US Experience with Navel Orangeworm

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Navel orangeworm introduction

• Four generations per year
• Larvae feed exclusively on kernels
• Larvae reduce yields and crop quality
• Infestations by larvae associated with fungi (Aspergillus sp.) that can produce aflatoxins
• #1 pest of almonds and pistachios; also in walnuts
  – Hosts exceed 700,000 ha of nut crops in CA
Management Pressures Increasing

- Huller thresholds
  - Pre-aflatoxins = goal of 2%, but often higher
  - Post-aflatoxins- nothing over 2% (goal of less than 0.5%)

- Climate change
  - Dry winters, no fog- increased overwinter survival
  - Warm springs, increased degree days
    - 4 generations in places that usually have 3

- Increases in grower returns
  - Pesticides appear cheaper
  - Increased crop value means more to protect

- Increased acreage, nuts over 700,000 ha acres in CA
  - Many new PCAs and PCAs covering too much territory

- Shifts in pesticides
  - OPs and Pyrethroids shifting to ‘greener’ products
NOW management

• Sanitation
  – Remove overwintering worms

• Monitoring
  – Egg traps, pheromone traps
  – Damage

• Insecticides
  – Based on degree-day and nut susceptibility models
  – Three options, resistance a problem

• Mating Disruption
  – Relatively new, green, sustainable
  – Research has been positive
  – Demonstration/extension/adoption still lacking
Seasonal development

- Overwinter in mummies as large larvae
- 1<sup>st</sup> flight from March to May
  - 1<sup>st</sup> generation in mummies in mummies
- 2<sup>nd</sup> flight late June through July
  - 2<sup>nd</sup> generation mostly in Nonpareil
- 3<sup>rd</sup> flight mostly in August
  - 3<sup>rd</sup> generation in Nonpareil (if not harvested yet) and Pollinizers
  - 3<sup>rd</sup> generation will overwinter in north, emerge in south
- 4<sup>th</sup> flight (south) in September
  - 4<sup>th</sup> generation overwinters
Sanitation

• Backbone of NOW management programs
• Remove mummies
  – This removes overwintering worms
  – This removes places for the 1st flight moths to lay eggs
• Goal of 2 mummies per tree
  – Higher in north
  – Lower in south

- Poling
- Shaking
- Crows
- Blowing off berms
- Disking
- Flail mowing
- Cleaning crotches
- Winter flooding
- Floor management
Data collected from 15 orchards in Kern & Tulare Counties.
Orchards 9 - 12 years old.
No insecticide use for NOW.

% NOW Infestation of Almonds at Harvest

Mummies per Tree (June counts)

*June mummy count is correlated w/ NOW infestation. Up to one mummy relates to 1.6 - 4.5% infestation. Engle and Barnes, 1983
Early/Timely harvest

- Damage increases over time
  - Low following 2rd flight
  - Increases exponentially with 3rd and 4th flight
  - Late pollinators all bets are off
- Harvest as soon as possible
  - Removes larvae before they become adults
    - Reduces subsequent flight
    - Reduces chance for reinfestation

\[ y = 5 \times 10^{-8}e^{0.0036x} \]
\[ R^2 = 0.9029 \]

<table>
<thead>
<tr>
<th>Degree-days from Jan 1</th>
<th>Percentage damage to split inshell</th>
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</thead>
<tbody>
<tr>
<td>2800</td>
<td>Kern Co.</td>
</tr>
<tr>
<td>3000</td>
<td>Tulare Co.</td>
</tr>
<tr>
<td>3200</td>
<td>Kings Co.</td>
</tr>
<tr>
<td>3400</td>
<td>Fresno Co.</td>
</tr>
<tr>
<td>3600</td>
<td>Madera Co.</td>
</tr>
</tbody>
</table>

Pistachio damage levels

<table>
<thead>
<tr>
<th></th>
<th>1.5%</th>
<th>2%</th>
<th>Damage doubling time</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>3508</td>
<td>3598</td>
<td>215 dd = ~10-11 days</td>
</tr>
<tr>
<td>2013</td>
<td>3547</td>
<td>3624</td>
<td>191 dd = ~9-10 days</td>
</tr>
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</table>
Natural Control

• Winter rain/humidity
  – Degradation of mummies in the winter, especially due to rain or dew
• Vertebrates
  – Birds, mice, etc., that eat mummy nuts, eat larvae in mummies, or that knock mummies to the ground
• Parasitoids
  – *Goniozus legneri* and *Copidosoma plethorica*
  – Rare at low NOW densities (even without the use of broad-spectrum insecticides)
• Predators
  – *Phytocoris* (seed bug) eats eggs
  – Lacewings, spiders, other generalists
Monitoring

• Mummy counts
  – Determine adequacy of sanitation

• Egg traps (eggs)
  – Almond meal and oil
  – Start in spring
  – Identify egg-laying of first flight for degree-day models
  – Not effective after hulls split

• Pheromone traps (adult males)
  – Start in spring
  – Difficult to interpret before June
  – Better that egg traps after June

• Nut evaluation
  – Crack nuts to assess damage

• PPO lures
  – For monitoring in orchards using MD
- Biofix from egg traps
- Degree-day model, 1050 dd per generation
- Spray at start of 2nd flight
- If 2 sprays are needed, second spray mid-second flight

Source: modified from Pistachio Production Manual, UCANR, 2016. Data from Kern Co. pistachios, red arrows indicate insecticide treatments
Decision-making tools

Number of Treatments
- Mummy assessments
- Previous year’s damage
- Neighbors/surroundings
- Pheromone trap compared to historic captures
- Crop size and value
- Anticipated harvest date
- Number of varieties
- Reliability of harvest date

Treatment timing
- Egg biofix to predict 2\textsuperscript{nd} flight
- Pheromone trap captures to determine overlap of 2\textsuperscript{nd} flight with start of hull split
- Nut evaluation at hull slit
- Progression of hull split (nonpareil and pollinators)
- How long since last spray?
  \quad Residues last about 2-3 weeks
- How long until harvest?
  \quad Are residues adequate?
- How long to spray across all your acreage

Product choice
- Green vs. broad spectrum
- Resistance to pyrethroids
- Number of treatments
- Can mating disruption be used
- Costs
Insecticides for Navel Orangeworm (CA)

- **Intrepid (methoxyfenozide)**
  - Ecdysone Receptor Agonists
  - IRAC Group 18
  - Larvicide
  - Toxin is ingested, larvae don’t develop

- **Altacor (chlorantraniliprole)**
  - Also referred to as rynaxypyr
  - Anthranilic Diamide
  - IRAC Group 28
  - Ovi-larvicides
  - Affects calcium channel in muscles, jaws won’t work

- **Pyrethroids (multiple)**
  - Broad spectrum
  - Also kill natural enemies
  - Issues with off-site movement into waterways

- **Delegate (spinetoram)**
  - Fungal fermentation product
  - Contact and ingestion toxin
  - Primarily a larvicides but not very effective

- **Lorsban (chlorpyrifos)**
  - Organophosphate nerve toxin
  - Under regulatory scrutiny due to mammalian toxicity and off-site movement into air or water
<table>
<thead>
<tr>
<th>Timing</th>
<th>Priority</th>
<th>Goal</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>First flight (Spring)</td>
<td>3</td>
<td>Achieve some secondary benefit on NOW of a PTB spray</td>
<td>No ideal application date (long flight); best if timed at PTB; generally only done in the north</td>
</tr>
<tr>
<td>Second flight (initiation of hull split)</td>
<td>1</td>
<td>Prevent oviposition into splitting nonpareils</td>
<td>Typical timing in almonds; applied to almost all orchards</td>
</tr>
<tr>
<td>Second flight (full split, initiation of pollinator split)</td>
<td>2</td>
<td>Maintain coverage on nonpareils (now 100% split) as well as splitting pollinators at the time that hull split spray residues are degrading.</td>
<td>Treatment based on weeks since hull split, monitoring fruit, weeks until harvest, pheromone trap captures</td>
</tr>
<tr>
<td>3rd flight (Immediately before/after first harvest)</td>
<td>3</td>
<td>Save pollinators from damage in fields with high nonpareil damage</td>
<td>Timing often impractical due to pre-harvest intervals</td>
</tr>
</tbody>
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Insecticide Efficacy

One application—typically ~50% reduction in damage

Two applications—typically ~65% reduction in damage

Law of diminishing returns thereafter

2012, Almond, UC West Side Research and Extension Center, nonpareil, individual tree plots, sprayed with hand gun, RCBD with 6 blocks, evaluations of ~350 nuts per tree, sprayed 2nd flight, harvested 2 weeks later
NOW Pyrethroid Resistance

RF = Resistance factor = LC$_{50}$ of field strain/LC$_{50}$ of USDA strain

Bifenthrin is evaluated as a surrogate for all pyrethroids

• New pyrethroids were initially very effective
• Efficacy has been reduced over time
• Current efficacy similar to that of other products like Altacor and Intrepid
• Repeated applications to pistachios, as well as exposure in almonds, continue to place selective pressure on NOW

Source: B. Higbee, Wonderful Farming Co.
Mating Disruption

- Dispensers are placed in the field
  - Typically 1-2 per acre
- Emit female pheromone
  - Every evening, all season
  - Males can’t find females
- Work best on large acreage
  - Minimized edge effects
- Compatible with other management options
- More expensive than insecticides
- No REI, PHI, PPE, MRLs
  - ‘Green’ technology
- Four commercial products
  - Each with their own strengths
NOW Mating Disruption History

1980’s
   Trap suppression documented by Landolt, Curtis et al.

1990’s
   Shorey showed trap shut-down with dispensers in 40 ac perimeters

2002-2007
   Higbee and Burks demonstrated impact on damage reduction in 20 and 40 ac almond plots using grids

2005- Commercial product available

2008-2012- USDA NOW Areawide Project

2017- Four commercial products available
Mating disruption products

- Puffer NOW
- Isomate NOW
- Cidetrak NOW Meso
- Semios NOW
## Mating Disruption Products

<table>
<thead>
<tr>
<th>Trade Name</th>
<th>Manufacturer</th>
<th>Dispensers per acre</th>
<th>Type</th>
<th>Release rate</th>
<th>Other perks and costs</th>
<th>Approved for Organic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Puffer NOW</td>
<td>Suterra® Wonderful</td>
<td>2</td>
<td>Aerosol</td>
<td>Static Nightly</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Semios NOW</td>
<td>semios</td>
<td>1</td>
<td>Aerosol</td>
<td>Variable</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Isomate NOW</td>
<td>Pacific Biocontrol</td>
<td>1</td>
<td>Aerosol</td>
<td>Static nightly</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Cidetrak NOW Meso</td>
<td>TRÉCÉ</td>
<td>20</td>
<td>Passive</td>
<td>Static 24/7</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
NOW damage at harvest- 2017

All 4 MD products effective
Average damage reduction- 46%
PMA- Pheromone trap captures (MD vs. no-MD)

Wasco ↓ 97.2%

Turlock ↓ 97.1%

Buttonwillow ↓ 94.7%

Escalon ↓ 97.6%
PMA- Harvest data (MD vs. No MD)

Wasco
Damage ↓73%
Value +$153

Turlock
Damage ↓50%
Value +$40

Buttonwillow
Damage ↓79%
Value +$363

Escalon
Damage ↓77%
Value +$334
NOW Damage Summary - DPR PMA Project, 2017

Square sites MD cost/benefit
~$120 for MD = ↑$222 in crop value

Triangle sites
~$120 for MD = ↓$17
Mating Disruption (400+ ha scale)

** Santa Fe NOW Areawide Project **
Historical NOW Damage - All varieties

** After 2007: 75-100% reduction in insecticide applications for NOW **
Conclusion- death by a thousand cuts

1. Sanitation, sanitation, sanitation
2. Monitoring program
   1. Eggs, adults, nuts
   2. Number of sprays needed
   3. Degree-day models to time sprays
3. Insecticides, rotation of active ingredients
4. Mating Disruption
5. Timely harvest
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Disclaimer: Discussion of research findings necessitates using trade names. This does not constitute product endorsement, nor does it suggest products not listed would not be suitable for use. Some research results included involve use of chemicals which are currently registered for use, or may involve use which would be considered out of label. These results are reported but are not a recommendation from the University of California for use. Consult the label and use it as the basis of all recommendations.