Efficacy and field longevity of insecticides used for codling moth

Chuck Ingels, UC Cooperative Extension, Sacramento County
Bob Van Steenwyk, Division of Insect Biology, UC Berkeley
Steve Welter, Division of Insect Biology, UC Berkeley
Frances Cave, Division of Insect Biology, UC Berkeley

Background

Control of codling moth in pear orchards will become substantially more difficult for many growers when Guthion is withdrawn from the market. Most other products that are currently available, when used with pheromone mating disruption, are generally effective where codling moth populations are relatively low, but they lack the ability to successfully control large populations. Products that are currently registered in pears and have at least partial control of codling moth are the organophosphates Guthion (azinphos-methyl) and Imidan (phosmet), the synthetic pyrethroids Danitol (fenpropathrin) and Asana (esfenvalerate), the neonicotinoid Assail (acetamiprid), insect growth regulators (IGRs) Confirm (tebufenozide), Intrepid (methoxyfenozide), Dimilin (diflubenzuron), and Esteem (pyriproxifen), the sodium inhibitor Avaunt (indoxacarb), and the organically acceptable Entrust (spinosad) , (ADD: Warrior Lambda cyhalothrin). Organic growers also use insecticidal spray oil for in-season control

Each of these insecticides has drawbacks. Guthion, the grower standard for several decades, increase spider mite populations, but they were effectively controlled by other pesticides. Guthion also controls many secondary pests, but long restricted entry intervals and the impending loss of the product from the market make its outlook bleak. Imidan has shown far less efficacy against codling moth than Guthion. The IGRs have generally been more effective at controlling leafrollers than codling moth. Synthetic pyrethroids are relatively effective, but they kill many beneficial insects and codling moth have a propensity to develop resistance to these materials. Another key factor is that most materials are substantially more expensive than Guthion.

Resistance bioassays conducted in 2003 by S. Welter found increases in azinphosmethyl resistance with levels up to 0.89 µg /µl per moth in one orchard. Anecdotal reports from S. Africa have suggested that levels of ca. 1.2 µg /µl per moth were correlated with field failure of the material, yet these reports have not been confirmed. Two compounds that were seen as some of the most promising replacements for Guthion are Assail and Danitol. Statistically significant, but low levels of resistance to Assail were found in 2003 in 4 orchards when compared to the most susceptible orchard, which also had the lowest levels of azinphosmethyl resistance. Resistance ratios ranged from 1.7 to 4.8. A similar pattern was observed for Danitol resistance with statistically significant resistance detected in 4 orchards in 2003. Resistance ratios were variable, but relatively low, at 1.9 to 8.1 in comparison to populations collected in the orchards with the lowest levels of azinphosmethyl resistance.

A key factor related to the timing of insecticide applications is the effective duration of insecticide residue on the fruit. The effective residual activity will vary with resistance levels and specific weather conditions. The occurrence of significant variation between populations in field based pheromone-assisted bioassays may correlate to variation in performance.

Objectives

1. To determine the relative efficacy and residual activity of several currently available insecticides on codling larval survival on field-treated fruit in laboratory bioassays.
2. To compare relative infestation rates over time under commercial pear growing conditions.

Methods and Materials

The field portions of the trials were conducted in Bartlett orchards near Walnut Grove and Fairfield. The insecticides tested and the rates used are listed below. (It should be noted that Intrepid works in part by ovicidal activity, but only larvae were used in the bioassays.) No other insecticides were applied to these trees during the growing season.

	Rate per acre	
Treatment	**Sacramento**[a]	**Fairfield**
Gal./Acre	150 gpa	200 gpa
Assail 70WP	3.4 oz	3.4 oz
Danitol 2.4EC	21.3 oz	21.3 oz
Guthion 50WP	3.0 lbs	2.0 lbs
Imidan 70W[b]	7.0 lbs	6.0 lbs
Intrepid 2F	16.0 oz	--
Success 2SC	--	5.7 oz
Untreated control	--	--
[a] *Latron B1956 was added at 0.125% by volume*		
[b] *Treatment pH was adjusted to < 6.*		

Sacramento Trial

In this orchard (spacing 10’ x 20’), each spray was applied to four consecutive replicate trees on May 18, May 25, June 1, June 8, and June 15. A partial row was used for each week’s spray, and each row was separated by an unsprayed row to prevent drift. Four untreated trees were selected at the end of one of the partial rows. Therefore, 104 trees were used in the trial (5 products x 4 replicate trees x 5 weekly timings, plus 4 untreated control trees). The sprays were applied using hand-held orchard sprayer operating at 250 psi with a finished spray volume of 150 gal./acre (1.45 gal/tree).

On June 16, 25 fruit per tree were harvested and taken to the Welter lab for larval assay #1 (see below). Thus, on the single pick date, a range of residue ages was sampled. On June 29, another 25 fruit per tree were harvested and taken to the lab for assay #2. These fruit were kept in cold storage for 2 weeks, during which time female moths were collected from the field for a portion of the study. The chart below shows the residue age for the two sets of fruit.

Spray	**Residue Age (weeks)**	
Date	**Assay #1**	**Assay #2 & #3**
18-May	4	6
25-May	3	5
1-Jun	2	4
8-Jun	1	3
15-Jun	0	2

Larval Bioassay #1. In early to mid June, numerous attempts were made to collect female codling moths from collection stations that consisted of a white sheet draped over a black light. Attempted collections took place in several pear districts during the evening hours in the weeks before fruit for assay #1 were harvested. However, insufficient moths were found to provide larvae for the first assay, so larvae from Guthion-susceptible moths reared in the lab were used in assay #1.

A total of 2,500 sprayed fruit and 25 control fruit were set up for bioassay #1 from June 16-18. Two larvae were placed on each fruit inside a gel cap, which was waxed onto each fruit. Larvae were evaluated 5 days after setup, and mortality was declared only when both larvae were dead.

Larval Bioassay #2. Larvae were placed on fruit from July 14-16 similar to assay #1, except that only 20 fruit per replicate were infested with larvae from the Guthion-susceptible lab colony. The residue age was defined by the pick date (June 29), since aging in cold storage (2 weeks) is presumably negligible compared to the UV exposure during field aging.

Larval Bioassay #3. Larvae were placed on fruit from July 14-16 as in assay #2, except that only 5 fruit per replicate were infested with larvae from moths collected from a Feather River apple orchard. Larvae from this population were highly resistant to Guthion, with a sample analysis showing 0.985 µg /µl resistance. There was no set up of 3-week-old residues (8 June sprays) except Assail; thus, we set up 2-,4-,5-, and 6-week-old residue samples for all products but Assail was assayed every week

Summary of bioassays:

	Fruit per Replicate	**Guthion Susceptibility**
Bioassay #1	25	Susceptible
Bioassay #2	20	Susceptible
Bioassay #3	5	Resistant
Fairfield	5	Susceptible

Fairfield Trial

In the Fairfield orchard (spacing 25' x 25'), foliar sprays were applied to individual trees with a hand-held orchard sprayer operating at 250 psi with a finished spray volume of 200 gal/acre (2.87 gal/tree). Sprays were applied once only, on 16 June (221 DD after 2nd biofix).

Five fruit per replicate were infested with laboratory-reared neonate larvae at 0, 7, 14 and 21 days after treatment. Each fruit was infested by placing two larvae in each of two gelatin capsules, which were secured to the pears by hot paraffin wax. Mortality was determined for each capsule 1 day after infestation.

Field control of CM was evaluated in this orchard at the same time as commercial harvest on 21 July by inspecting a maximum of 250 fruit per tree for CM infestation. In addition, 25 non-infested fruit were flagged per replicate (100 fruit per treatment) on the application day. The flagged fruit were examined at 7, 14, 21, 28 and 35 days after treatment (DAT) for CM infestation. Control of PP nymphs, motile TSSM adults, motile ERM adults and SJS crawlers was evaluated by leaf-brushing 10 exterior and 10 interior leaves collected from each tree weekly from 12 July through 25 July. The 25 leaves were bushed and the plates were counted under magnification in the laboratory.

Results

Larval Bioassay #1. Lab-susceptible larvae are larvae that were reared in the lab and therefore are not resistant to Guthion because they are not subjected to sprays of Guthion or cross-resistant insecticides. In the Sacramento assay #1, lab-susceptible larvae subjected to fruit treated with Guthion 0, 7, and 14 days prior had a very high mortality rate, and mortality began to decline 21 days after treatment (DAT) (Table 1). Mortality on fruit treated with Imidan began to decline about 14 DAT, whereas morality of Assail-treated fruit began to decline 7 DAT. Mortality on fruit treated with Danitol appeared to decline 14 DAT, but inexplicably increased 21 and 28 DAT. The mode of action of Intrepid is ovicidal in part, so its efficacy on larvae was significantly lower than other insecticides, but higher than untreated fruit.

Larval Bioassay #2. More fruit from each treatment were harvested 2 weeks after the last spray and were placed in cold storage for 2 additional weeks. The insecticide breakdown during this 2-week cold storage period was probably negligible, so this period was disregarded; i.e., the last spray (June 15) was considered 14 DAT even though fruit were not subjected to lab-susceptible larvae until July 14-16. At the first evaluation (14 DAT), Guthion again resulted in the greatest mortality numerically, but it was not significantly different from Danitol or Imidan (Table 2). Nor were these products significantly different at 28 and 35 DAT. At day 42, larvae subjected to Imidan had significantly greater mortality than those subjected to Danitol or Guthion. Assail resulted in significantly less mortality than Guthion at the first evaluation (14 DAT), but the differences were not significant at any later date. As in Assay #1, Danitol maintained a relatively similar level of mortality throughout the experiment, and at 42 DAT, it had the highest mortality, although not significantly higher than Guthion.

Larval Bioassay #3. Larvae from field-resistant codling moths showed very low mortality when subjected to Assail-treated fruit (Table 3). After 21 DAT, no larvae died. Mortality was relatively low even when larvae were subjected to residues for 12 days.

Fairfield Studies. In the Fairfield trial, in which fruit were sprayed once (June 16) and harvested and subjected to lab-susceptible codling moth larvae weekly for one day only, larval mortality from Guthion, Imidan, and Danitol did not differ significantly through 14 DAT, but Imidan was slightly more effective at 7, 14, and 21 DAT (Table 4). Assail and Success performed relatively poorly throughout the trial, but these products performed significantly better than the untreated control. The Abbott's conversion of these data, which corrects for the untreated control data, is shown in Table 5.

Damage in the field was evaluated weekly, but there were few differences between treatments (Table 6). By day 35, fruit treated with Success was infested to the same degree as the untreated control. Fruit treated with Imidan and Danitol maintained relatively low infestation levels. At commercial harvest, fruit treated with Imidan was significantly less infested than most other treatments (Table 7). Danitol and Guthion were nearly identical in infestation and also relatively low. Assail-treated fruit were significantly more infested, and Success was most infested of the sprayed treatments, but less infested than the untreated control.

Evaluations of secondary pests in July showed that the single use of Guthion and Imidan, and to a lesser extent Success, led to a substantial buildup of psylla (Table 8). All products reduced San Jose scale, but Assail and Guthion slightly increased twospotted spider mites, and Guthion and Success increased European red mites.

Discussion

As would be expected, mortality of lab-reared larvae was generally far higher after 5 days (Sacramento) than after only 1 day (Fairfield). After 5 days of exposure, Guthion killed nearly all larvae for at least 2 weeks and Imidan killed nearly all larvae for at least a week. After 1 day of exposure, Imidan and Guthion resulted in substantial, but lower mortality, even after 28 DAT. Danitol was similar after 1 day of exposure, but slightly less than Imidan and Guthion. Assail killed fewer larvae, after both 1 and 5 days of exposure.

Interestingly, larvae that were highly resistant to Guthion also exhibited strong resistance to Assail. Mortality on fruit treated identically with Assail killed far more lab-susceptible larvae than field-resistant larvae. This cross-resistance is problematic, although larvae in Sacramento district orchards are generally less resistant to Guthion than those from the Feather River apple orchard. Assail was very effective on lab-susceptible larvae immediately after spraying, but only after 5 days of exposure. Intrepid and Success performed less than optimally in these studies, although Intrepid also has ovicidal activity.

Table 1. **(Sacramento Assay #1)** Mean Percent Mortality of lab-susceptible codling moth at 0, 7, 14, 21 and 28 days after treatment (DAT) after 5 days of exposure of larvae to pears treated with various insecticides.

	Rate	Percent Mortality at DAT [a]				
Treatment	Form/ac	0	7	14	21	28
1. Assail 70WP	3.4 oz	95.9 c	82.0 c	79.9 c	83.9 c	70.5 c
2. Danitol 2.4EC	21.3 oz	92.0 c	89.0 cd	82.0 c	93.0 c	93.9 d
3. Guthion 50WP	3.0 lbs	98.0 c	99.0 d	99.0 d	85.0 c	84.8 d
4. Imidan 70W[a]	6.0 lbs	97.0 c	97.9 d	91.0 cd	84.0 c	88.0 d
5. Intrepid 2F	16.0 oz	49.9 b	37.0 b	23.0 b	41.0 b	43.0 b
6. Untreated	–	13.8 a	13.8 a	13.8 a	13.8 a	13.8 a

[a] *Means followed by the same letter within a column are not significantly different (Fisher's protected LSD, P ≤ 0.05).*

Table 2. **(Sacramento Assay #2)** Mean percent mortality of lab-susceptible codling moth larvae at 14, 21, 28, 35, and 42 days after treatment (DAT) after 5 days of exposure to pears treated with various insecticides (fruit placed in cold storage for 2 weeks).

	Rate	Percent Mortality at DAT [a]				
Treatment	Form/ac	14	21	28	35	42
1. Assail 70WP	3.4 oz	64.6 c	46.3	57.0 b	51.3 b	38.8 b
2. Danitol 2.4EC	21.3 oz	77.9 cd	--	70.1 b	71.3 c	53.8 c
3. Guthion 50WP	3.0 lbs	92.3 d	--	64.6 b	63.3 bc	45.6 bc
4. Imidan 70W[a]	6.0 lbs	82.5 d	--	69.6 b	70.9 c	35.1 b
5. Intrepid 2F	16.0 oz	45.5 b	--	27.8 a	47.5 b	37.5 b
6. Untreated	–	12.6 a	--	12.6 a	12.6 a	12.6 a

[a] *Means followed by the same letter within a column are not significantly different (Fisher's protected LSD, P ≤ 0.05).*

Table 3. **(Sacramento Assay #3)** Mean percent mortality of field-resistant vs. lab-susceptible codling moth larvae at 14, 21 28, 35, and 42 days after treatment (DAT) of pears with treated Assail (fruit placed in cold storage for 2 weeks).

Treatment	Rate Form/ac	Percent Mortality at DAT [a] 14	21	28	35	42
		After 5 Days of Exposure to Field-Resistant Larvae				
Assail 70WP	3.4 oz	20.0	10.0	0.0	0.0	0.0
Untreated	--	0.0	0.0	0.0	0.0	0.0
		After 12 Days of Exposure to Field-Resistant Larvae				
Assail 70WP	3.4 oz	40.0	29.4	15.8	23.5	--
Untreated	--	5.6	5.6	5.6	5.6	--
		After 5 Days of Exposure to Lab-Susceptible Larvae *(From Table 2)*				
Assail 70WP	3.4 oz	64.6	46.3	57.0	51.3	38.8
Untreated	--	12.6	12.6	12.6	12.6	12.6

Table 4. **(Fairfield Assay)** Mean percent codling moth mortality at 0, 7, 14, 21 and 28 days after treatment (DAT) with 1 day of exposure to pears treated in Fairfield.

Treatment	Rate Form/ac	Percent Mortality at DAT [a] 0	7	14	21	28
1. Assail 70WP	3.4 oz	47.8 b	40.0 bc	34.2 b	39.5 c	51.3 cd
2. Danitol 2.4EC	21.3 oz	90.9 d	78.4 d	82.1 c	44.4 c	68.4 de
3. Guthion 50WP	2.0 lbs	87.5 cd	81.6 d	91.9 c	78.9 d	86.8 e
4. Imidan 70W[a]	6.0 lbs	82.6 cd	97.4 d	95.0 c	92.1 d	73.7 e
5. Success 2SC	5.7 oz	63.6 bc	20.5 ab	31.6 b	10.0 ab	–
6. Untreated	–	8.3 a	2.5 a	2.6 a	5.1 a	10.3 a

[a] *Means followed by the same letter within a column are not significantly different (Fisher's protected LSD, P ≤ 0.05).*

Table 5. **(Fairfield Assay)** Mean percent corrected (Abbott's) codling moth mortality at 0, 7, 14, 21 and 28 days after treatment (DAT) with 1 day of exposure to pears treated in Fairfield.

	Rate	Percent Mortality at DAT [a]				
Treatment	Form/ac	0	7	14	21	28
1. Assail 70WP	3.4 oz	43.1	38.5	32.4	36.2	45.7
2. Danitol 2.4EC	21.3 oz	90.1	77.8	81.6	41.4	64.8
3. Guthion 50WP	2.0 lbs	86.4	81.1	91.7	77.8	85.3
4. Imidan 70W[a]	6.0 lbs	81.0	97.3	94.9	91.7	70.7
5. Success 2SC	5.7 oz	60.3	18.5	29.8	5.2	–
6. Untreated	–	0.0	0.0	0.0	0.0	0.0

Table 6. **(Fairfield Field Study)** Mean percent codling moth-infested fruit at 7, 14, 21, 28 and 35 days after treatment (DAT) of fruit that was not infested at day of application in Fairfield.

	Rate	Percent CM Infestation at DAT [a]				
Treatment	Form/ac	7	14	21	28	35
1. Assail 70WP	3.4 oz	8.0 a	9.0 a	13.3 ab	18.4 ab	25.9 ab
2. Danitol 2.4EC	21.3 oz	6.6 a	7.9 a	8.1 a	11.7 a	16.2 a
3. Guthion 50WP	2.0 lbs	10.7 a	12.8 a	13.3 ab	21.6 ab	26.2 ab
4. Imidan 70W[a]	6.0 lbs	7.5 a	8.5 a	8.5 a	8.5 a	12.7 a
5. Success 2SC	5.7 oz	3.0 a	7.3 a	18.9 ab	29.4 b	50.1 cd
6. Untreated	–	9.1 a	15.5 a	24.5 b	34.2 b	57.2 d

[a] *Means followed by the same letter within a column are not significantly different (Fisher's protected LSD, $P \leq 0.05$).*

Table 7. **(Fairfield Field Study)** Mean percent codling moth-infested fruit inspected at commercial harvest in Fairfield.

Treatment	Rate Form/ac	Mean[a] Percent Infested Fruit at Commercial Harvest
1. Assail 70WP	3.4 oz	52.4 c
2. Danitol 2.4EC	21.3 oz	38.9 b
3. Guthion 50WP	2.0 lbs	36.4 ab
4. Imidan 70W[b]	6.0 lbs	26.8 a
5. Success 2SC	5.7 oz	69.1 e
6. Untreated	–	80.9 f

[a] *Means followed by the same letter within a column are not significantly different (Fisher's protected LSD, P ≤ 0.05). Data analyzed using an arcsin transformation.*
[b] *pH was adjusted to < 6.*

Table 8. **(Fairfield Field Study)** Mean total pear psylla nymphs, San Jose scales, twospotted spider mites and European red mites per 20 leaves in Fairfield.

Treatment	Rate Form/ac	PP	SJS	TSSM	ERM
1. Assail 70WP	3.4 oz	8.8 a	13.8 ab	5.8 b	0.5 a
2. Danitol 2.4EC	21.3 oz	17.5 a	9.8 a	0.0 a	1.0 ab
3. Guthion 50WP	2.0 lbs	77.7 c	14.3 ab	3.5 ab	15.0 b
4. Imidan 70W[a]	6.0 lbs	54.0 bc	9.3 a	1.8 ab	3.0 ab
5. Success 2SC	5.7 oz	41.3 ab	19.8 abc	0.5 ab	11.3 ab
6. Untreated	–	17.8 a	32.8 c	0.0 a	0.0 a

Means followed by the same letter within a column are not significantly different (Fisher's protected LSD, P ≤ 0.05).
[a] *pH was adjusted to < 6.*