Resistance management tactics

**Cultural controls**
- Host plant resistance
- Transgenic plants IR traits
- Reduced-Risk Insecticides (mode of action rotation)
- Entomopathogens

**Natural enemies**
- Natural enemies

**Potato beetle IRM**
- Baits and baiting systems
- Population disruption

**Reduced-Risk Insecticides**
- Reduced-Risk Insecticides (mode of action rotation)
Resistance

- A genetically controlled decrease in susceptibility of a population to a control measure
  - resistance to insecticides (IRAC 2006)
    - 500+ insect species resistant to 1 or more insecticides
    - 1800+ species/insecticide resistance combinations
  - adaptation to pest resistant crop varieties
  - adaptation to crop rotation (behavioral)
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.
Resistance Development

- Resistance genes occur naturally at low frequencies
  - $10^{-6}$ to $10^{-10}$ (1 in 100,000 to 1 in 1,000,000,000)

- Proportionately more insects with R-genes survive and leave offspring when exposed to toxin than insects with only S-genes
Measuring Resistance

- $LD_{50}$ (or $LC_{50}$) = dose (or concentration) that is lethal to 50% of the test population under defined conditions

- $LD_{90}$ = dose that is lethal to 90% of the test population
Probit mortality vs. Log dose plot

- **Susceptible**
- **Resistant**

Log dose vs. Probit mortality plot

Log dose scale: $\text{LD}_{50}$, $\text{LD}_{90}$

Probit mortality scale: $\text{LD}_{50}$, $\text{LD}_{90}$
Resistance Ratio

- Ratio of LC$_{50}$ of test population to LC$_{50}$ of reference population
  - LC$_{50}$(test) / LC$_{50}$(reference)

- Resistance ratios of susceptible (controllable) populations can vary as much as 20-fold
Susceptible CPB Strain Attributes

Laboratory susceptible LD_{50} = 0.031

New Jersey Reference Control Strain
Slope: 13.9\% \pm 2.2
LD_{50} (95\% C.I.) = 0.031 (0.026 – 0.038)
Resistance Ratio = 0.031/0.031 (1.0)
Comparing Resistant and Susceptible CPB Populations

![Graph showing the comparison between resistant and susceptible CPB populations. The graph plots % mortality (probit scale) against dose (log ppm). The graph is divided into three sections: Sensitive (SS), Developing Insensitivity (RS), and Resistant (RR). Lab CPB LD_{50} = 0.031.](image)
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
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. λ-cyhalothrin)

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

Group 5 Nicotinic acetylcholine receptor channel agonists (allosteric)
5 Spinosyns (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 Fonicamid

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

Group 19 Octopamine receptor agonists
19 Amitraz

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

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 Difentrifuron
12B Organotin miticides (e.g. cyhexatin)
12C Propargite
12D Tetrafun

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

Group 20 Mitochondrial complex III electron transport inhibitors
20A Hydramethylinon
20B Acequinocyl
20C Fluacyprypyr

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. spirodifen)

Group 25 Mitochondrial complex II electron transport inhibitors
25 Cyenopyrafen

Growth & Development Targets

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

Group 10 Mite growth inhibitors
10A Clofentezine
10B Etoxazole

Group 15 Inhibitors of chitin biosynthesis, type 0
15 Benzoylureas (e.g. Novaluron)

Group 16 Inhibitors of chitin biosynthesis, type 1
16 Buprofezin

Group 18 Ecdysone agonists/moultiing disruptors
18 Diacylhydrazines (e.g. tebufenozide)

Unknown

UN compounds of unknown or uncertain mode of action
UN Azadiractin
UN Bifenazate
UN Pyridalyl
UN Pyrifluquinazone
Rotating insecticide Mode of Action groups

Effective IRM strategies: sequences or alternations of MoA

Insect abundance

sequence of insecticides through the season
Colorado Potato Beetle Generalized Management Program – 2 Successive Applications

- At-plant, systemic neonicotinoid
- Reduced-Risk-foliar (1st Generation)
- Reduced-Risk-foliar (2nd Generation)

Development threshold = 1st and 2nd instar stadia

Need to protect potato crop from CPB for 6-8 weeks

At-Plant Systemic

RR-Foliar (1st gen)

RR-Foliar (2nd Gen)

2nd Gen CPB

1st Gen CPB

Potato Crop

Vine Kill

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 (high-dose strategy). 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.
Neonicotinoids Used as Systemics, Potential for Sub-lethal Effects
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

![Graph](Sexson and Wyman, 2005)

<table>
<thead>
<tr>
<th>Distance from previous potato (m)</th>
<th>Mean ±SEM adults per ten plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100</td>
<td>4.0 ±0.5</td>
</tr>
<tr>
<td>100-400</td>
<td>2.0 ±0.5</td>
</tr>
<tr>
<td>400+</td>
<td>1.0 ±0.5</td>
</tr>
</tbody>
</table>
Key insect pests in NY potato

Potato leafhopper
*(Empoasca fabae)*

Colonizing Aphids
*(Myzus persicae & Macrosiphum euphorbiae)*

Colorado potato beetle
*(Leptinotarsa decemlineata)*
## Chronology of insecticide resistance: Long Island

<table>
<thead>
<tr>
<th>Insecticide</th>
<th>Chemical Group</th>
<th>1st Introduced</th>
<th>1st Failure</th>
</tr>
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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)
Potato beetle management in Wisconsin (1990-2012)

- Spray programs developed by a crop consultant scouting 27,000 acres annually
- Carbamate/OP resistance 1994
- Imidacloprid registered 1995
- 2012 neonicotinoid resistance common

What factors drive declining control?
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
Potato footprint describes resistance

High intensity potato production

Low intensity potato production

Years of potato in 9 years

- 1
- 2
- 3
- 4
- 5
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.
Life cycle & management: scouting and timing

- 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)
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
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

**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)
<table>
<thead>
<tr>
<th>Treatment Window</th>
<th>Active ingredient</th>
<th>IRAC MoA group</th>
<th>Delivery(^a)</th>
<th>Common trade names</th>
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<tr>
<td>early generations</td>
<td>abamectin</td>
<td>6</td>
<td>F</td>
<td>Agri-Mek, generics</td>
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<tr>
<td></td>
<td>chlorantraniliprole</td>
<td>28</td>
<td>F</td>
<td>Coragen</td>
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<tr>
<td></td>
<td>cyantraniliprole</td>
<td>28</td>
<td>F, IF</td>
<td>Exirel(^<em>), Verimark(^</em>)</td>
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<tr>
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<td>imidacloprid</td>
<td>4A</td>
<td>IF, ST</td>
<td>Admire Pro, generics</td>
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<td>novaluron</td>
<td>15</td>
<td>F</td>
<td>Rimon</td>
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<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>IF, ST</td>
<td>Platinum, Crusier Maxx Potato</td>
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<td>28</td>
<td>F</td>
<td>Coragen, Voliam Xpress(^{†})</td>
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<tr>
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<td>cyantraniliprole</td>
<td>28</td>
<td>F</td>
<td>Exirel(^*)</td>
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<tr>
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<td>imidacloprid</td>
<td>4A</td>
<td>F</td>
<td>Admire Pro, Leverage 360(^{‡}), generics</td>
</tr>
<tr>
<td></td>
<td>indoxacarb</td>
<td>22A</td>
<td>F</td>
<td>Avaunt</td>
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<td>spinetoram</td>
<td>5</td>
<td>F</td>
<td>Radiant</td>
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<td>F</td>
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<tr>
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<td>thiamethoxam</td>
<td>4A</td>
<td>F</td>
<td>Actara, Endigo ZC(^{†})</td>
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<tr>
<td>trap crop</td>
<td>indoxacarb</td>
<td>22A</td>
<td>F</td>
<td>Avaunt</td>
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<tr>
<td></td>
<td>phosmet</td>
<td>1B</td>
<td>F</td>
<td>Imidan</td>
</tr>
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</table>

\(^a\) 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*

<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**

- **A**
  - Rimon
  - Radiant
  - Verimark* (IF)
  - Avaunt
  - Platinum (IF)
  - Blackhawk

- **B**
  - Coragen
  - Radiant
  - Agri-Mek
  - Endigo ZC†
  - Verimark* (IF)
  - Blackhawk

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

- **D**
  - Admire Pro (IF)
  - Agri-Mek
  - Rimon
  - Radiant
  - Verimark* (IF)
  - Avaunt

**Full Foliar**

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

- **F**
  - Radiant
  - Coragen
  - Agri-Mek
  - Actara
  - Rimon
  - Exirel*

- **G**
  - Agri-Mek
  - Endigo ZC†
  - Rimon
  - Coragen
  - Radiant
  - Actara

**Short Maturity - Fresh Market**

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

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*Common formulations of A.I. presented. Other products available*
Barriers to Resistance Management: Plant Incorporated Protectants

- Must be implemented before resistance problem exists
- Involves added costs and/or complexity
- Pesticide dealers may not always stock inventory for required rotations
- Sales incentives favor maximizing pesticide sales in short-term
- No positive feedback
Barriers to Resistance Management: Plant Incorporated Protectants

- Costs Immediate and Certain, Benefits Come Later and Are Uncertain
- Farm Size Trends Put Premium on Simplicity, Convenience, and Flexibility
- Costs Borne By Farmer, Benefits Extend Beyond the Farmer’s Fields
- Coupling Insect, Weed, and Disease Management with Other Important Agronomic Traits
  - Lowers Seed Production and Distribution Costs,
  - But Also Can Reduce RM Options or Have Other Unintended Behavioral Effects
Key Points for the future...

• The future may be more than Insecticide Resistance Management
  – Insect, Weed, and Disease Management Increasingly Coupled with Other Important Agronomic Traits
  – Coupling Makes Business, But Not Necessarily Biological Sense

• Need More Economically & Biologically Sensible Options That Are
  – Aware of the Farm & Farm Policy Landscape Because RM Must Work With Instead of Against This Landscape
  – Cooperative Because the Incentives for Farmers, the Seed Industry, Policy Makers, and Other Stakeholders are not Always Well Aligned
  – Adaptive Because the Crop Protection, Farm and Policy Landscape Will Evolve Just Like the Insects, Weeds, and Diseases We Hope to Control
Management recommendations

- Consult management recommendations
- Always read insecticide label for use restrictions, REI, PHI, etc...
- Sign up for the Wisconsin Vegetable 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/
Questions?