Integrated control of codling moth and mites in Ohio apple orchards

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SUMMARY: A field trial was conducted to evaluate the effects of several insecticide programs on codling moth as well as effects on non-target pest mites and predatory mites. Each insecticide program was used with and without oil, and with and without miticide (Savey), with four replicates of each treatment combination. The insecticide programs used one product for control of first generation codling moth and one or two products for control of second generation codling moth. The programs were 1) Asana followed by Calypso/Guthion, 2) Rimon followed by Assail, 3) Imidan followed by Asana, 4) no insecticide. One additional treatment was Zeal miticide applied only with the Rimon/Assail insecticide program and no pre-bloom oil. Mite density was evaluated at 2-week intervals, and fruit were evaluated for insect injury at harvest. All three insecticide programs provided equally excellent control of codling moth. Savey and Zeal provided equally good mite control. Predatory mites were found in most plots, and they were not adversely affected by pyrethroid use. The pyrethroid caused less mite flare-up when used for second generation codling moth control than when used for first generation codling moth control. The density of European red mite showed that there were strong interactions between mite treatments and insecticide treatments. Where a pyrethroid like Asana was used without pre-bloom oil or post-bloom miticide, heavy infestations of mites resulted, but where a miticide was used along with a pyrethroid, mite populations were kept at tolerable levels. When oil was used pre-bloom and no miticide was used post-bloom, mites were suppressed only until mid-June. Despite this short period of control, use of pre-bloom oil is advocated for its benefit in resistance management.

Background:

Apple growers usually can keep codling moth and other key insect pests under control using organophosphate insecticides like Guthion or Imidan, which have been used in most commercial orchards for the past 30 years. Due to recent restrictions on use of organophosphates and due to failing efficacy of organophosphates for codling moth control at some orchards, more growers are becoming interested in whether or not pyrethroid insecticides (such as Asana) or insect growth regulators (such as Rimon) could be used to replace the conventional organophosphate program. Pyrethroids are cost effective and do a good job of controlling most insect pests but they are known for causing flare-ups of mites and scales due to toxicity to natural enemies. Insect growth regulators are known to be compatible with natural enemies but they are expensive, they do not control sucking pests such as leafhoppers, and they need to be applied at earlier timing than organophosphates. In 2003 and 2004, field trials were conducted to evaluate several new insecticides for efficacy on codling moth; results showed that the pyrethroids were not as harsh as expected if used at low rates, particularly in orchards where stigmaeid predatory mites were present. Research reported here was done to see how the full complex of pests can be managed under several insecticide programs, and integrated with biological control of mites.

A related pest management issue is whether worms found in apple fruit in Ohio are codling moth or other species. Codling moth has been the most common species found in apples in Ohio and elsewhere, but two other pests have recently become as common as codling moth in some orchards. Oriental fruit moth is best known as a peach pest but it has been causing severe problems in some apple orchards in Pennsylvania and other areas during the past few years. Control of Oriental fruit moth is more difficult than control of codling moth due to lower susceptibility to many insecticides and to a greater number of generations per year. There are two apple orchards in Ohio where Oriental fruit moth is known to be present as a significant part of the pest complex. Another pest, lesser appleworm, can also be present at high density such as in a research orchard in Columbus. This project included a survey to determine the extent that these pests are found in Ohio orchards. Once growers know which species are present in each orchard, the most appropriate insecticide and timing can be chosen.

Objectives:

1) Evaluate control of codling moth and other insect pests under three insecticide programs in comparison with untreated checks, and 2) evaluate these insecticide treatments in conjunction with oil and miticide treatments for their effects on predatory mites and European red mite. 3) Survey commercial orchards in major fruit-growing

areas of Ohio to determine whether caterpillars found inside fruit are just codling moth, or whether Oriental Fruit moth or lesser appleworm are also present in some orchards.

Methods:

The trial was conducted in small plots in a block of 3-year old Scarlet Spur Delicious apple trees at Ohio State University's Waterman Laboratory in Columbus, Franklin County, central Ohio. There were 17 treatments each with four replicates in a randomized complete block design, with four adjacent trees per plot. Sixteen of the treatments were all possible combinations of 3 factors: two levels of oil (treat with oil versus no oil), two levels of miticide (with Savey versus without Savey), and 4 levels of insecticide treatment (3 insecticide combinations, and an untreated check). A seventeenth treatment was identical to one of the factorial treatments except the miticide was Zeal rather than Savey. Savey and Zeal treatments were applied when summer egg laying reached a peak and the first summer eggs were beginning to hatch. Each treatment included one product for control of first-generation codling moth and one or two products for control of second-generation codling moth; intended timing and actual timing are detailed in Table 1. Insecticide treatments were Asana XL 0.66EC (esfenvalerate) at 4.8 fl oz per acre, Assail 30SG (acetamiprid) at 5 oz per acre applied with oil at 0.5%, Calypso 4F (thiacloprid) at 6 fl oz per acre, Guthion 50WP (azinphosmethyl) at 2 lb per acre, Imidan 70WP (phosmet) at 3 lb per acre, and Rimon 0.83EC (novaluron) at 20 fl oz per acre. Mite control treatments were Superior Oil at 2%, Savey 50DF (hexythiazox) at 3 oz per acre, and Zeal 72WDG (etoxazole) at 2 oz per acre. All plots except the insecticide checks were treated at petal-fall with Avaunt 30WDG (indoxacarb) at 6 oz per acre. There was a guard row of Gala, Fuji, and Golden Delicious between adjacent treatment rows. The guard rows were not sprayed with oil or miticide but were sprayed with Avaunt at petal-fall and Imidan at first cover and second cover. Insecticides and acaricides were applied in a dilute volume of 150 gallons of water per acre by a handgun sprayer operated at pressure of 100 psi, with a D6 ConeTip nozzle tip.

Table 1. Timing of insecticide and miticide applications in Delicious apples at OSU's Waterman Lab, Columbus, Ohio, 2005.

Target timing	1/2 inch green	Petal-fall	~1C	1C		2C		3C & 4C	5C	6C	7C
			After eggs laid	75-150 DD after biofix	250 DD after biofix	14 days after 1C		skip	after moth surge	14 days after 5C	14 days after 6C
Actual timing	4/11	5/10	5/20	5/23 (143 DD)	5/31 (241 DD)	6/6 (379 DD)	6/15 (626 DD)		7/29 (1737 DD)	8/12 (2128 DD)	8/25 (2451 DD)
Trtmt											
1	Oil	Avaunt	-	-	Asana	-	Asana	-	Calypso	Calypso	Guthion
2	Oil	Avaunt		-	Asana	-	Asana	-	Calypso	Calypso	Guthion
3	-	Avaunt	-	-	Asana	-	Asana	-	Calypso	Calypso	Guthion
4	-	Avaunt	Savey	-	Asana	-	Asana	-	Calypso	Calypso	Guthion
5	Oil	Avaunt	-	Rimon	-	Rimon	-	-	Assail	Assail	Assail
6	Oil	Avaunt	Savey	Rimon	-	Rimon	-	-	Assail	Assail	Assail
7	-	Avaunt	-	Rimon	-	Rimon	-	-	Assail	Assail	Assail
8	-	Avaunt	Savey	Rimon	-	Rimon	-	-	Assail	Assail	Assail
9	Oil	Avaunt	-	-	Imidan	-	Imidan	-	Asana	Asana	Asana
10	Oil	Avaunt	Savey	-	Imidan	-	Imidan	-	Asana	Asana	Asana
11	-	Avaunt	-	-	Imidan	-	Imidan	-	Asana	Asana	Asana
12	-	Avaunt	Savey	-	Imidan	-	Imidan	-	Asana	Asana	Asana
13	Oil	-	-	-	-	-	-	-	-	-	-
14	Oil	-	Savey	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-
16	-	-	Savey	-	-	-	-	-	-	-	-
17	-	Avaunt	Zeal	Rimon	-	Rimon	-	-	Assail	Assail	Assail

For fruit thinning, NAA at 10 ppm was applied to all plots including untreated checks on 5/20/05. A standard fungicide program was used in all plots. Fungicides were applied by an AgTech 4002 airblast sprayer operated at pressure of 20 psi, with TeeJet 6510 and 6520 nozzle tips. On all trees including checks, copper sulfate was sprayed on 3/31/05. Other fungicides applied were Captan at 3/4-inch green on 4/11/05 and at pink on 4/18/05; Captan and Nova at bloom on 4/26/05; Captan at bloom on 5/3/05, at petal-fall on 5/11/05, and in cover sprays on 5/23/05, 6/7/05, 6/15/05, 6/29/05, and 7/13/05; Topsin-M on 7/27/05 and 8/15/05.

Pheromone traps were used to monitor adult populations of codling moth and lesser appleworm. The date of sustained flight of codling moth was used as a biofix to start a degree-day count on which insecticide timing was based. Multipher-3 funnel traps were used with lures made by Trécé; for codling moth, long-life lures were changed every 8 weeks, while for lesser appleworm, standard lures were changed every 4 weeks. Oriental fruit moth was not monitored due to its absence at this site in the previous few years.

Mite populations were sampled at 12- to 15-day intervals from early May until early August. A sample of 20 randomly selected leaves was taken from two trees at the center of each plot. Leaves were brushed with a mite-brushing machine, and mites were counted in subsamples to determine the average number of European red mite and predatory mites per leaf. The density of apple rust mite was rated as low, moderate, or high for each sample. Cumulative mite-days were calculated using the plot means and the number of days in the interval between counts. Samples of predatory mites were preserved for species verification. Plots were scouted for nymphs of white apple leafhopper on 5/13/05, and for cumulative leafhopper damage on 6/23/05, using a sample of one mid-cluster leaf, and 25 samples per plot. Data was not taken for spotted tentiform leafminer because its population was negligible. Insect injury to fruit was evaluated on 100 fruit in the center of each plot from 9/26/04 to 9/29/05 with one replicate evaluated per day. Data were subjected to analysis of variance (ANOVA) and mean comparisons by least significant difference (LSD) tests in the general linear models (GLM) procedure of the SAS 6.12 microcomputer statistics program.

To survey for caterpillar species in apple fruit, several crop consultants were alerted to save fruit if infestations were found any time during the season. Infested fruit were dissected to extract larvae if still present. Extracted larvae were examined under a microscope for presence of an anal comb, which is absent in codling moth but present in oriental fruit moth and lesser appleworm. Larvae were preserved in alcohol.

Results and discussion:

European red mite (ERM) reached peak density in untreated check plots on 7/25/05 for motile stages (Table 2A) and on 7/11/05 for eggs (Table 3A). Stigmaeid predatory mites were present throughout the season but reached maximum density in early August (Table 4A). Phytoseiid predatory mites were absent in May but detected starting in mid-June and reached maximum density in late July (Table 5A). Apple rust mite was present in all treatments and peaked in late June (Table 6A). No phytotoxicity was observed.

There were statistically significant differences among the 17 treatments (P<0.01)in density of ERM motiles on the first seven sampling dates but not on the eighth date (Table 2A). When analyzed for effects of the main factors (Table 2B), prebloom application of oil had a significant effect from early May until late June, with significantly fewer mites in plots sprayed with oil than in plots not sprayed with oil. There was a significant effect of Savey from early June until early August, with significantly fewer mites in plots sprayed with Savey than in plots not sprayed with Savey. There was no significant effect of insecticide on any of the 8 sampling dates; ERM density was the same in plots treated with the 3 insecticide combinations and in the untreated check.

The cumulative effect of treatments on European red mite is shown by mite-day totals (Table 2A, final column), which differed significantly among the 17 treatments. Cumulative mite-days ranged from a low of 115 in treatment 10 to a high of 3673 in treatment 3. There was no significant difference between Zeal in treatment 17 and Savey in treatment 8. As shown in the analysis of main factors, there was a significant effect of oil, which resulted in lower mite-days where oil was used; a significant effect of Savey, which also resulted in lower mite-days where Savey was used; and a significant effect of insecticide, which resulted in significantly higher mite-days in the Asana/Calypso treatments. There was less disruption of ERM when Asana was used late than when used early. Within each of the three insecticide treatments, there was a consistent trend of higher mite-days where no oil and no miticide were used. Use of miticide (Savey or Zeal) had a much greater impact on mite-days than use of oil. Although the benefits of oil were shorter lived than Savey, it must be remembered that oil has great benefit in resistance management, and its use in combination with miticide is strongly encouraged.

The effects of oil and Savey treatment on density of ERM eggs were similar to effects on ERM motiles; plots treated with oil had significantly fewer eggs until late June, and plots treated with Savey had significantly fewer eggs until mid-July (Table 3A). The effect of insecticide on ERM eggs was different than ERM motiles; on the last 3 sampling dates, there were significantly more ERM eggs in some treatments than others. On the final sampling date in early August, there were significantly more ERM eggs in plots that had been treated in late July with Asana.

Density of stigmaeid predatory mites (*Zetzellia mali*) showed no significant effect of oil, Savey, or insecticide (Table 4B), but density of phytoseiid predatory mites (*Neoseiulus fallacis*) showed significant effects of insecticide in July (Table 5B), which was the time of peak density of their prey, ERM motiles; there were significantly more phytoseiid predators on 7/11/05 in the plots that had been treated with Asana for control of first generation codling moth. Apple rust mite, which is important as alternate prey for predatory mites, showed no significant effect of oil or Savey, but was significantly affected by insecticide (Table 6B); in mid-June, there were more rust mites in the untreated plots than in insecticide-treated plots, and in late June and mid-July, there were fewest rust mites where Rimon had been used.

White apple leafhopper showed a slight but insignificant effect by treatment at petal-fall; nymphs were detected on 5/13/05 only in plots that had not been treated with Avaunt at petal-fall. Although density of leafhopper nymphs was low on 5/13/05, there were significant treatment differences in damage by the end of nymphal development in late June. Leafhopper damage was significantly higher in plots where no insecticide and no miticide were used but where oil was used, than in any other treatments (Table 7).

Codling moth adults reached peak density in pheromone traps on 6/6/05 for the overwintering generation and on 7/29/05 for the summer generation (Table 8). Lesser appleworm adults peaked at the same time as codling moth for first flight, but on 7/18/05 for the second flight, which was earlier than codling moth. Although the cumulative degree-days showed the potential for a third brood of eggs, the catch of adults did not indicate the emergence of a second summer generation generation.

The most important insect injury at harvest was internal lepidoptera, which affected 0.0 to 15.9% of fruit (Table 9A). Tarnished plant bug injury and plum curculio oviposition injury were also found in most plots. A few plots had rosy apple aphid or San José scale damage, and there was a trace of late leafroller damage and late plum curculio adult feeding damage. Analysis showed significant treatment effects for internal Lepidoptera and plum curculio (Table 9A). Analysis of main treatment factors showed a significant effect of insecticide (Table 9B), which was significantly lower in all three insecticide treatments than in the untreated check, for internal lepidoptera and plum curculio.

The survey of internal Lepidoptera species in apple fruit resulted in 43 larvae from five counties (Table 10). Forty-one of the 43 larvae were codling moth. Only one Oriental fruit moth (OFM) larva was found; it was assumed to be OFM rather than LAW based on pheromone trap records at that orchard. The OFM was from Sandusky County, from one of the two orchards that were already known to have OFM in apples. One non-tortricid species was found in a Franklin County research orchard. To be meaningful, this survey needs to be much more intensive and include many more orchards, but the sample size was limited in 2005 due to shortage of time.

<u>Conclusions</u>:

All three insecticide programs provided equally excellent control of codling moth. Zeal provided mite control equal to Savey. Predatory mites were found in most plots, and they were not adversely affected by pyrethroid use. The pyrethroid caused less mite flare-up when used for second generation codling moth control than when used for first generation codling moth control. The density of European red mite showed that there were strong interactions between mite treatments and insecticide treatments. Where a pyrethroid like Asana was used without pre-bloom oil or post-bloom miticide, heavy infestations of mites resulted, but where a miticide was used along with a pyrethroid, mite populations were kept at tolerable levels. When oil was used pre-bloom and no miticide was used post-bloom, mites were suppressed only until mid-June. Despite this short period of control, use of pre-bloom oil is advocated for its benefit in resistance management.

Table 2A. Number of European red mite MOTILES per leaf (mean of four blocked replicates) on Delicious apple leaves in 17 treatments on eight sampling dates in 2005 at OSU's Waterman Lab, Columbus, Ohio.

Treatment				Date								Cumu-lative Mite days
	Oil	Miti-cide	Insecticide (1st gen./2nd gen[a])	5/5	5/17	6/1	6/13	6/27	7/11	7/25	8/8	
1	Yes	none	Asana/Calypso	0.5	0.2	0.4	2.8	32.4	82.3	130.5	13.6	3574 A
2	Yes	Savey	Asana/Calypso	0.4	0.3	0.3	0.1	1.3	6.5	5.5	2.5	216 D
3	No	none	Asana/Calypso	3.4	1.4	3.0	12.3	75.2	123.	41.7	10.9	3673 A
4	No	Savey	Asana/Calypso	4.9	2.0	1.9	0.9	1.4	5.4	2.3	1.0	221 D
5	Yes	none	Rimon/Assail	0.5	0.4	0.7	1.4	7.5	66.9	53.2	22.4	1981 BC
6	Yes	Savey	Rimon/Assail	0.7	0.4	0.5	0.2	0.8	3.9	15.4	2.4	317 D
7	No	none	Rimon/Assail	3.5	0.8	4.4	6.0	43.3	87.6	70.8	10.0	3064 AB
8	No	Savey	Rimon/Assail	5.2	1.9	2.9	0.8	1.2	7.4	17.5	3.9	501 CD
9	Yes	none	Imidan/Asana	0.9	0.5	1.9	5.8	41.1	89.7	57.6	9.2	3016 AB
10	Yes	Savey	Imidan/Asana	0.9	0.6	0.6	0.7	1.0	2.4	2.2	1.0	115 D
11	No	none	Imidan/Asana	3.3	0.8	3.5	9.5	42.9	81.5	23.3	4.7	2300 AB
12	No	Savey	Imidan/Asana	5.7	2.3	1.5	1.4	1.0	3.8	30.6	1.2	608 CD
13	Yes	none	none/none	0.4	0.2	0.4	1.4	8.2	28.5	6.9	2.2	654 CD
14	Yes	Savey	none/none	0.8	0.4	0.2	0.2	1.0	3.7	4.8	1.8	164 D
15	No	none	none/none	3.8	1.1	4.8	10.2	33.4	76.0	77.6	9.0	2916 AB
16	No	Savey	none/none	3.9	1.1	1.6	0.5	0.9	2.7	23.7	1.3	457 CD
17	No	Zeal	Rimon/Assail	1.6	1.7	0.6	0.3	1.0	7.5	25.4	26.2	703 CD
Probability value, treatment effect				*.0003*	*.004*	*.0006*	*.0001*	*.0001*	*.0001*	*.004*	*.06*	*0.0001*

Table 2B. Main treatment effects on number of European red mite MOTILES per leaf (mean of four blocked replicates) on Delicious apple leaves in 17 treatments on eight sampling dates in 2005 at OSU's Waterman Lab, Columbus, Ohio.

Treatment	Date								Cumu-lative Mite days
	5/5	5/17	6/1	6/13	6/27	7/11	7/25	8/8	
With oil	0.6 B	0.4 B	0.6 B	1.5 B	11.2 B	35.5	35.2	7.2	1227 B
No Oil	4.2 A	1.4 A	2.9 A	5.4 A	25.1 A	48.4	34.4	5.0	1688 A
P, oil effect	*0.0001*	*0.0001*	*0.0001*	*0.0007*	*0.0134*	*0.27*	*0.81*	*0.57*	*0.0001*
With Savey	2.6	1.1 A	1.1 B	0.6 B	1.1 B	4.5 B	12.6 B	1.9 B	394 B
No Savey	1.9	0.6 B	2.3 A	6.1 A	34.4 A	78.6 A	55.7 A	10.5 A	2511 A
P, Savey effect	*0.16*	*0.0047*	*0.0039*	*0.0001*	*0.0001*	*0.0001*	*0.0001*	*0.0025*	*0.0001*
Asana/Calypso	2.3	1.0	1.4	4.0	27.5	54.2	47.8	7.0	1934 A
Imidan/Asana	2.5	0.9	2.0	4.8	24.1	49.2	29.7	4.3	1621 B
Rimon/Assail	2.1	0.8	1.6	1.5	8.3	34.9	34.7	10.0	1226 C
None/none	2.2	0.7	1.7	3.1	10.9	27.7	28.2	3.6	1048 C
P, Insecticide effect	*0.92*	*0.41*	*0.72*	*0.43*	*0.09*	*0.36*	*0.51*	*0.35*	*0.0001*

Table 3A. Number of European red mite EGGS per leaf (mean of four blocked replicates) on Delicious apple leaves in 17 treatments on eight sampling dates in 2005 at OSU's Waterman Lab, Columbus, Ohio.

Treatment				Date							
	Oil	Miti-cide	Insecticide (early/late)	5/5	5/17	6/1	6/13	6/27	7/11	7/25	8/8
1	Yes	none	Asana/Calypso	0	1	1	18	87	330	97	11
2	Yes	Savey	Asana/Calypso	0	2	2	2	30	156	198	35
3	No	none	Asana/Calypso	0	15	13	64	141	128	43	14
4	No	Savey	Asana/Calypso	0	18	31	21	46	169	93	38
5	Yes	none	Rimon/Assail	0	1	1	8	59	230	132	57
6	Yes	Savey	Rimon/Assail	0	2	3	2	17	94	140	38
7	No	none	Rimon/Assail	0	16	7	26	175	161	99	17
8	No	Savey	Rimon/Assail	0.14	15	31	22	51	207	269	157
9	Yes	none	Imidan/Asana	0	3	3	28	156	238	70	10
10	Yes	Savey	Imidan/Asana	0	2	6	3	19	64	54	14
11	No	none	Imidan/Asana	0.02	7	8	38	110	162	29	6
12	No	Savey	Imidan/Asana	0.07	22	23	24	42	104	69	22
13	Yes	none	none/none	0	1	1	6	49	134	96	6
14	Yes	Savey	none/none	0	2	2	5	20	43	37	18
15	No	none	none/none	0.15	15	9	46	97	179	72	11
16	No	Savey	none/none	0.10	14	17	7	24	49	119	9
17	No	Zeal	Rimon/Assail	0	9	18	9	43	151	250	206
Probability value, treatment effect				*0.02*	*0.002*	*0.0001*	*0.0001*	*0.0001*	*0.0002*	*0.003*	*0.0001*

Table 3B. Main treatment effects on number of European red mite EGGS per leaf (mean of four blocked replicates) on Delicious apple leaves on eight sampling dates in 2005 at OSU's Waterman Lab, Columbus, Ohio.

Treatment	Date							
	5/5	5/17	6/1	6/13	6/27	7/11	7/25	8/8
With oil	0.00 B	2 B	2 B	9 B	54 B	161	104	25
No Oil	0.06 A	15 A	18 A	32 A	82 A	146	98	35
P, oil effect	*0.0026*	*0.0001*	*0.0001*	*0.0001*	*0.0104*	*0.39*	*0.96*	*0.08*
With Savey	0.04	9	14 A	10 B	30 B	111 B	126 A	42 A
No Savey	0.02	7	5 B	29 A	104 A	197 A	78 A	18 B
P, Savey effect	*0.33*	*0.34*	*0.0001*	*0.0001*	*0.0001*	*0.0001*	*0.08*	*0.0004*
Asana/Calypso	0.00	9	12	26	76	196 A	109 AB	24 B
Imidan/Asana	0.02	8	9	24	86	145 AB	54 B	12 B
Rimon/Assail	0.03	6	10	12	58	173 A	164 A	71 A
None/none	0.06	8	7	16	48	101 B	81 B	11 B
P, Insecticide effect	*0.10*	*0.99*	*0.43*	*0.21*	*0.15*	*0.0077*	*0.0035*	*0.0001*

Table 4A. Number of stigmaeid predatory mite motiles per leaf (mean of four blocked replicates) on Delicious apple leaves in 17 treatments on eight sampling dates in 2005 at OSU's Waterman Lab, Columbus, Ohio.

Treatment				Date							
	Oil	Miti-cide	Insecticide (early/late)	5/5	5/17	6/1	6/13	6/27	7/11	7/25	8/8
1	Yes	none	Asana/Calypso	0	0	0	0	0	0	0	0
2	Yes	Savey	Asana/Calypso	0	0	0	0	0	0	0	0.02
3	No	none	Asana/Calypso	0	0	0.02	0.02	0	0	0	0.02
4	No	Savey	Asana/Calypso	0	0	0	0	0	0	0	0.08
5	Yes	none	Rimon/Assail	0	0	0.04	0	0	0	0.02	0.06
6	Yes	Savey	Rimon/Assail	0	0	0.02	0	0	0	0	0
7	No	none	Rimon/Assail	0.07	0	0	0	0	0	0	0.05
8	No	Savey	Rimon/Assail	0.03	0	0	0	0	0	0	0.02
9	Yes	none	Imidan/Asana	0	0	0	0.02	0	0	0.02	0
10	Yes	Savey	Imidan/Asana	0.03	0	0	0.02	0	0	0	0
11	No	none	Imidan/Asana	0	0.02	0.08	0	0	0	0.06	0.10
12	No	Savey	Imidan/Asana	0.04	0	0	0	0	0	0.03	0.03
13	Yes	none	none/none	0	0	0	0	0	0	0.02	0.32
14	Yes	Savey	none/none	0	0	0	0	0	0	0	0.02
15	No	none	none/none	0	0	0	0	0.02	0	0	0.08
16	No	Savey	none/none	0.05	0	0	0	0.03	0	0	0.02
17	No	Zeal	Rimon/Assail	0.03	0	0	0	0	0	0	0
Probability value, treatment effect				*0.25*	*0.70*	*0.08*	*0.57*	*0.46*	-	*0.81*	*0.05*

Table 4B. Main treatment effects on number of stigmaeid predatory mites per leaf (mean of four blocked replicates) on Delicious apple leaves on eight sampling dates in 2005 at OSU's Waterman Lab, Columbus, Ohio.

Treatment	Date							
	5/5	5/17	6/1	6/13	6/27	7/11	7/25	8/8
With oil	0.003 B	0.000	0.009	0.006	0.000	0	0.009	0.053
No Oil	0.019 A	0.003	0.017	0.003	0.007	0	0.014	0.053
P, oil effect	*0.019*	*0.51*	*0.59*	*0.62*	*0.13*	-	*0.86*	*0.92*
With Savey	0.017	0.000	0.003	0.003	0.003	0	0.003	0.025
No Savey	0.004	0.003	0.022	0.006	0.003	0	0.018	0.081
P, Savey effect	*0.29*	*0.45*	*0.07*	*0.48*	*0.97*	-	*0.37*	*0.11*
Asana/Calypso	0.00	0	0.006	0.006	0.000	0	0.000	0.031
Imidan/Asana	0.014	0.006	0.025	0.012	0.000	0	0.029	0.038
Rimon/Assail	0.016	0	0.019	0.000	0.000	0	0.006	0.031
None/none	0.013	0	0.000	0.000	0.013	0	0.006	0.112
P, Insecticide effect	*0.22*	*0.63*	*0.48*	*0.36*	*0.12*	-	*0.29*	*0.16*

Table 5A. Number of phytoseiid predatory mite motiles per leaf (mean of four blocked replicates) on Delicious apple leaves in 17 treatments on eight sampling dates in 2005 at OSU's Waterman Lab, Columbus, Ohio.

Treatment				Date							
	Oil	Miti-cide	Insecticide (early/late)	5/5	5/17	6/1	6/13	6/27	7/11	7/25	8/8
1	Yes	none	Asana/Calypso	0	0	0	0	0.02	0.18	0.02	0.05
2	Yes	Savey	Asana/Calypso	0	0	0	0	0	0.13	0.32	0.25
3	No	none	Asana/Calypso	0	0	0	0	0.08	0.15	0.08	0.03
4	No	Savey	Asana/Calypso	0	0	0	0	0.02	0.18	0.13	0.10
5	Yes	none	Rimon/Assail	0	0	0	0	0.06	0.02	0.16	0.10
6	Yes	Savey	Rimon/Assail	0	0	0	0	0	0.04	0.12	0.08
7	No	none	Rimon/Assail	0	0	0	0	0	0	0.40	0
8	No	Savey	Rimon/Assail	0	0	0	0.02	0	0.02	0.18	0.18
9	Yes	none	Imidan/Asana	0	0	0	0	0.05	0	0.06	0.08
10	Yes	Savey	Imidan/Asana	0	0	0	0	0.02	0.05	0.95	0.08
11	No	none	Imidan/Asana	0	0	0	0.02	0.02	0.02	0.20	0.08
12	No	Savey	Imidan/Asana	0	0	0	0	0	0.10	0.53	0.23
13	Yes	none	none/none	0	0	0	0	0.02	0.08	0.45	0.10
14	Yes	Savey	none/none	0	0	0	0	0	0.08	0.18	0.02
15	No	none	none/none	0	0	0	0	0	0.02	0.08	0
16	No	Savey	none/none	0	0	0	0	0	0.05	0.20	0.18
17	No	Zeal	Rimon/Assail	0	0	0	0	0.08	0.02	0.12	0.05
Probability value, treatment effect				-	-	-	*0.73*	*0.85*	*0.38*	*0.01*	*0.08*

Table 5B. Main treatment effects on number of phytoseiid predatory mites per leaf (mean of four blocked replicates) on Delicious apple leaves on eight sampling dates in 2005 at OSU's Waterman Lab, Columbus, Ohio.

Treatment	Date							
	5/5	5/17	6/1	6/13	6/27	7/11	7/25	8/8
With oil	0	0	0	0.000	0.024	0.069	0.269	0.094
No Oil	0	0	0	0.007	0.017	0.070	0.203	0.100
P, oil effect	-	-	-	*0.24*	*0.65*	*0.99*	*0.51*	*0.88*
With Savey	0	0	0	0.003	0.006	0.079	0.320	0.134 A
No Savey	0	0	0	0.003	0.034	0.060	0.164	0.060 B
P, Savey effect	-	-	-	*0.95*	*0.19*	*0.38*	*0.08*	*0.0044*
Asana/Calypso	0	0	0	0.000	0.031	0.159 A	0.140 B	0.106
Imidan/Asana	0	0	0	0.006	0.025	0.038 B	0.395 A	0.106
Rimon/Assail	0	0	0	0.006	0.019	0.025 B	0.181 AB	0.100
None/none	0	0	0	0.000	0.006	0.056 B	0.225 AB	0.075
P, Insecticide effect	-	-	-	*0.65*	*0.73*	*0.0100*	*0.0446*	*0.73*

Table 6A. Apple rust mite density rating[a] (mean of four blocked replicates) on Delicious apple leaves in 17 treatments on eight sampling dates in 2005 at OSU's Waterman Lab, Columbus, Ohio.

Treatment				Date							
	Oil	Miti-cide	Insecticide (early/late)	5/5	5/17	6/1	6/13	6/27	7/11	7/25	8/8
1	Yes	none	Asana/Calypso	0.2	1.2	1.0	2.0	2.2	2.0	1.8	1.5
2	Yes	Savey	Asana/Calypso	0.5	0.8	1.0	1.8	2.2	1.8	1.2	2.0
3	No	none	Asana/Calypso	0.5	1.2	1.2	1.8	2.5	1.5	1.0	1.2
4	No	Savey	Asana/Calypso	1.0	1.2	1.8	2.0	2.0	2.0	1.3	1.5
5	Yes	none	Rimon/Assail	0.2	1.2	1.6	1.8	1.6	1.2	1.4	1.0
6	Yes	Savey	Rimon/Assail	0.6	1.0	1.2	1.6	2.0	1.6	1.4	1.0
7	No	none	Rimon/Assail	0.5	0.5	1.0	2.0	2.0	2.0	1.0	1.5
8	No	Savey	Rimon/Assail	0.8	1.8	1.5	2.0	2.0	2.0	1.8	1.5
9	Yes	none	Imidan/Asana	0.8	1.0	1.0	2.0	2.8	2.0	1.6	1.8
10	Yes	Savey	Imidan/Asana	0.8	1.0	1.5	2.0	3.0	2.2	1.8	1.5
11	No	none	Imidan/Asana	0.8	1.4	1.4	2.2	3.0	2.0	1.4	1.8
12	No	Savey	Imidan/Asana	0.3	1.0	1.7	2.0	3.0	2.3	2.0	1.7
13	Yes	none	none/none	0.5	1.0	1.5	2.2	2.8	2.0	1.8	1.8
14	Yes	Savey	none/none	0.8	1.5	2.0	2.5	2.8	2.2	1.5	1.5
15	No	none	none/none	0.5	1.0	1.8	2.2	3.0	2.0	1.5	2.0
16	No	Savey	none/none	0.8	1.0	1.5	2.2	3.0	1.8	1.2	1.8
17	No	Zeal	Rimon/Assail	1.0	1.0	1.2	1.2	2.0	1.8	1.5	2.0
Probability value, treatment effect				*0.62*	*0.18*	*0.47*	*0.01*	*0.0001*	*0.02*	*0.64*	*0.08*

[a] Density rating scale: 0 = none; 1 = low (<5 per leaf); 2 = moderate (5 to 50 per leaf); 3 = high (>50 per leaf).

Table 6B. Main treatment effects on apple rust mite rating[a] (mean of four blocked replicates) on Delicious apple leaves on eight sampling dates in 2005 at OSU's Waterman Lab, Columbus, Ohio.

Treatment	Date							
	5/5	5/17	6/1	6/13	6/27	7/11	7/25	8/8
With oil	0.5	1.1	1.4	2.0	2.4	1.9	1.5	1.5
No Oil	0.7	1.2	1.5	2.1	2.6	1.9	1.4	1.6
P, oil effect	*0.47*	*0.73*	*0.45*	*0.51*	*0.12*	*0.45*	*0.27*	*0.40*
With Savey	0.7	1.2	1.5	2.0	2.5	2.0	1.5	1.5
No Savey	0.5	1.1	1.3	2.0	2.5	1.8	1.5	1.6
P, Savey effect	*0.19*	*0.49*	*0.23*	*0.66*	*0.96*	*0.11*	*0.50*	*0.90*
Asana/Calypso	0.6	1.1	1.2 B	1.9 B	2.2 B	1.8 BC	1.3	1.6 A
Imidan/Asana	0.7	1.1	1.4 B	2.1 AB	2.9 A	2.1 A	1.6	1.7 A
Rimon/Assail	0.5	1.2	1.4 B	1.8 B	1.9 C	1.6 C	1.4	1.2 B
None/none	0.6	1.1	1.7 A	2.3 A	2.9 A	2.0 AB	1.5	1.8 A
P, Insecticide effect	*0.86*	*0.99*	*0.18*	*0.0062*	*0.0001*	*0.0215*	*0.28*	*0.0485*

Table 7. White apple leafhopper density and damage rating (mean of four blocked replicates) on Delicious apple leaves in 17 treatments on two dates in 2005 at OSU's Waterman Lab, Columbus, Ohio.

Treatment					Number of leafhopper nymphs per leaf on 5/13/05 (3 days after petal-fall spray)	Damage rating[1, 2] on 6/23/05 (17 days after 2C with Rimon; 8 days after 2C spray with Asana and Imidan)
	Oil (applied on 4/11)	Insecticide at Petal-fall	Miticide (applied on 5/20)	Insecticide used for first-generation codling moth control		
1	Yes	Avaunt	None	Asana (on 5/31 & 6/15)	0	0.00 B
2	Yes	Avaunt	Savey	Asana(on 5/31 & 6/15)	0	0.00 B
3	No	Avaunt	None	Asana (on 5/31 & 6/15)	0	0.00 B
4	No	Avaunt	Savey	Asana (on 5/31 & 6/15)	0	0.00 B
5	Yes	Avaunt	None	Rimon (on 5/23 & 6/6)	0	0.00 B
6	Yes	Avaunt	Savey	Rimon (on 5/23 & 6/6)	0	0.02 B
7	No	Avaunt	None	Rimon (on 5/23 & 6/6)	0	0.00 B
8	No	Avaunt	Savey	Rimon (on 5/23 & 6/6)	0	0.00 B
9	Yes	Avaunt	None	Imidan (on 5/31 & 6/15)	0	0.01 B
10	Yes	Avaunt	Savey	Imidan (on 5/31 & 6/15)	0	0.01 B
11	No	Avaunt	None	Imidan (on 5/31 & 6/15)	0	0.00 B
12	No	Avaunt	Savey	Imidan (on 5/31 & 6/15)	0	0.00 B
13	Yes	-	None	None	0.02	0.22 A
14	Yes	-	Savey	None	0	0.03 B
15	No	-	None	None	0.01	0.04 B
16	No	-	Savey	None	0.01	0.05 B
17	No	Avaunt	Zeal	Rimon (on 5/23 & 6/6)	0	0.00 B
Probability value for treatment effect, from ANOVA					*P = 0.10*	*P = 0.0001*

[1] Within each column, means followed by same letter are not significantly different (*P*>0.05); mean separations by LSD.
[2] Damage rating scale: 0 = none; 1 = light; 2 = moderate; 3 = heavy.

Table 8. Seasonal activity of codling moth and lesser appleworm as monitored by pheromone traps, and degree days for codling moth after trap-based biofix on 5/11/05, in apple orchards at OSU's Waterman Lab, Columbus Ohio.

Date	Codling moths caught in previous 7 days				Lesser appleworm caught in previous 7 days	Cumulative degree days[c] (base 50F) after biofix
	Trap 1[a]	Trap 2[a]	Trap 3[b]	Mean of 3 traps		
4/27	0	0	0	0.0	0	-
5/4	0	0	0	0.0	0	-
5/11	5	4	0	3.0	19	23
5/18	12	6	6	8.0	6	85
5/25	9	17	6	10.7	5	159
6/1	14	18	6	12.7	15	258
6/8	16	22	18	18.7	37	434
6/15	19	18	18	18.3	17	626
6/22	8	2	6	5.3	7	757
6/29	8	5	5	6.0	12	954
7/6	3	3	2	2.7	11	1103
7/13	5	2	2	3.0	13	1279
7/20	6	0	1	2.3	29	1480
7/27	7	5	1	4.3	14	1693
8/3	12	8	2	7.3	13	1873
8/10	7	6	5	6.0	11	2065
8/17	4	4	7	5.0	13	2254
8/24	4	2	3	3.0	6	2428
8/31	4	4	4	4.0	5	2597
9/7	6	3	2	3.7	7	2738
9/14	5	3	6	4.7	8	2900
9/21	2	3	4	3.0	7	3050
9/28	2	1	2	1.7	2	3189
10/5	0	2	5	2.3	2	3303
10/12	0	3	0	1.0	0	3369

[a] Traps 1 and 2 located in check plots in orchard where trial conducted.
[b] Trap 3 located in check plot in older orchard 50 meters from orchard where trial conducted.
[c] Degree-days calculated as mean of daily maximum and minimum temperature, base 50F, with threshold temperature substituted for minimum temperature if actual minimum below threshold.

Table 9A. Insect injury on Delicious apple fruit at harvest on 26 September 2005, based on sample of 100 fruit per plot; OSU's Waterman Lab, Columbus, Ohio.

Treatment				Percentage of fruit (mean of 4 blocked replicates)[a]					
	Oil	Miti-cide	Insecticide (1st generation/ 2nd generation)	Clean	Internal lepido-ptera [b]	Tarnished plant bug	Plum curculio oviposition	Rosy apple aphid	San José scale
1	Yes	none	Asana/Calypso	97.2 A	0.0 C	0.7	0.0 C	2.1	0.0
2	Yes	Savey	Asana/Calypso	98.4 A	0.6 C	0.7	0.3 BC	0.0	0.0
3	No	none	Asana/Calypso	96.4 ABC	0.3 C	1.7	1.1 BC	0.0	0.0
4	No	Savey	Asana/Calypso	96.3 AB	0.2 C	2.3	0.7 BC	0.0	0.0
5	Yes	none	Rimon/Assail	97.1 AB	0.2 C	2.1	0.4 BC	0.2	0.0
6	Yes	Savey	Rimon/Assail	98.1 A	0.0 C	1.2	0.2 BC	0.3	0.0
7	No	none	Rimon/Assail	94.6 ABC	0.0 C	4.3	1.1 BC	0.0	0.0
8	No	Savey	Rimon/Assail	98.3 A	0.0 C	1.5	0.0 C	0.2	0.0
9	Yes	none	Imidan/Asana	97.0 AB	0.3 C	2.0	0.7 BC	0.0	0.0
10	Yes	Savey	Imidan/Asana	98.3 A	1.0 C	0.5	0.2 BC	0.0	0.0
11	No	none	Imidan/Asana	97.2 AB	1.0 C	0.9	0.8 BC	0.2	0.0
12	No	Savey	Imidan/Asana	97.0 ABC	0.0 C	1.6	0.0 C	1.1	0.0
13	Yes	none	None/none	62.0 E	15.9 A	1.6	15.5 A	0.0	1.0
14	Yes	Savey	None/none	81.9 D	11.5 AB	2.0	3.5 B	0.0	0.0
15	No	none	None/none	90.1 BCD	4.9 B	3.2	0.9 BC	0.0	0.0
16	No	Savey	None/none	86.3 CD	10.4 AB	1.6	0.5 BC	0.3	0.0
17	No	Zeal	Rimon/Assail	98.0 A	0.0 C	1.5	0.5 BC	0.0	0.0
Probability value from ANOVA				*0.0001*	*0.0001*	*0.44*	*0.01*	*0.77*	*0.47*

[a] Within each column, means followed by same letter are not significantly different (P>0.05); mean separations by LSD. Values shown are actual percentages but ANOVA based on transformed values.
[b] The target populations were codling moth and lesser appleworm; Oriental fruit moth was absent.

Table 9B. Effect of insecticide program on insect injury on Delicious apple fruit at harvest on 26 September 2005, based on sample of 100 fruit per plot; OSU's Waterman Lab, Columbus, Ohio.

Treatment	Insecticide (1st generation/ 2nd generation)	Percentage of fruit (mean of 4 blocked replicates)[a]					
		Clean	Internal lepidoptera	Tarnished plant bug	Plum curculio oviposition	Rosy apple aphid	San José scale
1, 2, 3, 4	Asana/Calypso	97.1 A	0.3 B	1.3	0.5 B	0.5	0.0
5, 6, 7, 8	Rimon/Assail	97.5 A	0.1 B	1.9	0.3 B	0.2	0.0
9, 10, 11, 12	Imidan/Asana	97.4 A	0.6 B	1.2	0.5 B	0.3	0.0
13, 14, 15, 16	none/none	80.1 B	10.7 A	2.1	5.1 A	0.1	0.3
Probability value from ANOVA		*0.0001*	*0.0001*	*0.16*	*0.0051*	*0.92*	*0.40*

[a] Within each column, means followed by same letter are not significantly different (P>0.05); mean separations by LSD. Values shown are actual percentages but ANOVA based on transformed values.

Table 10. Caterpillar species found in Ohio apples, 2005.

County	Orchard type	Date	Number of larvae	Species
Franklin	Research	7/7/05	4	Codling moth
Franklin	Research	9/26/05	13	Codling moth
Franklin	Research	9/27/05	4	Codling moth
Franklin	Research	9/30/05	1	Non-tortricid
Franklin	Research	10/6/05	2	Codling moth
Erie	Commercial	7/12/05	1	Codling moth
Erie	Commercial	8/9/05	3	Codling moth
Erie	Commercial	8/25/05	1	Codling moth
Sandusky	Commercial	7/18	1	Oriental fruit moth
Lorain	Commercial	7/27	1	Codling moth
Lorain	Commercial	7/27	4	Codling moth
Fairfield	Commercial	8/25	8	Codling moth