letter are not significantly different, p=0.05 (SNK).

[1] Plant growth stage: HIG=half-inch green tip, P=pink, FB=full bloom.

The potential to enhance Bt product efficacy against leafroller by adding a “feeding stimulant” to the spray mixture was investigated in the laboratory and field. In the laboratory the feeding stimulant Coax® was tested to determine if any increase in mortality could be observed when it was mixed with a Bt product. The test consisted of dipping leaves in a solution containing a Bt product diluted to the recommended field rate or a solution containing a Bt product plus Coax. In most tests the addition of Coax increased leafroller larval mortality, suggesting it might also provided better control of leafrollers in the field (Table 3). In field trials, however, results of adding Coax to Bt products have produced highly variable results so specific recommendations on adding Coax to Bt treatments have not been made.

Table 3. Percent mortality of pandemis leafroller larvae exposed to Bt product s with or without the addition of the feeding stimulant Coax®.

		Average percent mortality[1]			
Treatment	Rate/acre (400 gal)	Test 1	Test 2	Test 3	Test 4
Dipel	1 lb	60b	70b	36c	48b
Dipel+Coax	1 lb+ 1 gal	82a	48c	64b	64a
Javelin	1 lb	62b	90a	94a	---
Javelin+Coax	1 lb+ 1 gal	88a	94a	78ab	---
Untreated	--------	12c	6d	10d	20c

[1] Means in the same column followed by the same letter are not significantly different (p=0.05, Fisher's protected LSD).

In the spring, applications need to be applied when daily maximum temperatures are at or above 65°F for at least 3 days. This ensures that larvae are actively feeding and therefore consuming toxic doses of the product. One negative side effect of using Bt products noted in recent years has been that some larvae surviving exposure to Bt products have a delayed development and thus produce moths and larvae of the next generation out of sequence with the “normal” or “expected” time. This may make the leafroller degree day models of little use in timing summer control sprays. Dr. Alan Knight (USDA-ARS, Wapato) has conducted research into the delayed development of leafrollers exposed to Bt products and suggests that a delayed development of the summer generation of about 7 days can be expected with each Bt application made in the spring. Continued use of Bt products is recommended as a means to keep leafroller control programs “soft” and to reduce overuse of Lorsban or new insecticides in a resistance management program.

New insecticide chemistry for leafroller control

The Food Quality Protection Act of 1996 (FQPA-96) will affect the availability of chemical control tools used for codling moth and leafroller control in tree fruits for nearly 30 years. This will likely occur within the next three to five years. How FQPA-96 will specifically affect different insecticides is unknown, and speculation could take up hours of fruitless discussion. However, there is hope in the form of some new (novel) insecticide chemistries that are reviewed in this article. Three new insecticides, Confirm, Comply and Success, show promise as controls for leafrollers and codling moth, and registration is anticipated within the next one to three years.

CONFIRM® (tebufenozide, Rohm and Haas) is a new chemistry that stimulates a premature molt in the larvae of Lepidoptera. CONFIRM binds to the ecdysteroid receptor in Lepidoptera almost exclusively. Because it is a novel chemistry it should be effective against insect species that have developed resistance to traditional insecticides (Fig. 2).

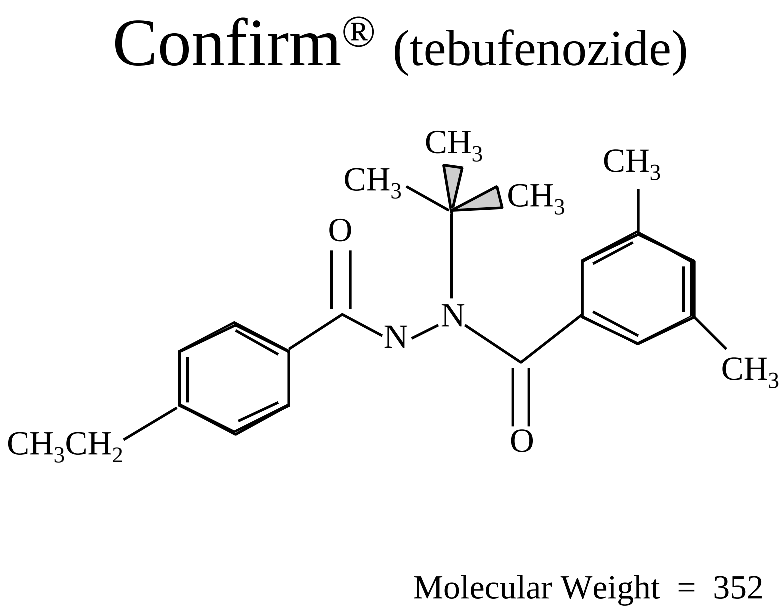


Figure 2. Chemical structure of tebufenozide (Confirm®, Rohm and Haas).

The molt that is initiated by CONFIRM® is not completed, and the larva becomes trapped within its old skin, is unable to feed and eventually dies. Death is often slow, and there is some indication that sublethal doses that allow larvae to survive result in adults that are not able to reproduce. In addition, it has been shown that for some insects exposure of adults to residues of CONFIRM can result in reduced fecundity or egg viability.

The targeted stage against codling moth for CONFIRM is the newly hatched larva. The timing is the same as that traditionally used for Guthion or Imidan, i.e. at 250°D following BIOFIX (first moth capture in pheromone traps in the spring), and the treatment is repeated at about 21 days following the first spray to cover the entire first generation hatch. In a timing study conducted in 1996, the traditional first cover timing used for Guthion or Imidan seemed to work best for CONFIRM (Table 4). This test was conducted in an orchard where codling moth densities were extremely high, and CONFIRM does not perform as well as more traditional products under high pressure situations.

Table 4. Control of codling moth with CONFIRM at different degree day timings for the first cover spray, 1996.

		Timing		% Injured fruit	
Treatment	Rate/100	Degree days	Dates	7 Jun	4 Jul
Confirm 70 WP + Latron B-1956	48 g 0.06%	100°D, 550°D	11 May, 9 Jun	12.0a	31.2a-c
Confirm 70 WP + Latron B-1956	48 g 0.06%	200°D, 550°D	18 May, 9 Jun	12.0a	25.6ab
Confirm 70 WP + Latron B-1956	48 g 0.06%	250°D, 550°D	19 May, 9 Jun	17.6a	21.6a
Confirm 70 WP + Latron B-1956	48 g 0.06%	300°D, 550°D	22 May, 9 Jun	16.8a	39.6bc
Confirm 70 WP + Latron B-1956	48 g 0.06%	400°D, 550°D	31 May, 9 Jun	44.0b	44.4c
Untreated	None			56.0b	63.2d

Means in the same column followed by the same letter not significantly different (p=0.05, Fisher's Protected LSD).

The size and structure of the CONFIRM molecule (Fig. 2) make it difficult for it to move readily through the insect skin and therefore it must be consumed to have activity. This means that spray coverage with CONFIRM on the target site, the fruit, is crucial to efficacy. A uniform distribution of a CONFIRM residue is probably the best way to ensure maximum codling moth control. Dilute spray volumes are recommended, and the addition of a surfactant that will evenly distribute the product over the plant is the best strategy to gain the greatest effect. Several years of experience with CONFIRM against codling moth suggest that it should not be rated as a "superior" product for controlling this pest. Factors reducing its effect are the uniform distribution of residues, that is spray coverage, and timing. Because only the first stage larva is controlled, residues must be in a place where the larva will eat a toxic dose.

In a study where CONFIRM was used in a Delicious orchard as the sole control for codling moth, suppression was never as good numerically as the conventional program; however, in one of three years, crop loss was statistically the same as the untreated control (Table 5). It must be recognized that in this test CONFIRM residues were put to a severe test because the adjacent untreated plot had an extremely high codling moth population.

Table 5. Codling moth and leafroller control with CONFIRM over a three-year period compared to a "standard" control program and an untreated check.

	Percent fruit injury at harvest					
	Codling moth			Leafroller		
Treatment	1995	1996	1997	1995	1996	1997
CONFIRM	4.3b	1.5a	13.1a	2.6b	1.0a	1.4a
Standard	1.0a	0.3a	5.6a	0.3a	0.1a	0.2a
Untreated	73.9c	58.6b	87.8b	8.8c	13.2b	6.1b

Means in the same column followed by the same letter not significantly different (p=0.05, Fisher's Protected LSD).

In a study where apples were produced without the use of neuroactive insecticides CONFIRM became a critical tactic used to protect the crop from both codling moth and leafrollers. In the first year of the project, mating disruption was the primary control used for codling moth and it was supplemented by oil sprays where populations were too high for codling moth alone. Leafrollers were controlled primarily with Bt products. At four sites after the first year of the study, codling moth or leafroller populations had reached levels where it was feared that the ability of available tactics to provide control in the second year would not be adequate to protect the crop. CONFIRM was made available as a fresh-fruit EUP in 1996 on limited acres and used at these four sites because it had no neuroactivity associated with its mode-of-action. Results of codling moth and leafroller control from the first two years of this study are summarized in Table 6. At sites B1 and W2 codling moth damage at harvest in 1995 was too high to expect mating disruption and available supplemental controls to provide crop protection in 1996. Similarly, at sites W2, Y1 and D1, leafroller damage to fruit was high and there was concern that Bt products alone would not provide adequate crop protection in 1996. With the use of CONFIRM codling moth and leafroller populations were controlled in 1996, with the exception of site W2 where a spray was missed and where damage was all located at the top of a slope where mating disruption had least effect on codling moth. In 1997 (data not shown) CONFIRM was again used to supplement codling moth mating disruption and to control leafrollers. This combination of tactics provided excellent protection of the crop at all locations.

Table 6. Codling moth and leafroller damage in orchards treated with a standard pest control program and one combining Isomate C^+ with CONFIRM at four different sites.

	Percent damage by CM			Percent damage by LR		
Treatment	1995	1996	1997	1995	1996	1997
Isomate C^+/CONFIRM Program						
B1	4.1	0.2		1.0	0.0	
W2	3.5	5.1		1.8	0.1	
Y1	0.1	0.2		1.3	0.24	
D1	0.0	0.0		8.9	0.4	
Standard Program[1]						
B1	1.7	0.0		0.0	0.0	
W2	1.8	0.9		0.1	0.0	
Y1	0.3	0.4		0.3	0.1	
D1	0.0	0.0		1.2	0.1	

[1] The standard program consisted of 3 to 5 OP sprays during summer.

A fresh fruit-only experimental use permit (EUP) has allowed the testing of CONFIRM on 50 to 100 acres of apple in Washington in 1996 and 1997. It is expected that the fresh fruit EUP will be available again in 1998. Full registration of CONFIRM is anticipated for 1999.

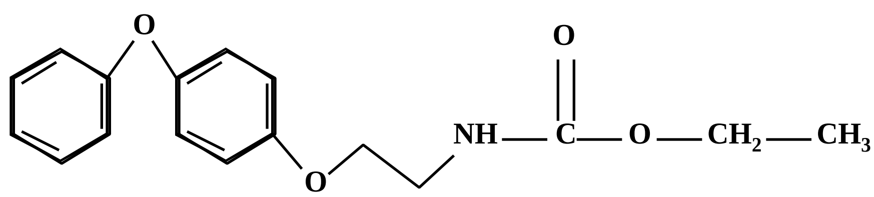
CONFIRM is highly selective, acting only on larvae of moths, and thus is safe to bees, predator and parasitic insects, and mammals. In the figure below, the relative toxicity of CONFIRM and Guthion against mammals (rats), birds, fish and bees is shown. CONFIRM is essentially nontoxic to all these organisms. This should make CONFIRM an ideal tool to use in IPM systems as a highly selective control against Lepidoptera while preserving natural enemies.

Ecotoxicology Comparisons

Organism - Test	Guthion®	Confirm®
Rat - Acute oral	**Highly toxic**	**Non-toxic**
LD50	**4.4 mg/kg**	**>5000 mg/kg**
Rat - Acute dermal	**Highly toxic**	**Non-toxic**
LD50	**88 mg/kg**	**>5000 mg/kg**
Quail - oral toxicity	**Highly toxic**	**Non-toxic**
LD50	**32.2 mg/kg**	**>2150 mg/kg**
Duck - dietary tox.	**Slightly toxic**	**Non-toxic**
LC50	**1940 mg/kg**	**>5000 mg/kg**
Rainbow Trout	**Highly toxic**	**Slightly toxic**
LC50-96h	**0.003 mg/L**	**5.7 mg/L**
Honeybee	**Highly toxic**	**Non-toxic**
LD50	**???? mg/bee**	**>234 mg/bee**

COMPLY (fenoxycarb, Novartis) has been used for several years in pear for psylla control under an emergency exemption (Section-18) to control pear psylla. The chemical structure of COMPLY is shown in Fig. 3. This chemical is classified as a carbamate insecticide although it does not act anything like a carbamate. Carbamate insecticides are nerve toxins that block the transmission of nerve impulses at the synapse, the junctions between nerves, in a manner very similar to the action of organophosphate insecticides. While COMPLY looks like a carbamate, it acts as an insect growth regulator. In fact it mimics the action of the insect's juvenile hormone. In the normal process of insect development, juvenile hormone is at a high concentration in the younger life stages and declines in concentration as the insect matures; that is, the juvenilizing effect of the hormone becomes less, allowing mature structures to be expressed. When COMPLY is introduced at a time in the insect's life cycle when juvenile hormone is supposed to be low it causes abnormal development to occur, and usually this results in the insect's death.

Comply® (fenoxycarb)



ethyl [2-(*p*-phenoxyphenoxy)ethyl] carbamate

Molecular Weight = 301

Figure 3. Chemical structure of fenoxycarb (COMPLY®, Novartis).

COMPLY is another large molecule and thus is most effective when consumed by the insect. It has little or no contact activity. The exception to this is activity COMPLY has on insect eggs. COMPLY kills the eggs of codling moth and leafminer though it has not been shown to be toxic to leafroller eggs. COMPLY disrupts the normal embryonic development of codling moth and leafminer eggs and is most effective when the eggs are deposited on top of the residue so it important to have control sprays in place prior to egg laying. Several studies have been conducted testing the efficacy of COMPLY against codling moth. Table 7 shows data from one such test. Note that the COMPLY treatments were applied early, at petal fall, just as codling moth were beginning to lay eggs, and treatments were repeated in 21 days to provide coverage of the entire oviposition period. The recommended timing of the first codling moth spray with COMPLY is between 75-100°D. Fruit damage in this test was high, owing to the extreme pressure of the pest population, and still COMPLY provided control similar to Guthion even at low rates. While this test was carried out for the entire season, COMPLY use will be restricted to the early spring so the opportunity to use it against the second codling moth generation will not exist.

Table 7. Control of codling moth with COMPLY and Guthion, 1995.

		Application		Avg. percent injury CM	
Treatment	Rate/100	Dates	Timings[1]	1st gen.	2nd gen.
Comply 25 WP	0.75 oz	10, 31 May; 5, 25 Jul	100˚D+21d; 1000˚D+21d	6.4ab	59.0bc
Comply 25 WP	1.0 oz	10, 31 May; 5, 25 Jul	100˚D+21d; 1000˚D+21d	8.0ab	47.6ab
Comply 25 WP	1.5 oz	10, 31 May; 5, 25 Jul	100˚D+21d; 1000˚D+21d	4.8ab	44.2a
Guthion 50 WP	227 g	19 May, 9 Jun; 18 Jul, 8 Aug	250˚D+21d; 1250˚D+21d	1.6a	36.8a
Untreated	None			32.8c	95.8e

[1] ˚D = accumulated degree days after first moth capture in pheromone trap (biofix), calculated from daily maximum and minimum temperatures using the method described by Baskerville and Emin (Ecol. 50: 514-516, 1969). Means in the same column followed by the same letter not significantly different (p=0.05, Fisher's Protected LSD).

The stage of leafroller controlled by COMPLY is the last larval instar. Younger leafroller larvae are not affected by the consumption of COMPLY. Targeting the last larval instar of leafrollers means that COMPLY treatments should be applied at petal fall and possibly repeated in 14 to 21 days to cover the entire development of leafroller larvae in the spring. It will be important to not delay COMPLY treatment too long because leafroller larvae stop feeding and pupae are not affected by COMPLY near the time when they pupate. Table 8 shows results from a test conducted in 1990 where COMPLY was applied to control the overwintering stage of PLR in a nonbearing orchard. In this test both rates of COMPLY were similar in their control. Table 9 shows results of a similar test conducted against OBLR larvae. In this test control was better than Lorsban against a very high leafroller population. Note that efficacy in both of these tests was evaluated by counting the number of leafrollers in the summer generation, that is, in the generation following the one actually treated. This is often the means used to evaluate products like COMPLY since their mode-of-action results in a slow death of the target stage and it is difficult to assess effects on the generation that is actually treated.

Table 8. Control of PLR overwintering larvae with COMPLY near Pasco, WA in 1990.

Treatment	Rate (lbs AI/A)	Timing: Stage	Timing: Date	Larvae per tree (June 27)
Comply 25 WP	0.094	PF; PF + 14 d	Apr 24, May 7	0.04
Comply 25 WP	0.125	PF; PF + 14 d	Apr 24, May 7	0.04
Untreated	none	none	none	1.6
Untreated	none	none	none	9.7

Table 9. Control of OBLR overwintering larvae with COMPLY in Milton-Freewater, OR in 1997.

Treatment	Rate (AI/100)	Timing	Pretreatment 29 Apr OBLR/50 trees	Post-treatment 22 May OBLR/50 trees	Post-treatment 11 July OBLR/50 trees
Comply 40 WP	10.6 g	Petal fall; PF +21 d	23	8	62
Lorsban 50 WP	170.0 g	Petal fall	17	17	169
Untreated	none		---	---	827

COMPLY is generally not toxic to insect natural enemies and thus is very compatible with pest management approaches that encourage biological control of pests. One caution is that COMPLY can be toxic to bees if pollen is contaminated. When contaminated pollen is taken back to the hive and fed to bee larvae they do not develop normally; therefore, COMPLY should never be used when bees are present in the orchard. COMPLY registration on apple is anticipated for 1998 or 1999. Its use will be restricted to the early postbloom period, probably with a long PHI of 70+ days. In the figure below, the relative toxicity of COMPLY and Guthion against mammals (rats), birds, fish and bees is shown. COMPLY is essentially nontoxic to all these organisms with the exception of fish and bees. COMPLY should be an ideal tool to use in IPM systems as a highly selective control against Lepidoptera while preserving natural enemies.

Ecotoxicology Comparisons

Organism - Test	Guthion®	Comply®
Rat - Acute oral	**Highly toxic**	**Non-toxic**
LD50	**4.4 mg/kg**	**>5000 mg/kg**
Rat - Acute dermal	**Highly toxic**	**Non-toxic**
LD50	**88 mg/kg**	**>5000 mg/kg**
Quail - oral toxicity	**Highly toxic**	**Non-toxic**
LD50	**32.2 mg/kg**	**>7000 mg/kg**
Duck - dietary tox.	**Slightly toxic**	**Non-toxic**
LC50	**1940 mg/kg**	**>20000 mg/kg**
Rainbow Trout	**Highly toxic**	**Moderately toxic**
LC50-96h	**0.003 mg/L**	**0.66 mg/L**
Honeybee	**Highly toxic**	**Low toxicity***
LD50	**???? mg/bee**	**>100 mg/bee**

* When bee larvae are fed contaminated pollen mortality can occur in pupae.

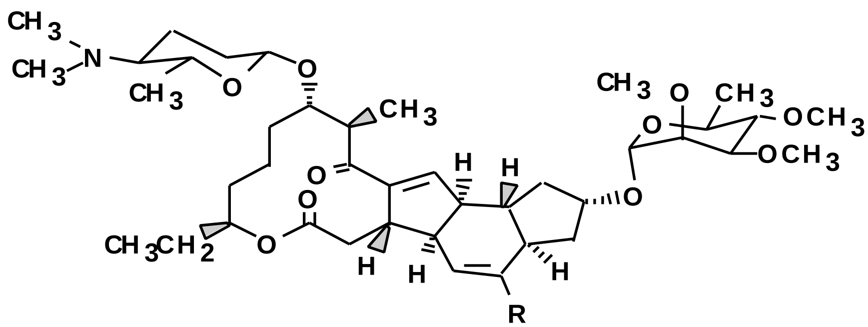
SUCCESS® (spinosad, DowElanco) is a new insecticide discovered by DowElanco scientists. You may have heard this product referred to as "spinosad," which is the proposed common name for the chemical. The name "spinosad" comes from the active chemicals in the insecticide called spinosyns. Spinosyns are a naturally derived set of molecules with insecticidal activity produced from a new species of Actinomycetes, *Saccharopolyspora spinosa*. Two of the most active spinosyns, A and D, make up the product called SUCCESS.

The structure of SUCCESS is shown in Fig. 4. Like the other insecticides discussed above, it is a large molecule and is not readily absorbed across the insect's skin. Its main effect then is through ingestion, carrying with it all the requirements of good spray coverage already discussed with the other products.

Success® (spinosad)

Spinosad is a mixture of spinosyn A and spinosyn D

spinosyn A: 65-95%
spinosyn D: 5-35%



spinosyn A: R = H Molecular Weight = 732
spinosyn D: R = CH_3 Molecular Weight = 746

Figure 4. Chemical structure of spinosad (SUCCESS®, DowElanco).

The actual mode-of-action of SUCCESS has recently been determined. It acts on the insect's nervous system at the nerve synapse as described in the following quote from a DowElanco publication: "Spinosad depolarizes insect neurons by activating nicotinic receptors, causing widespread hyperactivity in the nervous system, which leads to involuntary muscle contractions and tremors. Eventually, insects become prostrate with tremors and, after prolonged exposure, become paralyzed from neuro-muscular fatigue" (from "The Modes of Action of Spinosad and Other Insect Control Products" by V. L. Salgado, Senior Scientist, DowElanco, *Down to Earth* 52: 35-43). Following paralysis, the insect dies, usually after a relatively short time period.

SUCCESS has been shown to provide excellent control of leafrollers and leafminer. For leafrollers, the target of SUCCESS is the larval stage, and good control of all stages has been achieved. Both spring and summer control trials have demonstrated that SUCCESS is highly effective against leafrollers applied as either a dilute or concentrate spray as long as good coverage of foliage is achieved. The best timing of spring applications to control the overwintering larvae is at petal fall. In Table 10 the 01 May count occurred just prior to the petal fall application. In this trial SUCCESS provided better control than Lorsban when both were applied at petal fall or when Lorsban was applied at a more traditional timing, half-inch green tip (HIG).

Summer applications timed at young larvae following egg hatch have provided the best control (Table 11). SUCCESS has been reported to have a relatively short residual life and, under moderate to high leafroller population pressure, two applications in the summer may be required to achieve maximum effect. In the test results shown in Table 11 two applications of SUCCESS provided better control than one, and control was comparable to traditional summer leafroller control products.

Table 10. Density of OBLR larvae following applications of SUCCESS and Lorsban in the spring of 1997.

			Avg no. live OBLR larvae per		
			Pretreatment	Post-treatment	
	Rate		100 buds	entire tree	
Treatment	(AI/100 gal)	Timing	25 Mar	01 May	16 May
Success 2 F	177.6 ml	Pink	35.0a	3.0a	3.8ab
Success 2 F	266.4 ml	Pink	48.7a	3.1a	5.1b
Success 2 F	118.4 ml	Petal fall	54.7a	17.5c	3.3ab
Success 2 F	177.6 ml	Petal fall	50.3a	14.3c	1.2a
Lorsban 50 WP	340.0 g	Pink	39.3a	7.7b	6.2b
Lorsban 50 WP	1360 g	Petal fall	45.3a	13.9c	5.9b
Lorsban 4 E	473.6 ml	HIG	36.7a	7.3b	4.8b
+ Orchex 796	+ 1% v:v				
Untreated	none	none	48.3a	16.1c	11.6c

Means in the same column followed by the same letter not significantly different (p=0.05, Fisher's Protected LSD).

Table 11. Density of OBLR larvae following applications of SUCCESS and Lorsban in the summer of 1997.

	Rate		OBLR/20 trees
Treatment	(AI/100 gal)	Timing	30 Jul
Success 2 F	28.3 g	20% hatch	12.5bc
Success 2 F	28.3 g	20% hatch, 20%+14d	4.5ab
Success 2 F	42.6 g	20% hatch	6.5ab
Success 2 F	42.6 g	20% hatch, 20%+14d	4.5ab
Penncap-M 2 F	940.4 g	20% hatch	3.0a
Lorsban 50 WP	680.0 g	20% hatch, 20%+14d	2.5a
Untreated	none	none	16.5c

Means in the same column followed by the same letter not significantly different (p=0.05, Fisher's Protected LSD).

SUCCESS is used at very low rates and appears to have very little negative impact on the environment of human health. In the figure below, the relative toxicity of SUCCESS and Guthion against mammals (rats), birds, fish and bees is shown. SUCCESS is essentially nontoxic to all these organisms with the exception of honey bees. Test have shown, however, that dried residues of SUCCESS have little, if any, effect on honey bees and it should be possible to use SUCCESS during or near the blossom period in a manner similar to how Carzol is used. SUCCESS should be an ideal tool to use in IPM systems as a fairly selective control of leafroller and leafminer while preserving natural enemies. SUCCESS has been shown to be toxic to some parasitic hymenoptera and may affect biological control of certain insects if it is used when adult parasites are active in the orchard; however, the residues of SUCCESS are toxic to parasitic wasps for only a relatively short time, 5 to 7 days. Full registration of SUCCESS is anticipated for 1998.

Ecotoxicology Comparisons

Organism - Test	Guthion®	Success®
Rat - Acute oral LD50	**Highly toxic** 4.4 mg/kg	**Non-toxic** >5000 mg/kg
Rat - Acute dermal LD50	**Highly toxic** 88 mg/kg	**Non-toxic** >2000 mg/kg
Quail - oral toxicity LD50	**Highly toxic** 32.2 mg/kg	**Non-toxic** >2000 mg/kg
Duck - dietary tox. LC50	**Slightly toxic** 1940 mg/kg	**Non-toxic** >5000 mg/kg
Rainbow Trout LC50-96h	**Highly toxic** 0.003 mg/L	**Slightly toxic** 30.0 mg/L
Honeybee LD50	**Highly toxic** ???? mg/bee	**Highly toxic*** 0.0025 mg/bee

* Toxic if directly sprayed on bees but dried residues are not toxic.

Resistance management and new chemicals: As new insecticide chemistry becomes available for use in tree fruit crops, it is imperative that the industry think of implementing these new tools with a sound resistance management strategy. A direct substitution of new chemistry for the "old" insecticide chemistries currently in use will be the surest way to promote resistance development in pest populations. We have gathered baseline data on the levels of susceptibility of CONFIRM and SUCCESS to leafroller populations within the state and in reference to known susceptible populations maintained at the TFREC in Wenatchee. Table 12 gives the LC_{50} values for laboratory colonies of PLR and OBLR, plus values for two field populations of OBLR for CONFIRM and SUCCESS and two conventional insecticides. These values provide a reference point to which future data can be compared in order to determine if resistance levels to different insecticides are changing.

Table 12. The lethal concentration values (ppm and 95% confidence limits) that killed 50% of PLR and OBLR neonate larvae exposed to residues for seven days.

		Avg. corrected % mortality- 7 d			
Chemical	LC value	PLR col.	OBLR col.	Mattawa (ob)	M-F (ob)
CONFIRM	LC_{50}	6.3	12.4a	34.0b	31.6b
		(3.3-9.2)	(7.1-17.8)	(20.6-53.2)	(16.8-46.4)
SUCCESS	LC_{50}	0.18	0.28b	0.13a	0.31b
		(0.09-0.24)	(0.21-0.35)	(0.09-0.17)	(0.21-0.42)
LORSBAN	LC_{50}	0.7	2.6a	2.4a	4.3b
		(0.5-1.0)	(1.5-3.6)	(1.3-3.6)	(2.6-5.8)
GUTHION	LC_{50}	7.2	4.9a	49.1b	45.3b
		(5.2-9.2)	(3.9-6.0)	(16.6-228.4)	(23.5-67.0)

Lethal concentration limits calculated by Polo-PC using a p=0.95. Means in the same ROW followed by the same letter not significantly different (P=0.05, Lethal Ratio Significance Test, Robertson and Priesler, 1991). LCs from the PLR colony were not compared to the OBLR populations.

Initial resistance survey results suggest that leafroller, and probably codling moth, populations in Washington do not exhibit cross-tolerance (resistance) between COMPLY, CONFIRM and SUCCESS and organophosphate insecticides. Hopefully as new insecticides are registered they will work equally well to control leafrollers in all regions of the state. The optimum resistance management strategy to follow when and if all three new insecticide chemistries become available is to use an insecticide only against one generation of leafroller over a two-year period. Because the new insecticides should be more effective than current insecticides, populations of leafrollers in general are expected to decline markedly compared to what is experienced now. The judicious use of any insecticide is always the best resistance management strategy.

Integration of new insecticides into a pheromone-based IPM program also represents a valuable resistance management strategy for using these new insecticides. CONFIRM and COMPLY provide control of both codling moth and leafrollers. They can be used as "soft" supplemental controls in codling moth mating disruption programs and, as pheromone delivery technology continues to develop, in mating disruption programs for leafrollers.

Other "Bullets" Being Developed for Leafroller Control

Mating disruption: The potential to use pheromones to disrupt mating of leafrollers has been a "work in progress." A dual codling moth-leafroller pheromone dispenser has been tested within the fruit industry, primarily by Dr. Alan Knight (USDA-ARS, Wapato), and has shown some promise in reducing leafroller damage while providing codling moth control. This dual dispenser will be registered for use in 1998, but the distribution will be somewhat limited in Washington until more information on its performance is obtained.

Formulations of sprayable pheromone for leafroller control are also under development, and one product produced by Ecogen has federal registration. Research trials conducted on sprayable leafroller pheromones to date do not provide sufficient evidence to positively state that they do control populations of leafrollers in orchards. However, there is promise that as these products continue to be improved they will provide yet another control tactic to battle leafrollers in fruit orchards.

Attract & kill: SIRENE®-CM (IPM Technologies) is a new product for codling moth control that uses removal of male moths as the mode-of-action. It is a combination of pheromone and synthetic pyrethroid in a black tacky tar-like substance that is placed as a small drop on a tree. Male moths are attracted to the drop by the pheromone and upon touching the "false female" receive a lethal dose of insecticide. There is good potential that this same approach could be used as a control for leafrollers. An active research program will begin in 1998 to develop a SIRENE product for leafrollers.

Biological control: A large number of parasitic insects, 15 or more species, has been identified as attacking leafrollers in Washington. Some of these parasites have great potential to help reduce leafroller populations in commercial orchards, especially when reliance on broad-spectrum insecticides is reduced as new insecticides become available. Research by Chris Nobbs (graduate student at WSU) and Dr. Robert Pfannenstiel (WSU-TFREC, Wenatchee) has shown the potential for culturing a nonpest leafroller on a cover crop plant. This cover-crop leafroller can provide a host for parasites, thus maintaining natural enemy populations within the orchard with the potential to greatly impact the biological control of pest leafroller species.

SUMMARY: Are there really any "magic bullets?" I would have to say no. There are, however, some exciting new insecticides and other pest control tactics under development or very close to registration that hold great promise in the fight against leafrollers in fruit orchards. The new insecticides in particular will require growers and crop consultants to adopt new strategies for timing of sprays and different expectations on how fast the kill of the target will occur. If some new insecticides with novel modes-of-action are not registered prior to the full effect of FQPA-96 being realized, pest control in tree fruits will indeed be challenging. With the registration of CONFIRM, COMPLY and SUCCESS, and the availability of additional technology, such as mating disruption and "attract & kill," the control of leafrollers and codling moth will be better and will allow for a more complete expression of biological controls in orchards than at any time since the introduction of synthetic organic insecticides.

The figures below summarize information for three insecticides that hold a promise of providing better and "softer" control of codling moth and leafrollers in Washington apple orchards. The mode-of-action of each insecticide is briefly given as well as the targeted life stages. The optimum timing to control each pest based on current research is shown for each product in the next figure. And, finally, there is a series of figures showing graphically the best timing for codling moth and leafrollers.

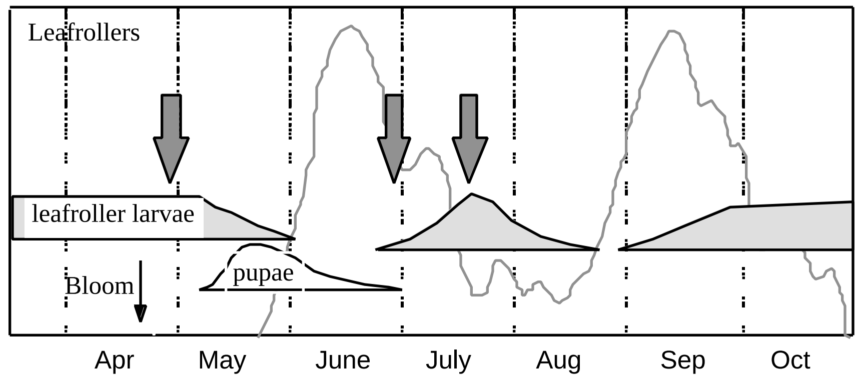
Mode-of-action and target of Chemicals

Insecticide	Mode-of-action	Target: effect
Comply	Mimics action of the insects natural juvenile hormone	Last larval instar or egg: disrupts the transition to pupa OR egg development
Confirm	Binds to the insects ecdysteroid receptor causing initiation of a lethal molt	Larval stages: insects stop feeding, make new skin and die in 7-10 days
Success	Works at the nerve synapse by activating nicotinic acetylcholine receptors/Na influx	Larval stages: insect become intoxicated (paralyzed) in short time and dies.

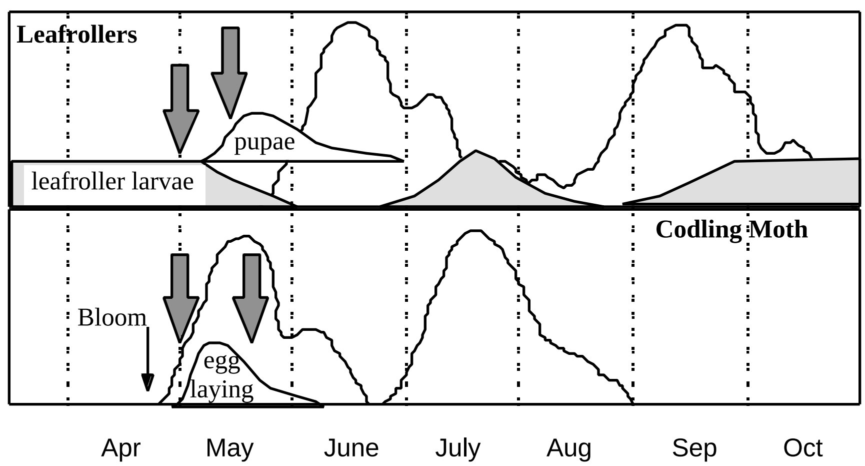
Implementation Summary
New Insecticide Chemistry in Apple IPM

	Confirm	Comply	Success
Leafroller Overwintering	petal fall repeat 14-21 days	petal fall repeat 14-21 days	petal fall
Leafroller Summer	20% hatch repeat 14-21 d	NA	20% hatch repeat 14-21 d
Codling Moth 1st generation	250 °D repeat 17-21 days	petal fall repeat 14-21 days	NA
Codling moth 2nd generation	1250 °D repeat 17-21 days	NA	NA

Success use strategy in Apple IPM



Comply use strategy in Apple IPM



Confirm use strategy in Apple IPM