Managing for insecticide resistance, new approaches with new tools

UW – WPVGA Grower Education Conference

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Key insect pests in NY potato

Potato leafhopper
(*Empoasca fabae*)

Colonizing Aphids
(*Myzus persicae* & *Macrosiphum euphorbiae*)

Colorado potato beetle
(*Leptinotarsa decemlineata*)
Life cycle & management

- Overwinter in non-crop habitats
- Colonize crop by walking
- 2-3 generations per year
- Larvae are the insecticide target
- Neonicotinoids remain important part of management (Admire, Platinum, Cruiser Maxx)
## Chronology of insecticide resistance: Long Island

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Chemical Group</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; Introduced</th>
<th>1&lt;sup&gt;st&lt;/sup&gt; Failure</th>
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<tbody>
<tr>
<td>carbaryl</td>
<td>carbamate</td>
<td>1957</td>
<td>1958</td>
</tr>
<tr>
<td>azinphosmethyl</td>
<td>OP</td>
<td>1959</td>
<td>1964</td>
</tr>
<tr>
<td>phosmet</td>
<td>OP</td>
<td>1973</td>
<td>1973</td>
</tr>
<tr>
<td>phorate</td>
<td>OP</td>
<td>1973</td>
<td>1974</td>
</tr>
<tr>
<td>carbofuran</td>
<td>carbamate</td>
<td>1974</td>
<td>1976</td>
</tr>
<tr>
<td>oxamyl</td>
<td>carbamate</td>
<td>1978</td>
<td>1978</td>
</tr>
<tr>
<td>fenvalerate</td>
<td>pyrethroid</td>
<td>1979</td>
<td>1981</td>
</tr>
<tr>
<td>permethrin</td>
<td>pyrethroid</td>
<td>1979</td>
<td>1981</td>
</tr>
<tr>
<td>fenvalerate + PBO</td>
<td>pyrethroid + synergist</td>
<td>1982</td>
<td>1983</td>
</tr>
<tr>
<td>imidacloprid</td>
<td>neonicotynl</td>
<td>1995</td>
<td>2000</td>
</tr>
<tr>
<td>spinosad</td>
<td>spinosyns</td>
<td>1997</td>
<td>2003</td>
</tr>
<tr>
<td>thiamethoxam</td>
<td>neonicotynl</td>
<td>1999</td>
<td>2003</td>
</tr>
</tbody>
</table>

(Arthropod Pesticide Resistance Database, 2012)
How does resistance develop?

- All populations have individuals that are resistant
- Spraying eliminates susceptible individuals
- Resistant traits passed to offspring
- Repeated application selects for populations of resistant individuals
Potato beetle management in Wisconsin (1990-2012)

- Spray programs developed by a crop consultant scouting 27,000 acres annually.
- Imidacloprid registered 1995.
- 2012 neonicotinoid resistance common.

What factors drive declining control?

Environmental Impact Quotient\textsuperscript{a}

<table>
<thead>
<tr>
<th>Year</th>
<th>Benzoylureas</th>
<th>Carbamate</th>
<th>Neonicotinoid</th>
<th>Pyrethroid</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990-1994</td>
<td></td>
<td>0.3</td>
<td>1.2</td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td>1995-2005</td>
<td></td>
<td>0.2</td>
<td></td>
<td></td>
<td>1.2</td>
</tr>
<tr>
<td>2006-2012</td>
<td></td>
<td></td>
<td>0.3</td>
<td></td>
<td>0.3</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Kovach et al. 2012
Current neonicotinoid resistance in WI

Cumulative degree-days (CDD) of systemic control

- Loss of 3.5 days of control per year
- 52.5 days on average after 15 years of neonicotinoids

\[ CDD_{control} = CDD_{spray} - CDD_{planting} \]

Cumulative degree-days of control (base = 10°C)

Years of neonicotinoid use
Insecticide Resistance Management (IRM): Principles

I. **Problem Identification:** If you suspect resistance, first eliminate other possible causes.

Lack of control can be attributed to application error, equipment failure, or less-than-optimal environmental conditions.

II. **Product Rotation:** Avoid the consecutive use of a single product, or multiple products with similar modes of action. Insecticide Resistance Action Committee (IRAC) has developed and updates a Mode of Action (MoA) classification system.

http://www.irac-online.org/


- rotate different modes of action across generations

- successive foliar applications
Rotating insecticide Mode of Action groups

Effective IRM strategies: sequences or alternations of MoA

Insect abundance

sequence of insecticides through the season
Insecticide Resistance Management (IRM): Principles

III. **Rates and Spray Intervals:** Use insecticides at labeled rates and follow prescribed spray intervals. Do not reduce or increase rates from labeled recommendations as this can hasten resistance development. Use products at their full, recommended doses. Reduced (sub-lethal) doses quickly select populations with average levels of tolerance.

IV. **Cultural Control(s):** Where possible, consider adopting all non-chemical techniques to suppress pest populations, including crop rotation. Rotations > 400 m (¼ mile) away from previous potato crop.

V. **Pest Surveillance and Scouting:** Monitor the pest population and track stages of development. Reduced-risk foliar insecticides generally require accurate timing of applications against susceptible life stages.
Resistance management tactics

- Host plant resistance
- Transgenic plants IR traits
- Reduced-Risk Insecticides (mode of action rotation)
- Entomopathogens
- Population disruption
- Baits and baiting systems
- Natural enemies
- Cultural controls

Potato beetle IRM
Crop rotation in space and time

- Rotate over distances > 400m (1/4 mile)
- Reduces frequency of insecticide exposure
- Causes adult infestations to occur on field edges first
  - facilitates efficient early season scouting
  - spot or perimeter applications

Mean (±SEM) adults per ten plants

Distance from previous potato (m)

Sexson and Wyman, 2005
Resistance management

Field risk: *do conventional insecticide bioassay techniques* best describe resistance?

Landscape risk: *are more broad assessments of resistance more representative?*

**Spatial scale**

field risk

agroecosystem risk
NASS CDL – Cropscape: [http://nassgeodata.gmu.edu/CropScape/](http://nassgeodata.gmu.edu/CropScape/)

- 110 agriculture related classes
- 2008-2012 full 48 coverage
**Cropland Data Layer Accuracy Estimates:**

<table>
<thead>
<tr>
<th>Year</th>
<th>Overall Accuracy</th>
<th>Producers Accuracy (%)*</th>
<th>Dates Sampled**</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Producer(%)</td>
<td>Kappa Coefficient</td>
<td>Corn</td>
</tr>
<tr>
<td>2003</td>
<td>89.28</td>
<td>77.68</td>
<td>93</td>
</tr>
<tr>
<td>2004</td>
<td>90.8</td>
<td>88.92</td>
<td>98</td>
</tr>
<tr>
<td>2005</td>
<td>77.38</td>
<td>72.35</td>
<td>87</td>
</tr>
<tr>
<td>2006</td>
<td>88.7</td>
<td>83.97</td>
<td>96</td>
</tr>
<tr>
<td>2007</td>
<td>90.04</td>
<td>84.12</td>
<td>96</td>
</tr>
<tr>
<td>2008</td>
<td>84.26</td>
<td>76.76</td>
<td>92</td>
</tr>
<tr>
<td>2009</td>
<td>84.06</td>
<td>77.73</td>
<td>95</td>
</tr>
<tr>
<td>2010</td>
<td>84.42</td>
<td>78.23</td>
<td>95</td>
</tr>
</tbody>
</table>

*Producer's Accuracy' is calculated for each cover type in the ground truth and indicates the probability that a ground truth pixel will be correctly mapped (across all cover types).

**Dates sampled also provided accuracy estimates which were specific to LANDSAT flight path including Central Wisconsin River Basin.
Fields in a four year rotation

Potato occurrence

Average field (µ = 0.49)

- Potato occurs frequently in the landscape
- Bioassay data may reflect the abundance of potato
- Production is increasingly a maize/potato rotation
Potato in space and time matters...

**Average years in potato**

<table>
<thead>
<tr>
<th>Year</th>
<th>Mean</th>
</tr>
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<tbody>
<tr>
<td>one</td>
<td>0.7093</td>
</tr>
<tr>
<td>two</td>
<td>0.2766</td>
</tr>
<tr>
<td>three</td>
<td>0.0138</td>
</tr>
<tr>
<td>four</td>
<td>0.0003</td>
</tr>
</tbody>
</table>

**Incidence of potato (out of 4 yrs)**

![Graph showing the proportion of potato years](image)

- **Proportion Potato**
- **Years of Potato Production**

![Map showing potato incidence](image)
Potato footprint describes resistance

High intensity potato production

Low intensity potato production

Years of potato in 9 years

<table>
<thead>
<tr>
<th>Color</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>5</td>
</tr>
<tr>
<td>Orange</td>
<td>4</td>
</tr>
<tr>
<td>Yellow</td>
<td>3</td>
</tr>
<tr>
<td>Green</td>
<td>2</td>
</tr>
<tr>
<td>Dark Green</td>
<td>1</td>
</tr>
</tbody>
</table>
Resistance and landscapes

- Is field-evolved neonicotinoid resistance in Colorado potato beetle related to intensity of potato production?

- Can we manage neonicotinoid tolerant populations in a more dynamic way to delay onset of resistance to new modes of action?

Data & Methods
- Topical bioassay data 2007-2012
- 50 bioassay sites
- NASS Cropland data layers
- 1,500m buffers from bioassay points
- GIS extractions and regression

Collaborators
- Szendrei Lab
- Poveda Lab
- Nault Lab
- Kennedy Lab
Resistance and landscapes

- Resistance to neonicotinoids correspond with intensity of potato production
- Simplified agricultural landscapes do not strongly relate to resistance
- Composition of the “insecticide landscape” may have large effects on resistance
Rotation matters within a field...

- Less frequently rotated fields had greater neonicotinoid resistance
- Potato production in fields likely corresponds with broader trends in the agroecosystem
IRAC - Insecticide Mode of Action Classification

Insecticide Resistance Action Committee  www.irac-online.org

Nerve & Muscle Targets

Group 1 Acetylcholinesterase (AChE) inhibitors
1A Carbamates (e.g. methomyl)
1B Organophosphates (e.g. chlorpyrifos)

Group 2 GABA-gated chloride channel antagonists
2A Cyclodiene Organochlorines (e.g. endosulfan)
2B Phenylpyrazoles (e.g. fipronil)

Group 3 Sodium channel modulators
3A Pyrethrins, Pyrethroids (e.g. l-cyhalothrin)

Group 4 Acetylcholine receptor (nAChR) agonists
4A Neonicotinoids (e.g. imidacloprid)
4C Sulfoximines (e.g. sulflaniloflor)

Group 5 Nicotinic acetylcholine receptor channel agonists (allosteric)
5 Spinoxyins (e.g. spinetoram)

Group 6 Chloride channel activators
6 Avermectins (e.g. abamectin)

Group 9 Non-specific mode of action (feeding blockers)
9B Pymetrozine
9C Flicamid

Group 14 Nicotinic acetylcholine receptor channel blockers
14 Neeristoxin analogs (e.g. Cartap)

Group 19 Octopamine receptor agonists
19 Amitraz

Group 22 Voltage dependent sodium channel blockers
22A Indoxacarb
22B Metaflumizone

Group 28 Ryanodine receptor modulators
28 Diamides (e.g. cyantraniliprole)

Midgut Targets

Group 11 Microbial disruptors of insect midgut membranes
11A Bacillus thuringiensis
11B Bacillus sphaericus

Respiration Targets

Group 12 Inhibitors of mitochondrial ATP synthesis
12A Difethialon
12B Organotin miticides (e.g. cyhexatin)
12C Propargite
12D Teflafon

Group 13 Uncouplers of oxidative phosphorylation via disruption of H proton gradient
13 Chlorfenapyr

Group 20 Mitochondrial complex III electron transport inhibitors
20A Hydroxymycolon
20B Acnecoumoyl
20C Fluacrypyrim

Group 21 Mitochondrial complex I electron transport inhibitors
21A METI acaricides (e.g. tebufenpyrad)

Group 23 Inhibitors of acetyl CoA carboxylase
23 Tectonic & Tetramic acid derivatives (e.g. spiridiclofen)

Group 25 Mitochondrial complex II electron transport inhibitors
25 Cyanopyrafen

Growth & Development Targets

Group 7 Juvenile hormone mimics
7A Juvenile hormone analogues (e.g. methoprene)
7B Fenoxycarb
7C Pyrimprole

Group 10 Mite growth inhibitors
10A Clofentizine
10B Etoxazole

Group 18 Inhibitors of chitin biosynthesis, type 0
18 Benzoylureas (e.g. Nivaluron)

Group 18 Inhibitors of chitin biosynthesis, type 1
18 Buprofezin

Group 18 Ecylsene agonists/moulting disruptors
18 Diacylyhydrazines (e.g. tebufenozide)

Unknown

UN compound of unknown or uncertain mode of action
UN Azadirachtin
UN Bifenazate
UN Pyridalyl
UN Pyrifluquinazon
Many new reduced-risk MoA groups

Pre-packs of MoA groups are common

Insecticide MoA groups can be arranged into an effective resistance management rotation
New foliar tools for CPB

Radiant® (spinetoram) Blackhawk® (spinosad)
- nAChR allosteric activators (MoA group 5)
  - Use rate 4.5 – 8 fl oz / ac
  - Control of larval CPB, ECB

Rimon® 0.83 EC (novaluron):
- Chitin biosynthesis inhibitors (MoA Group 15)
  - Control of CPB eggs and larvae
  - Use rate 9 – 12 fl. oz / ac (foliar)
  - Season maximum 24 fl. oz / ac
  - Timing critical (3x apps: 9+8+7 fl. oz / ac)

Agri-Mek 0.7SC® & 0.15EC (abamectin)
- Chloride channel activator (MoA group 6)
  - Control of CPB adults and larvae, and Leps
  - Use rate 1.75 – 3.5 fl oz (foliar – SC form)
  - Use rate 8 – 16 fl oz (foliar – EC form)
  - Verimark and Exirel in 2014 (cyazypyr)
New foliar tools for CPB

- **Voliam Flexi®** (chlorantraniliprole + thiamethoxam)
  - MoA groups 28 + 4A
  - Use rate 4 oz / ac (CPB)
  - Control of CPB adults and larvae, PLH, aphids, and Leps

- **Besiege®** (lambda-cyhalothrin + chlorantraniliprole)
  - MoA groups 3 + 28
  - Use rate 6 – 9 fl oz / ac (CPB)
  - Control of CPB adults and larvae, PLH, aphids, and Leps

- **Endigo® ZC** (lambda-cyhalothrin + thiamethoxam)
  - MoA groups 3 + 4A
  - Use rate 2.5 – 4.5 fl oz / ac (CPB)
  - Control of CPB, adults and larvae, PLH, aphids, and Leps
New foliar tools for CPB

Benevia® / Exirel® / Verimark® (cyazypyr):

- Anthranilic diamide (MoA Group 28)
  - Control of CPB eggs, larvae, & adults
  - Proposed use rate 3.5 - 5 fl. oz / ac (foliar)
  - Proposed use rate 10 – 13.5 fl oz (IF)
  - Season maximum 28 fl. oz / ac

Coragen® (rynaxypyr)

- Anthranillic diamide (MoA group 28)
  - Control of CPB adults and larvae, and Leps
  - Verimark and Exirel in 2014 (cyazypyr)
How do these insecticides fit with CPB life cycles?

- New compounds often target larvae
- Certain compounds perform better on specific larval instars (i.e. small larvae)
- Treatment windows pair Active Ingredients with seasonal distribution of CPB larvae
- Foliar application timing critical
<table>
<thead>
<tr>
<th>Treatment Window</th>
<th>Active ingredient</th>
<th>IRAC MoA group</th>
<th>Delivery</th>
<th>Common trade names</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>early generations</strong></td>
<td>abamectin</td>
<td>6</td>
<td>F</td>
<td>Agri-Mek, generics</td>
</tr>
<tr>
<td></td>
<td>chlorantraniliprole</td>
<td>28</td>
<td>F</td>
<td>Coragen</td>
</tr>
<tr>
<td></td>
<td>cyantraniliprole</td>
<td>28</td>
<td>F, IF</td>
<td>Exirel*, Verimark*</td>
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<tr>
<td></td>
<td>imidacloprid</td>
<td>4A</td>
<td>IF, ST</td>
<td>Admire Pro, generics</td>
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<tr>
<td></td>
<td>novaluron</td>
<td>15</td>
<td>F</td>
<td>Rimon</td>
</tr>
<tr>
<td></td>
<td>spinetoram</td>
<td>5</td>
<td>F</td>
<td>Radiant</td>
</tr>
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<td></td>
<td>spinosad</td>
<td>5</td>
<td>F</td>
<td>Blackhawk, Entrust</td>
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<tr>
<td></td>
<td>thiamethoxam</td>
<td>4A</td>
<td>IF, ST</td>
<td>Platinum, Crusier Maxx Potato</td>
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<tr>
<td><strong>late generations</strong></td>
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<td>6</td>
<td>F</td>
<td>Agri-Mek, generics</td>
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<td></td>
<td>chlorantraniliprole</td>
<td>28</td>
<td>F</td>
<td>Coragen, Voliam Xpress†</td>
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<td></td>
<td>cyantraniliprole</td>
<td>28</td>
<td>F</td>
<td>Exirel*</td>
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<tr>
<td></td>
<td>imidacloprid</td>
<td>4A</td>
<td>F</td>
<td>Admire Pro, Leverage 360‡, generics</td>
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<tr>
<td></td>
<td>indoxacarbazepine</td>
<td>22A</td>
<td>F</td>
<td>Avaunt</td>
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<tr>
<td></td>
<td>spinetoram</td>
<td>5</td>
<td>F</td>
<td>Radiant</td>
</tr>
<tr>
<td></td>
<td>spinosad</td>
<td>5</td>
<td>F</td>
<td>Blackhawk, Entrust</td>
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<tr>
<td></td>
<td>thiamethoxam</td>
<td>4A</td>
<td>F</td>
<td>Actara, Endigo ZC†</td>
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<tr>
<td><strong>trap crop</strong></td>
<td>indoxacarbazepine</td>
<td>22A</td>
<td>F</td>
<td>Avaunt</td>
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<td></td>
<td>phosmet</td>
<td>1B</td>
<td>F</td>
<td>Imidan</td>
</tr>
</tbody>
</table>

*Foliar (F), in-furrow (IF), and Seed treatment (ST)
†Contains lambda-cyhalothrin, use when PLH and CPB at threshold
‡Contains cyfluthrin, use when PLH and CPB at threshold
Multi-year rotation plans*

- New compounds fit in as foliar rotation partners to at-plant neonicotinoids.
- Full foliar rotations for areas with neonicotinoid resistance.
- Short maturity programs can use new effective groups to cut down application number.

*Common formulations of A.I. presented. Other products available.
How do these insecticides fit with CPB life cycles?

- New compounds fit in as foliar rotation partners to at-plant neonicotinoids.
- Full foliar rotations for areas with neonicotinoid resistance.
- Short maturity programs can use new effective groups to cut down application number.
In-furrow + Foliar Program

<table>
<thead>
<tr>
<th>Year One - 2014</th>
<th>Year Two - 2015</th>
<th>Year Three - 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>early</td>
<td>early</td>
<td>early</td>
</tr>
<tr>
<td>late</td>
<td>late</td>
<td>late</td>
</tr>
</tbody>
</table>

In-furrow + Foliar

- Blackhawk
- Voliam Xpress†
- Admire Pro (IF)
- Agri-Mek
- Verimark* (IF)
- Avaunt

IRAC MoA groups

- avermectins (6)
- diamides (28)
- neonicotinoids (4A)
- benzoylureas (15)
- oxadiazines (22A)
- spinosyns (5)

- Neonicotinoid used in 2013
- CPB easily controlled with neonicotinoids
- Foliar with diamide pre-pack in 2014, rotate diamide only if PLH not present
# Full foliar program

<table>
<thead>
<tr>
<th>Year One - 2014</th>
<th>Year Two - 2015</th>
<th>Year Three - 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>early</td>
<td>early</td>
<td>early</td>
</tr>
<tr>
<td>late</td>
<td>late</td>
<td>late</td>
</tr>
</tbody>
</table>

## Full Foliar

- **Blackhawk**
- **Voliam Xpress**
- **Rimon**
- **Agri-Mek**
- **Radiant**
- **Exirel**

## IRAC MoA groups

- avermectins (6)
- diamides (28)
- neonicotinoids (4A)
- benzoyleurues (15)
- oxadiazines (22A)
- spinosyns (5)

- Foliar program where neonicotinoid resistance is suspected
- Voliam Xpress = chlorantraniliprole + lambda
- Rimon (3x apps: 10+7+7 fl. oz / ac)
Short Maturity Cultivars

<table>
<thead>
<tr>
<th>Year One - 2014</th>
<th>Year Two - 2015</th>
<th>Year Three - 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>early</td>
<td>early</td>
<td>early</td>
</tr>
<tr>
<td>late</td>
<td>late</td>
<td>late</td>
</tr>
</tbody>
</table>

Short Maturity - Fresh Market

- **Coragen**
- **Radiant**
- **Rimon**

- If pressure is low early a single application window (2x apps) may be sufficient.
- Companion groups (hatched boxes) could be foliar Actara, Endigo, or Agri-Mek.
- Foliar diamide should only be used in the late window of 2016.
Management recommendations

- Consult management recommendations
- Always read insecticide label for use restrictions, REI, PHI, etc...
- Sign up for Cornell Cooperative Extension Veg Edge newsletter

Useful resources
Wisconsin Veg Guidelines: http://labs.russell.wisc.edu/vegento/files/2012/05/A3422.pdf
Veg Entomology: http://labs.russell.wisc.edu/vegento/

Labels: http://www.agrian.com/home/
http://www.cdms.net/

IRAC: http://www.irac-online.org/
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• R. Keith Chapman and Jeffery A. Wyman – Wisconsin Distinguished Fellowship in Vegetable Entomology 2010
• National Potato Council Graduate Scholarship 2011
• National Potato Council. FY09-12 State Cooperative Potato Research Program
Questions?