Behaviorally-Based Attract and Kill Systems for Apple Maggot and Spotted Wing Drosophila

Leskey Laboratory
USDA ARS
Appalachian Fruit Research Station
Kearneysville, WV 25430
Pest Status of Key Tephritids in Eastern US

* Transition region defined as less than 85% prevalence (by acreage) of either major eastern tree fruit crop.

Design a trap-based control system for apple maggot fly that can replace broadcast insecticide sprays in commercial orchards with no loss in pest control and little increase in cost.
Building a Trap-Based Control System

**Background Research**

- 1983: Olfactory Cues Used by Apple Maggot in Host Finding
- 1990: Deployment Strategies for Traps Using Visual and Olfactory Cues
- 2007: Development of Efficient Trap Mechanism
- 2007: Optimal Odor Bait**
- 2007: Optimal Visual Trap*
- 2007: USDA-ARS Adopts AMF Trap Development Project

First studies of AMF behavior in New England

University of Massachusetts begins tree fruit IPM project
Optimizing Components of Trap-Based Monitoring and Management Systems

- Visual Stimulus
- Olfactory Stimulus
- Deployment Strategy
- Capture Mechanism
Optimizing Components of the Trapping System

Visual Stimulus

- 9.8b
- 68.3a
- 3.0b
- 0.3b
- 609.8a
- 299.3b
- 119.7c
- 35.5d
- 48.0bc
- 102.7a
- 74.3ab
- 20.0cd
- 7.0d
Optimizing Components of the Trapping System

**Olfactory Stimulus**

- AMF attracted to odor of ripening apple.
- 5-component blend outperforms a single compound (Zhang et al. 1999).

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Unbaited</td>
<td>98.9c</td>
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<tr>
<td>Single Component</td>
<td>247.2b</td>
</tr>
<tr>
<td>Multiple Component</td>
<td>500.5a</td>
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</table>
Optimizing Components of the Trapping System

Deployment Strategy

- Perimeter deployment, risk-based

Trap spacing based on scale of threat and susceptibility of plot.
Optimizing Components of the System

Capture Mechanism

From 1991-1996, attempts to sustain effectiveness of pesticide-treated spheres using chemical and physical barriers.
In 1996, began prototyping of traps that were renewed by environmental moisture, rather than depleted.
Meeting the Environmental Challenges

Inherent challenges with deploying starch-based structure in nature. Does not fit the context of the cropping system.
External Renewal of Feeding Stimulant

Slow progress toward feeding stimulant release mechanism that would last 15 weeks without regard to field conditions.
Attracticidal Sphere Components

Visually integrated cap and sphere body, nonpersistent toxicant bound in expendable cap

- Sphere hanger
- Compressed cap of soluble feeding stimulant, insoluble structural carrier, and toxicant
- Prefabricated, flat-topped, hollow plastic upper trap section
- Prefabricated, hollow plastic lower hemisphere
Perimeter-Based Attract and Kill System for Apple Maggot

Wright et al. 2012
Enhancing Attract and Kill for Apple Maggot

Morrison et al. 2016
# Field Performance in Commercial Orchards

## 0.5% Spinosad + 10% AC

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total fruit sampled</th>
<th>No. of damaged fruit</th>
<th>% Damaged fruit</th>
<th>$\chi^2$</th>
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<tr>
<td>2010</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red sphere</td>
<td>997</td>
<td>29</td>
<td>2.91%</td>
<td>a</td>
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<tr>
<td>Grower control</td>
<td>1,023</td>
<td>30</td>
<td>2.93%</td>
<td>a</td>
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<tr>
<td>2011</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Red sphere</td>
<td>751</td>
<td>25</td>
<td>3.33%</td>
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<tr>
<td>Grower control</td>
<td>961</td>
<td>17</td>
<td>1.77%</td>
<td>a</td>
</tr>
</tbody>
</table>

- **No. Insecticide Sprays**
  - Control = 3.0 per season
  - Sphere = 0.3 per season

Morrison et al. 2016
Can we use attracticidal sphere system developed for apple maggot for SWD?
“Proof of Concept” Attract-and-Kill Study

Will SWD alight on red spheres?
What effect does their presence have on infestation?

- Released 25 males and 25 females into field cages.

- Treatments
  - Sphere Alone
  - Sphere + Raspberry Plant
  - Raspberry Plant Alone
  - Control

- Flies foraged freely for 48 h.

- Recorded number of SWD captured on spheres and number of SWD recovered from fruit.
SWD alighted on spheres, but captures reduced by 50% in presence of raspberry plant.

SWD infestation in raspberries reduced by 50% when sphere included in the cage.

Rice et al. in press
Can We Develop an Attract and Kill System for SWD?

- Visual Stimulus
- Olfactory Stimulus
- Deployment Strategy
- Capture or Kill Mechanism
Does SWD Respond To Visual Cues?
Visual Stimuli

Color

Shape

Size
• Release 20 colony-reared, mature anesthetized SWD into cage.
• SWD permitted to freely forage for 6h.

• Release 30 colony-reared, mature anesthetized SWD.
• SWD permitted to freely forage for 48h.

• Assess response of wild SWD populations.
• Stimuli in field for 48h.
Color

Laboratory

Semi-Field

Field

Shape

Size

Significant

Rice et al. 2016
Conclusions From Visual Ecology Trials

• SWD do respond to visual cues.

• Color appears important as black and red routinely outperformed other colors.

• A spherical shape with a size greater than 2.5 cm appears acceptable.

Rice et al. 2016
While Tangletrap is a good capture and kill mechanism, it requires a great deal of labor, is messy and not likely to be adopted.
Can We Replace Tangletrap as the Capture or Killing Agent?

• Evaluate lethality of attracticidal spheres developed for AMF for SWD.

• Cap contains a feeding stimulant (sugar) and toxicant.

• Exploits environmental moisture to continuously renew toxicant on sphere surface.

Morrison et al. 2016, Wright et al. 2012
Laboratory Evaluation of Lethality

- **Insecticides**: Bifenthrin, Lambda-cyhalothrin, Spinetoram, and Spinosad.
- **Rates**: 0.0, 0.01, 0.1, 0.5 and 1.0% a.i.
- Evaluated a minimum 20 males and 20 females/insecticide/rate.
- Released at sphere equator and allowed to forage freely for 5 min. Measured foraging time.
- Evaluated toxic effects at 0, 24 and 48 h after exposure.
Laboratory Lethality Results

![Bar chart showing percent mortality for different active ingredients: Bifenthrin, \(\lambda\)-cyhalothrin, Spinetoram, and Spinosad. The chart compares the effects of different concentrations (1.0, 0.5, 0.1, 0.01, 0.0) on percent mortality. Each bar has a letter label indicating significant differences among treatments.](chart.png)
Additional Lethality Trials

• Conventional
  – Dinotefuran
  – Imidacloprid
  – Spinetoram
  – Acephate
  – Permethrin
  – Lambda-Cyhalothrin

• Organic
  – Spinosad
  – Grandevo
  – Boric Acid
<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Rate (% A.I)</th>
<th>Mortality (%)</th>
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</thead>
<tbody>
<tr>
<td>Dinotefuran</td>
<td>1.0</td>
<td>100.0</td>
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<tr>
<td>Dinotefuran</td>
<td>0.5</td>
<td>92.5</td>
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<tr>
<td>Dinotefuran</td>
<td>0.1</td>
<td>70.0</td>
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<tr>
<td>Imidacloprid</td>
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<td>55.0</td>
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<tr>
<td>Imidacloprid</td>
<td>0.5</td>
<td>70.0</td>
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<tr>
<td>Imidacloprid</td>
<td>0.1</td>
<td>80.0</td>
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<tr>
<td>Spinetoram</td>
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<td>100.0</td>
</tr>
<tr>
<td>Spinosad</td>
<td>1.0</td>
<td>100.0</td>
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<tr>
<td>Boric Acid</td>
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<td>Acephate</td>
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<td>Permethrin</td>
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<td>Lambda-Cyhalothrin (WG)</td>
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<tr>
<td>Chromobacterium subtsugae</td>
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<td>15.0</td>
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<tr>
<td>Chromobacterium subtsugae</td>
<td>10.0</td>
<td>16.7</td>
</tr>
</tbody>
</table>
The goal is to create a system that remains lethal and visually attractive for a 12 week period. This includes exposure to UV and rainfall (1”/week).
How Quickly Does Rain Degrade Spheres?

- 1 " rainfall/week for 6 weeks (equivalent to average rainfall rates during summer)
- SWD exposed to sphere 5 min.
- Mortality assessed at 48 hrs
How Quickly Does UV Degrade Spheres?

- Full spectrum light 16:8 (L:D) for 6 weeks (equivalent to 6 weeks of UV exposure during summer)
- SWD exposed to sphere for 5 min
- Mortality assessed 48 hrs

![Graph showing mortality (%) for different treatments](image)
How quickly does the combination?

- Light may dry excess moisture providing improved efficacy compared with rain-only treatment.

<table>
<thead>
<tr>
<th></th>
<th>Actara</th>
<th>Danitol</th>
<th>Delegate</th>
<th>Lannate</th>
<th>Spinosad</th>
<th>Venom</th>
<th>Warrior</th>
<th>Control</th>
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<tr>
<td>Mortality (%)</td>
<td>40</td>
<td>80</td>
<td>90</td>
<td>80</td>
<td>80</td>
<td>60</td>
<td>90</td>
<td>&lt;1</td>
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</tbody>
</table>

**In 2017, spheres will be exposed to natural environmental conditions**
Can we reduce SWD infestation in a susceptible crop using attracticidal spheres?
Experimental Set-Up

- Four experimental treatments evaluated for SWD management.
  1) weekly sprays (Brigade, Entrust or Danitol)
  2) 1% Delegate/Spinetoram (2013) and 1% Venom/Dinotefuran (2014) attracticidal spheres at a rate of 1/plant
  3) sprays + spheres
  4) Control

- Monitored SWD populations with traps baited with yeast/sugar.

- Harvested ripe berries and evaluated infestation rates.
Rice et al. in press

Experimental Set-Up

Mean No. *D. suzukii* Per Fruit

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Sphere</th>
<th>Insecticide</th>
<th>Sphere and Insecticide</th>
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</thead>
<tbody>
<tr>
<td>0% Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1% Spinetoram</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1% Dinotefuran</td>
<td></td>
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</tbody>
</table>

All Ripe Fruit Harvested

Subsample of Fruit Taken

Rice et al. in press
Tentative Conclusions and Key Questions

• We can replace Tangletrap with attracticidal spheres as capture/kill mechanism.
  – *Optimal insecticides and % AI for organic and conventional plantings?*

• Attracticidal spheres reduced infestations of SWD infestations in experimental plantings.
  – *How does other horticultural practices influence overall efficacy?*

• Spheres hung at top of plant.
  – *What is the optimal deployment strategy?*
Deployment Strategy For Attracticidal Spheres
Deployment Strategy For Attracticidal Spheres

- Where do SWD prefer to forage within a single host plant?
- How do SWD move among plants within plots?
Within Plant

Within Plot
Where do SWD Choose To Forage Within a Host Plant?

- Clean, ripe berries for oviposition
- Tangletrap-coated ripe berries for alightment
Within-Plant Foraging Semi-Field Bioassay
Where do SWD Choose To Forage Within a Host Plant?

• 4 heights.
• 5 berries per height. Four exterior berries and one center.
• Release 120 sexually mature adults.
• Recovered after 24h.
Influence of Berry Height

Mean No. SWD ± SE Per Berry

Heights

Low
Middle Low
Middle High
High

Rice et al. submitted
Influence of Berry Position

Mean No. SWD ± SE Per Berry

Center

Exterior

Berry Position

Rice et al. submitted
Where do SWD Choose To Forage Within a Host Plant?

Oviposition

Mean No. SWD ± SE Per Berry

Rice et al. submitted
Where do SWD Choose To Forage Within a Host Plant?

Mean No. SWD ± SE Per Berry

Center

Exterior

Berry Position

Rice et al. submitted
Deployment Strategy For Attracticidal Spheres

- Where do SWD prefer to forage within a single host plant?
- How do SWD move among plants within plots?
Mark-Release-Recapture Study
Sticky Sentinel Berries
1.8% Non-Fliers
2.3% Recaptured
Where do SWD Choose To Forage Within a Host Plant?

Rice et al submitted
Where do SWD Choose To Forage Within a Plot?

Rice et al. submitted
Wild Populations
Where do SWD Choose To Forage Within a Host Plant?

Rice et al. submitted
Where do SWD Choose To Forage Within a Plot?

Rice et al. submitted
Potential Deployment Strategies?
Optimization of Attract and Kill for SWD

If we allow SWD to persist, patterns within plants and within plots break down.
Optimization of Attract and Kill for SWD

Influence of horticultural practices?
Competition with ripening fruit?
Tentative Conclusions and Next Steps

- Attract and kill holds promise for SWD. Attracticidal spheres reduced SWD infestation in small plot trials.
- SWD appear to prefer fruit that is low on the plant and at the center of the canopy.

- What are the best materials for conventional and organic systems?
- If we deploy attracticidal spheres at ‘low-center’ positions, does this reduce infestation compared with ‘high’ deployment sites?
- What is the influence of horticultural practices on the system?

- Olfactory cues or baits?
Can We Develop an Attract and Kill System for SWD?

- Visual Stimulus
- Olfactory Stimulus
- Deployment Strategy
- Capture or Kill Mechanism
Acknowledgements

• Northeastern Regional IPM Award
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• NE SARE
• USDA-ARS Post-doctoral Program