Obliquebanded Leafroller Management for Apple Production: Investigating Strategies for Resistance Management with Emerging Insecticide Tools

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The Tortricidae, a family of lepi dopteran insects, have challenged New York State fruit growers since the arrival of the first European apple trees in the early 17th century. 'Apple worms' and surface feeding larvae continue to damage our commercially grown fruit. This 'Lepidoptera Complex' includes numerous species, more commonly known as the codling moth, oriental fruit worm, lesser apple worm, and the obliquebanded leafroller. In abandoned and poorly managed orchards many more species can be found, comprising a very diverse complex of insect pests feeding on the fruit, foliage, and wood of apple throughout the northeast.

Agricultural research conducted during the past 100 years has provided a variety of literature citations regarding insecticide resistance of the insect pest complex plaguing the apple. The codling moth is the most notable of these pests, exhibiting insecticide resistance during the early era of chemical development. Its believed to be the first lepidopteran insect noted to be resistant to the arsenical insecticides in the late 1920's and again shortly after the development of DDT. Recent reports from Western New York, Michigan, Ohio and Pennsylvania indicate a significant increase of the internal lepidopteran complex (codling moth, oriental fruit worm and lesser apple worm) in commercially managed loads of fruit, demonstrating an increase in tolerance to the organophosphate (OP) class of insecticides (Reissig et al. 2005). Reissig and Waldenstein (2000) reported insecticide resistance of the Obliquebanded leafroller (OBLR): *Choristoneura rosaceana* (Harris) to the organophosphate insecticide (OP), Azinphosmethyl, in 1999, in addition to cross-resistance to the insecticide, tebufenozide (Confirm) prior to significant commercial use, In recent studies using 'soft' insecticide programs throughout NYS, the OP resistance in OBLR appears relatively stable, forcing producers to find OP replacements for OBLR management (Reissig et al.,).

Why then are we seeing insecticide resistance in some insects and not in others? In commercial apple production we observe many resistant insect species to have endemic life cycles. That is to say these insects typically begin and complete their life cycles within the orchard environment. They often have more than one generation per year leading to increased selection pressure. Three mechanisms of resistance that can be exhibited by insects resistant to insecticides are either morphological (physical 'mutations'), through altered behavior, or metabolic, through detoxification mechanisms. Two additional factors influencing selection for resistance are the potency and persistence of the insecticides we use (Walsh, 1999).

Current thinking on managing insecticide resistance lies in *rotation of insecticide classes.* By making field applications of a different insecticidal group for each insect generation, selection pressure can be decreased, minimizing the resistance potential. The insecticides effective on OBLR today may not be effective tomorrow. Although SpinTor has been highly effective on the OBLR, its ability to manage leafrollers in western states is declining. The rotation of materials will increase the longevity of the materials effective in managing the OBLR.

When the potency or environmental prevalence ("selection pressure") of an insecticide is great and the insecticide is used extensively over a large geographic area, the likelihood of developing tolerance or resistance in pest populations is substantial. The selection differential that an insecticide imposes on a population is then a mixture of many variables (Falconer, 1981).

Examples of insects resistant to commonly used insecticides in the Northeast are found within the mite complex, the aphid complex, the leafminer complex and the lepidopteran complex, San Jose scale, and the white apple leafhopper. Yet insects such as the plum curculio and apple maggot have not exhibited resistance to the OP's Guthion (Azinphosmethyl) and Imidan (Phosmet), in use since the early 1960's. In commercially managed orchards these pests typically have one generation per year and are regionally or locally migratory. They characteristically have mates that exist on alternate hosts with a greater genetic diversity from their limited expo-

Photo 1. Overwintering OBLR larval damage on spur red delicious.

Photo 2. 1st generation OBLR larval damage on spur red delicious

sure to the selection pressure of season long insect management programs. They pass along this genetic diversity to the next generation reducing selection pressure for resistance.

The development of insecticide resistance has over the years prompted significant research and development into new methods and materials for managing insect pest populations. Since the 1980's we've seen a shift away from the development of organochlorine, organophosphate and carbamate classes of insecticides (Class 1 - neurotoxins which inhibit acetylcholine esterase of the nervous system in both insects and mammals, making them toxic to humans). Beginning with the introduction of pyrethroids (Class 3) the industry has moved toward new chemistries with novel modes of action (MoA). Of the new classes of chemistries, the earliest of the reduced risk materials developed were the fermentation microbial products (derived from the bacteria *Bacillus thuringiensis* or Bt's) and juvenile hormone analogs (Insect growth regulators). The fermentation microbial products include Bt's (Class 11 - Dipel), the abamectins (Class 6 - AgriMek, Proclaim) and spinosads (Class 5 – SpinTor, Delegate). The juvenile hormone analogs include insect growth regulators: Formamidines (Class 19 - Mitac) and Thiadiazines (Class 18 - Neem), and the juvenile hormone mimics (Class 7 - Esteem, Confirm, Intrepid). We have also seen a wave of new chemistries currently in use or on the horizon including the neonicotinyls (Class 4A - Provado, Assail, Actara, Calypso), carboxamides (Class 10 - Savey), carboxylic acid esters (Acramite), granulosis viruses for codling moth, diphenyloxazolines (Class 10 - Zeal), benzoyl urea growth regulators (Class 15 - Novaluron), tetronic acids (Class 23 - Envidor), oxadiazenes (Class 22 - Avaunt), particle films (Surround), phenoxypyrazoles (Class 2 - Fujimite), pheromones for mating disruption (including Isomate products), pyridazinones (Class 21 - Nexter), tetrazines (Class 10 - Apollo), quinolines (Class 20 - Kanemite) and the diamides (Class 28 - Altacor).

Is insecticide resistance manageable?

Current thinking on managing insecticide resistance lies in *insecticide rotation of insecticide classes*. By knowing the insecticidal mode of action or insecticide class *and* making field applications of a different insecticidal group for each insect generation, selection pressure can be decreased, minimizing the resistance potential.

Bringing this to a practical level, managing resistance for the OBLR will require the use of two or three different classes of insecticide for each generation for which we make applications during each season. In the Hudson Valley many growers are specifically targeting the over-wintering OBLR generation during the pre-bloom / early post bloom period with at least one application. Leafroller damage during this period often aborts from the tree and harvest damage appears heavily callused (Figure 1). Two to three additional applications are used to manage the 1st generation summer surface feeding damage (Figure 2) in mid-June – July. An additional application is applied in late August or early September to reduce 2nd generation damage to late varieties (Figure 3) and reduce the over-wintering population for the following season.

The materials currently registered in NYS, effective for managing the OBLR, are available in six different MoA classes that include: Lorsban & Lannate – Class 1A & 1B; Pyrethroids (Ambush, Pounce, Asana, Baythroid, Danitol, Warrior) – Class 3; SpinTor – Class 5; Proclaim – Class 6; Bt (Biobit, Dipel, Javlin, MVP) – Class 11B; Intrepid – Class 18A. Through the judicious use of these insecticides, their placement can be made to both optimize OBLR management through rotation of classes while achieving management of other insect pests requiring attention.

2006 OBLR Study

To determine how well some of these insecticides would work against an OP resistant population of OBLR, we conducted a trial in 2006, making treatments to single-tree plots of 'Red Delicious' replicated in a randomized complete block design in Milton, NY.

Treatments were applied on schedule shown in Tables 1-4. Developmental phenology corresponding to application dates beginning at pink (P) occurred on 25 April; 340 DD first hatch of the OBLR or fifth cover (5C) on 30 June, sixth cover (6C) on 18 July. Damage to fruit was assessed by randomly selecting 100 fruit on 3 evaluation dates; 8 June prior to 'June drop', mid-season on 19 July and at harvest on 21 September of 'Red Delicious'. Fruit were rated in the field and scored for external damage for OBLR for each generation that caused fruit injury and early season damage by TPB. Terminal rating for

Photo 3. 2nd generation OBLR larval damage of Jonamac at harvest.

Photo 4. Adult Obliquebanded leafroller **(OBLR).**

TABLE 1

Evaluation of insecticides for controlling overwintering obliquebanded leafroller larvae on apple[1], Crist Brothers Orchard., Milton, N.Y.-2006

Treatment	Formulation amt./100 gal.	Timing	OBLR feeding damage to foliage # terminals/3 min. eval.	# OBLR larvae /3 min. eval.	"June Drop" % damaged fruit TPB	"June Drop" % damaged fruit OBLR	% Clean
1.Lorsban 4EC	16.0 oz.	Pink	1.4 ab	0.0 a	0.0 a	0.2 a	99.5 c
2.Calypso 4SC	2.0 oz.	Pink	2.4 bc	0.2 a	0.2 a	0.9 a	98.6 bc
3.Asana XL 0.66EC	5.8 oz.	Pink	1.0 ab	0.7 a	0.2 a	0.7 a	98.6 bc
4.Baythroid 2E	1.7 oz.	Pink	0.0 a	0.0 a	0.2 a	0.0 a	99.5 c
5.Dipel DF	10.7 oz.	Pink	8.2 cd	0.7 a	1.4 a	2.6 a	96.3 a
6.Intrepid 2F	5.3 oz.	Pink	2.1 abc	0.0 a	0.0 a	2.2 a	99.5 c
7.Untreated			11.5 d	0.0 a	0.7 a	2.6 a	96.8 a

[1] Data from 'Red Delicious evaluation on 8 June prior to "June drop".

TABLE 2

Evaluation of insecticides for controlling summer obliquebanded leafroller larvae on apple[1], Crist Brothers Orchard., Milton, N.Y.-2006

Treatment	Formulation amt./100 gal.	Timing	OBLR feeding damage to foliage # terminals / 3 min. eval.	# live OBLR larvae/ terminal 3 min. eval.	% OBLR damaged fruit mid-season fruit injury
1. Danitol 2.4EC	3.6 oz.	340 DD (5C), 6C	1.3 ab	0.5 a	0.0 a
2. Calypso 4SC	2.0 oz.	340 DD (5C), 6C	9.3 c	5.5 b	0.8 a
3. Asana XL 0.66EC	5.8 oz.	340 DD (5C), 6C	3.3 b	1.0 a	0.0 a
4. Baythroid 2E	2.0 oz.	340 DD (5C), 6C	0.3 a	0.0 a	0.0 a
5. Dipel DF	10.7 oz.	340 DD (5C), 6C	0.9 a	0.5 a	0.0 a
6. Intrepid 2F	5.3 oz.	340 DD (5C), 6C	1.0 ab	0.0 a	0.0 a
7. Untreated		-	15.0 c	8.5 b	1.0 a

1 Data from 'Red Delicious evaluation on 19 July. 340 DD application made on 30 June, 6C on 18 July.
Treatment means followed by the same letter are not significantly different. Mean separation by Fishers Protected LSD (P=<0.05; LSD). Data were transformed to log10(x+1) for analysis. Percent fruit damage data were transformed using the arcsineee transformation for analysis. Untransformed field means presented.

TABLE 3

Harvest evaluation of insecticides for controlling obliquebanded leafroller larvae on apple[1], Crist Brothers Orchard., Milton, N.Y.-2006

Treatment	Formulation amt./100 gal.	Timing	% OBLR damaged fruit at harvest early season fruit injury	% OBLR damaged fruit at harvest late season fruit injury
1. Danitol 2.4EC	3.6 oz.	340 DD (5C), 6C	0.3 a	2.3 bc
2. Calypso 4SC	2.0 oz.	340 DD (5C), 6C	0.3 a	3.3 cd
3. Asana XL 0.66EC	5.8 oz.	340 DD (5C), 6C	0.0 a	1.0 abc
4. Baythroid 2E	2.0 oz.	340 DD (5C), 6C	0.3 a	0.3 a
5. Dipel DF	10.7 oz.	340 DD (5C), 6C	0.8 a	2.8 bc
6. Intrepid 2F	5.3 oz.	340 DD (5C), 6C	0.3 a	0.0 a
7. Untreated		-	0.5 a	9.3 d

[1]Data from 100 ' Red Delicious' fruit. Evaluation on 21 September. 340 DD application made on 30 June, 6C on 18 July.

OBLR was conducted on 8 June and 19 July by counting the number of terminals exhibiting OBLR feeding damage in three minutes / tree. To stabilize variance in fruit % damage evaluations, transformation using the arcsine *(square root of x) was conducted prior to analysis while the transformation using the Log_{10} (X + 1) was used for foliar evaluations. Fisher's Protected LSD (P=<0.05) was performed on all data and untransformed data are presented in each table

Results and Discussion

The over-wintering generation of OBLR larvae was suppressed by sustained pre-bloom rainfall and extended cool temperatures, representing very low orchard presence and fruit damage (Table 1). A single application at the phenological pink stage of apple to manage larval damage, evaluated on 8 June, showed Baythroid 2E and Lorsban 4EC provided excellent numeric reductions of foliar feeding, larval presence and lowest early-season fruit damage while Calypso 4SC and Dipel DF gave less overall suppression of the population. Applications for the summer generation evaluated on 19 July demonstrated low levels of injury in the untreated trees of 1% with overall suppression of the population by all insecticide treatments. Excellent control of foliar feeding and larval reduction was achieved by Baythroid 2E, Intrepid 2F and Dipel DF and significantly less control with Calypso 4SC (Table 2). Evaluations made at harvest (Table 3) demonstrated >9% fruit injury caused by the summer generation in the untreated trees. Excellent control of fruit feeding was obtained by Intrepid 2F, Baythroid 2E and Asana XL. Suppression of the green aphid complex was best obtained by Calypso 4SC and Asana XL (Table 4).

TABLE 4

Evaluation of insecticides for controlling green aphid complex on apple [1], Crist Brothers Orchard., Milton, N.Y.-2006

Treatment	Formulation amt./100 gal.	Timing	Green aphid complex* rating 0 – 3 on apical lvs.
1. Danitol 2.4EC	3.6 oz.	340 DD 1st hatch	2.7 c
2. Calypso 4SC	2.0 oz.	340 DD 1st hatch	0.9 a
3. Asana XL 0.66EC	5.8 oz.	340 DD 1st hatch	1.9 b
4. Baythroid 2E	1.7 oz.	340 DD 1st hatch	2.6 c
5. Dipel DF	10.7 oz.	340 DD 1st hatch	2.7 c
6. Intrepid 2F	5.3 oz.	340 DD 1st hatch	2.8 c
7. Untreated			2.8 c

Data from ' Red Delicious evaluation on 5 July.
* GAA = Green apple aphid / Spirea aphid. Rating of 0-3 for green apple aphids / leaf (0=0 GAA / lf, 1 = 1-10 GAA / lf, 2 = 11-50 GAA / lf, 3 = >50 GAA / lf).

Phytophagous and predacious mite populations were also evaluated by sampling 25 leaves from each plot on 19 July. Sustained rainfall throughout the season and relatively mild temperatures provided less opportunity for mite populations to reach action threshold in commercial orchards. In all treatments (Table 5), the phytoseiids were prevalent throughout the plots. Higher numbers of ERM were observed in the untreated treatment, with lowest numbers observed in the Lorsban 4EC / Danitol 2.4EC treatments. There was no evidence of flaring of ERM, TSM or rust mite populations. There were no detrimental effects on predatory mites observed in the plots. However, the phytoseiids present were *Neoseiulus (=Amblyseius) fallacies,* which respond to pyrethroid applications in a 'rebound' response compared to *Typhlodromus pyri,* which often are removed from the orchard environment after a pyrethroid application.

'Why fix it if it ain't broke' ?

The insecticides effective on OBLR today may not be effective tomorrow. Although SpinTor has been highly effective on the OBLR, its ability to manage leafrollers after extensive use in western states is now declining. The rotation of materials will increase the longevity of the materials effective at managing the OBLR.

To construct a practical plan for managing resistance, begin foremost with monitoring for the adult male flight through the use of pheromone traps to determine the biofix (Figure 4). When you start seeing a 'sustained flight', begin the calculation of degree days on your farm or through the NEWA degree day calculator (http://www.nysaes.cornell.edu/ipm/specware/newa/), which will assist you in making a more accurate timing of the insecticide for first hatch of the summer generation (340 DD base 43°F). Incorporating insecticide efficacy, placement timing for optimum use, efficacy spectrum for managing additional key pests, and possible negative consider-

TABLE 5

Evaluation of insecticides for controlling phytophagous and predatory mite complex on apple[1], Crist Brothers Orchard., Milton, N.Y.-2006

Treatment	Formulation amt./100 gal.	Timing	#mite or egg/leaf[1] ERM	ERME	TSM	TSME	AMB	AMBE	ZM	ZME	ARM
1. Lorsban 4EC	16.0 oz.	Pink	0.1 a	0.4 a	0.0 a	0.1 a	0.1 a	0.1 a	0.0 a	0.0 a	0.0 a
Danitol 2.4EC	3.6 oz.	340 DD 1st hatch									
2. Calypso 4SC	2.0 oz.	Pink 340 DD 1st hatch	1.4 bc	4.5 bc	0.1 a	1.0 a	0.4 a	0.1 a	0.0 a	0.0 a	0.0 a
3. Asana XL 0.66EC	5.8 oz.	Pink 340 DD 1st hatch	1.0 ab	2.2 ab	0.2 a	0.7 a	0.1 a	0.2 a	0.0 a	0.0 a	0.2 a
4. Baythroid 2E	1.7 oz.	Pink 340 DD 1st hatch	1.5 bc	3.5 bc	0.1 a	0.2 a	0.4 a	0.7 a	0.0 a	0.0 a	0.0 a
5. Dipel DF	10.7 oz.	Pink 340 DD 1st hatch	0.4 ab	1.2 ab	0.1 a	0.3 a	0.1 a	0.5 a	0.0 a	0.0 a	0.0 a
6. Intrepid 2F	5.3 oz.	Pink 340 DD 1st hatch	0.6 abc	1.5 ab	0.0 a	0.2 a	0.1 a	0.1 a	0.0 a	0.0 a	0.2 a
7. Untreated			2.0 c	7.2 c	0.1 a	0.9 a	0.4 a	0.2 a	0.0 a	0.0 a	0.0 a

Data from ' Red Delicious evaluation on 19 July. Pink application made on 25 April, 340 DD on 30 June.
Log_{10} (X+1) transformation applied to data. Mean separation by Fishers Protected LSD (P=<0.05). Treatment means followed by the same letter are not significantly different. Untransformed means presented. Mite sampled by examining 25 terminals leaves per tree using mite brushing machine to remove mite onto soaped glass plates for evaluation under dissecting scope > 18x magnification. **ERM** = European red mite *Panonychus ulmi*; **TSM** = Two spotted spider mite *Tetranychus urticae* ; **ZM** = *Zetzellia mali*; (AMB): Phytoseiid mite predators including *Neoseiulus (=Amblyseius) fallacies* (Garman), **ARM** = apple rust mite *Aculus schlechtendali*

CHART 1. **Materials efficacious for use in OBLR resistance management programs.**

Insecticides	IRAC Class	Optimum use	Optimum timing	Considerations	Insecticidal spectrum
Lannate	1A	Pre-bloom - petal fall / Summer	All larval stages	Disruption of natural enemies	RAA, GFW, EAS / STLM, CM, OFM, LAW, CUTWORM, ECB
Lorsban	1B	Pre-bloom - petal fall only	Over-wintering larvae	Possible OP resistance	RAA, SJS, PC, EAS, OFM, (CM, OFM, LAW, RBLR @ PF)
Pyrethroid: Ambush, Pounce, Asana, Baythroid, Danitol, Warrior	3	Cooler temperatures	Tight cluster to pink / pre-harvest in late varieties	Disruption of natural enemies/ decrease in efficacy in high temperature	TPB, MPB, RAA, STLM, GFW, CM, OFM, LAW, EAS, PC
SpinTor	5	Summer generation	Sustained adult flight - 340 DD base 43°F – first hatch	Possible decrease in efficacy in high temperature	CM
Proclaim	6	Summer	Sustained adult flight - 340 DD base 43°F – first hatch	Requires oil or LI700 for absorption	STLM, RBLR
Bt: Biobit, Dipel, Javlin, MVP	11B	Petal Fall; 5-7 day intervals @ low rates during summer	Over-wintering larvae / early instar larvae	Requires multiple applications at shortened intervals for greatest efficacy	RBLR, CUTWORM, ECB
Intrepid	18A	Petal Fall, Summer	Sustained adult flight - 340 DD base 43°F – first hatch	Possible decrease in efficacy from cross resistance	CM, OFM, LAW

Codling moth (CM): *Cydia pomonella* (Linnaeus)**, European apple sawfly** (EAS): *Hoplocampa testudinea* (Klug),), **European corn borer** (ECB): **Green fruitworm** (GFW):including *Lithophane antennata* (Walker)**, Mullen plant bug** (MPB): *Campylomma verbasci* (Meyer)**, Obliquebanded leafroller** (OBLR): *Choristoneura rosaceana* (Harris) **Oriental fruitworm** (OFM) *Grapholitha molesta* (Busck), **Plum curculio** (PC): *Conotrachelus nenuphar* (Herbst), Redbanded leafroller (RBLR): Argyrotaenia velutinana (Walker), **Rosy apple aphid** (RAA): *Dysaphis plantaginea* (Passerini) **San Jose scale** (SJS): Quadraspidiotus perniciosus (Comstock), **Tarnished plant bug** (TPB): Lygus lineolaris (P. de B.)

ations should then be determined. Materials effective in managing the OBLR, IRAC classes, effective use windows, optimum timing and insecticidal spectrum are outlined in Chart 1. Examples of programs for rotation of materials using all available materials *or* reduced risk / non-OP programs are outlined in Chart 2. Additional re-entry periods and pre-harvest intervals, varietal susceptibility, population density and weathering should also be considered when choosing materials.

CHART 2. Examples of rotational strategies for OBLR management.

	Using all classes of efficacious materials		
YEAR	OW OBLR TC-PF	1st Gen. Summer June-July	2nd. Gen. Summer Aug.-Sept.
1	Lorsban	SpinTor	Pyrethroid
2	Pyrethroid	Proclaim	Intrepid
3	Intrepid	Lannate	Bt
4	Bt	SpinTor	Pyrethroid
	Using a reduced risk program - Non-OP		
YEAR	OW OBLR TC-PF	1st Gen. Summer June-July	2nd. Gen. Summer Aug.-Sept.
1	Intrepid	SpinTor	Bt
2	Bt	Proclaim	Intrepid
3	Intrepid	SpinTor	Bt
4	Bt	Proclaim	Intrepid

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