Soil Insecticides, Bt Traits & Corn Rootworm: Are We Coming Full Circle?

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What’s the Current Situation with Corn Rootworms and Bt-RW Resistance?

- Roller coaster ride in resistance-related Bt-RW performance problems (peaking in 2012-2013)
- Only western corn rootworm issue so far
- Majority of fields corn after corn with multiple-year history of trait; no problems in rotated fields so far
- Cry3Bb1 (VT3 / VT3P) dominated but is phasing out
- Scattered performance issues all traits; even pyramids
- Resistance detected to all proteins, primarily Cry3Bb1
- Cross-resistance documented with mCry3A (Agrisure) and eCry3.1A (present in Duracade)
- Reports have decreased markedly, reflecting weather, greater use of pyramids, and soil insecticides
- Resistance genes have not disappeared!
Status of Bt-RW Resistance

- Bt-RW resistance confirmed for every trait but risk is not equal (Cry3Bb1 >> mCry3A > Cry34/35Ab1, eCry3.1Ab ?)
- Resistance is not complete; cross-resistance detected with all Cry3 proteins
- Soil insecticide overlay 25% rotated corn, >50% continuous corn;
- Insecticides cannot make up for a failing trait
- Seed industry shifting to pyramids of Bt-RW traits
- New traits probably not available until later this decade
Evaluating MN Populations for Bt-RW Resistance

- **Two Plant Assays (seedling and greenhouse) and Diet Assay**
<table>
<thead>
<tr>
<th>Population</th>
<th>Cry3Bb1</th>
<th>eCry3.1Ab</th>
<th>Cry34/35Ab1</th>
<th>mCry3A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rosemount</td>
<td>Susceptible</td>
<td>Susceptible</td>
<td>N.S.</td>
<td>Susceptible</td>
</tr>
<tr>
<td>Canby</td>
<td>Resistant</td>
<td>Resistant</td>
<td>N.S.</td>
<td>Intermediate</td>
</tr>
<tr>
<td>Hills</td>
<td>Resistant</td>
<td>Resistant</td>
<td>N.S.</td>
<td>Resistant</td>
</tr>
<tr>
<td>Brookings, SD</td>
<td>Susceptible</td>
<td>Susceptible</td>
<td>N.S.</td>
<td>Susceptible</td>
</tr>
</tbody>
</table>

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<tr>
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<td>Intermediate</td>
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<td>N.S.</td>
<td>Susceptible</td>
</tr>
<tr>
<td>Brookings, SD</td>
<td>Susceptible</td>
<td>N.S.</td>
<td>N.S.</td>
<td>Susceptible</td>
</tr>
<tr>
<td>Dennison</td>
<td>Resistant</td>
<td>N.S.</td>
<td>N.S.</td>
<td>Susceptible</td>
</tr>
</tbody>
</table>

### Diet Toxicity Assay - LC$_{50}$ μg/cm$^2$ (95% C.I.)

<table>
<thead>
<tr>
<th>Population</th>
<th>Cry3Bb1</th>
<th>eCry3.1Ab</th>
<th>Cry34/35Ab1</th>
<th>mCry3A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rosemount</td>
<td>16.2 (5.3-27.8)</td>
<td>0.8 (0.3-1.1)</td>
<td>0.9 (0.5-1.5)</td>
<td>0.7 (0.4-1.2)</td>
</tr>
<tr>
<td>Canby</td>
<td>553.2 (278.8-3109.6)</td>
<td>9.7 (5.6-21.5)</td>
<td>4.1 (1.7-8.2)</td>
<td>11.9 (5.2-56.3)</td>
</tr>
<tr>
<td>Hills</td>
<td>65.9 (22.4-133.7)</td>
<td>5.0 (2.9-9.7)</td>
<td>3.8 (2.4-5.6)</td>
<td>8.2 (4.3-22.3)</td>
</tr>
<tr>
<td>Dennison</td>
<td>199.7 (82.0-419843)</td>
<td>3.0 (1.9-5.3)</td>
<td>1.5 (1.0-2.1)</td>
<td>1.8 (1.2-2.6)</td>
</tr>
<tr>
<td>Brookings</td>
<td>0.4</td>
<td>0.4 (0.2-0.6)</td>
<td>1.8 (1.1-2.6)</td>
<td>0.9 (0.6-1.3)</td>
</tr>
</tbody>
</table>
Cross-Resistance in Diet Bioassays

\[ P = 0.0027 \]
Rootworm Populations Dynamics: What’s Needed for Resistance to Appear (or Re-appear)?

\[ Time = Density \]

- Resistance Genes
- Corn Trait
- Exposure
Extended diapause problem fields re-emerged in 2015
WI Corn Rootworm Beetle Counts
(WI Department of Agriculture)

YEAR

Beetle/Plant

N:W Ratio
What’s the Prognosis for Extended Diapause Problems?

Remember: We’ll be dealing with eggs laid by 2014 corn rootworm beetles in rotated corn and by 2014-5 beetles in continuous corn!
Planting Date Effects on CRW Management

Rosemount Research and Outreach Center - 2011

- **RR**
- **RR+Force**
- **VT3**
- **SSX**

Root Injury (Iowa State Scale)

Date of Planting (Julian Date)

- May 3
- May 12
- May 26
- June 8
Planting Date Effects on CRW Management

2011 Planting Date and Efficacy

- RR
- RR+Force
- VT3
- SSX

Adult Emergence (1000's/ha)

Date of Planting (Julian Date)

May 3
May 12
May 26
June 8
A New Complication?
Corn Rootworm Egglaying
Near RoundUp Ready® Volunteer Corn
and Late-Season Resistance Weeds
Your Challenge: Control Weedy Grass Hosts Early in Bt - RW Corn

Stewardship critical: Keep early-season weedy grasses under control!
Corn Rootworms, Volunteer Corn and 2008 Corn Yield
Rosemount, MN

![Graph showing seasonal captures per trap vs. volunteer corn density and yield.](image)

**Western Corn Rootworms**

- Captures/Trap/Day for different volunteer corn densities:
  - 0
  - 2,500
  - 5,000
  - 10,000

- Bar graph showing seasonal captures per trap for different volunteer corn densities:
  - 0
  - 2,500
  - 5,000
  - 10,000

- Line graph showing yield (bu/A) over time with captures/Trap/Day.
2007 Corn Rootworms, Volunteer Corn and 2008 Corn Yield

Rosemount, MN

Yield = 204.1 - 0.22 x Cumulative Sticky Trap Count

$R^2 = 0.501$
Volunteer Corn Density and Northern Corn Rootworm Activity

Sticky Trap Captures per Day

- 0 volunteer corn
- 1 volunteer corn (1875 ppa)
- 2 volunteer corn (3750 ppa)
- 3 vol. corn (7500 ppa)

<table>
<thead>
<tr>
<th>Date</th>
<th>No Volunteer Corn</th>
<th>1875 ppa</th>
<th>3750 ppa</th>
<th>7500 ppa</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/23/07</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>7/30/07</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>8/7/07</td>
<td>0</td>
<td>3</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>8/14/07</td>
<td>0</td>
<td>3</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>8/21/07</td>
<td>0</td>
<td>3</td>
<td>5</td>
<td>8</td>
</tr>
</tbody>
</table>
Hints of Bt-RW Performance Issues Surfaced w/ Northern CRW in 2013

What about Bt-RW Trait Performance Against Northern Corn Rootworms?
## How Well do Bt-RW Events Perform Against Northern Corn Rootworms?

<table>
<thead>
<tr>
<th>Hybrid Family / Event</th>
<th>Northern Corn Rootworm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Refuge</td>
</tr>
<tr>
<td>DK 5263/5259 VT3</td>
<td>545</td>
</tr>
<tr>
<td></td>
<td>49.2%</td>
</tr>
<tr>
<td>P37Y13/14 Herculex Xtra</td>
<td>418</td>
</tr>
<tr>
<td></td>
<td>16.2%</td>
</tr>
<tr>
<td>N40T Agrisure</td>
<td>297</td>
</tr>
<tr>
<td></td>
<td>-2.4%</td>
</tr>
</tbody>
</table>

Data represents sum of seasonal emergence from 16 traps covering 32 plants.

_Sponsored by MN Corn Research & Promotion Council_  
_MN Legislative Rapid Agricultural Response Fund_
How Well do Bt-RW Events Perform Against Northern Corn Rootworms?

*Efficacy expressed as % of emergence in refuge hybrid.*
Comparative Efficacy of Bt - RW Events Against NCR

- **Design:** Factorial combinations of 3 Bt-RW events (YieldGard VT3, Herculex Xtra, Agrisure) and their isolines from the same genetic family.
- **Soil insecticide:** Force 3G only on both Bt-RW and non Bt-RW hybrids.
- **Seed treatment:** Poncho 250 on all seed.
- **Traps:** Placed in field July 2-3 with each covering two plants, 4 cages per plot, replicated 4 times.
- **Data collected:** Beetles collected three times per week. Identified by species and sex.
- **Funding:** Rapid Agricultural Response Fund, MN Corn Research & Promotion Council
Lodging under Different Corn Rootworm Management Strategies

Aztec and Bt-RW corn provided equal lodging protection!
Yield Response to Corn Rootworm Management

Pioneer Hybrids – 2006
- Aztec IF
- Herculex RW

Dekalb Hybrids – 2006
- Aztec IF
- YieldGard RW

Yield Advantage (bu/A)

Nodal Injury Rating (IA)

Do farmers have a handle on their risk level?
Layer a Soil Insecticide?

Root Protection Strategy!
Corn Root Protection: Insecticides vs Bt-RW Corn

Zone of Root Protection for T-band Insecticides & Seed Treatments

Zone of Root Protection For Bt-RW Protein
Performance of Insecticide vs Bt-RW Traits:

Seed Treatment

Insecticide NIR (IA 0-3)

Injury potential

Insecticide NIR vs Injury potential

Soil Insecticides

Insecticide NIR (IA 0-3)

Injury potential

Insecticide NIR vs Injury potential

Single Bt-RW Trait (+ Soil Insecticide)

Insecticide NIR (IA 0-3)

Injury potential

Insecticide NIR vs Injury potential

Pyramid Bt-RW Trait (+ Soil Insecticide)

Insecticide NIR (IA 0-3)

Injury potential

Insecticide NIR vs Injury potential
What about Insecticide Performance in MN Situations?
Soil Insecticide Overlay – Does it Protect More Roots?

Root Protection from Corn Rootworm Management

Rosemount MN 2011
Soil Insecticide Overlays on Bt-Traits

2015 Rosemount MN – Field I7

Nodal Injury Rating (0-3 scale)

Management Option (Bt-RW Trait / Soil Insecticide)
Soil Insecticide Overlays on Bt-Traits

2015 Rosemount MN – Field I7

Management Option (Bt-RW Trait / Soil Insecticide)
Soil Insecticide Overlays on Bt-Traits

2015 Rosemount MN – Field I7

Yield (bu/A)

Management Option (Bt-RW Trait / Soil Insecticide)
Managing Bt-RW Performance Problems: Layering Insecticide on Traits (2012)
Bt-RW Trait / Force 3G Performance in Cry3Bb1 Problem Field: Northfield MN

Preliminary Data

Yield Benefit *(bu/A)

none

Force 3G

HXX

HXX RIB

SSX

SSX RIB

VT3

HXX

AM1

3000GT

62.6

54.6

67.1

68.8

78.3

74.4

85.9

78.8

5.3

26.1

32.3

65.4

32.6
Soil Insecticides and Bt-RW Traits
2015 Rosemount MN

<table>
<thead>
<tr>
<th>Trait</th>
<th>Insecticide</th>
<th>Nodal Injury Rating (&lt;3”)</th>
<th>Yield (bu/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study #1 (Field D2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None (RR2)</td>
<td>None</td>
<td>1.07</td>
<td>177.7</td>
</tr>
<tr>
<td></td>
<td>Capture LFR</td>
<td>0.78</td>
<td>178.7</td>
</tr>
<tr>
<td></td>
<td>Force CS</td>
<td>0.66</td>
<td>194.3</td>
</tr>
<tr>
<td></td>
<td>Aztec 4.67G</td>
<td>0.45</td>
<td>217.0</td>
</tr>
<tr>
<td></td>
<td>L.S.D.</td>
<td></td>
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</tr>
<tr>
<td>Study #2 (Field E)</td>
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<td></td>
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</tr>
<tr>
<td>Cry3Bb1 (VT3)</td>
<td>None (RR2)</td>
<td>1.14</td>
<td>197.6</td>
</tr>
<tr>
<td></td>
<td>None</td>
<td>0.58</td>
<td>213.6</td>
</tr>
<tr>
<td></td>
<td>Capture LFR</td>
<td>0.16</td>
<td>213.7</td>
</tr>
<tr>
<td></td>
<td>Force CS</td>
<td>0.34</td>
<td>214.4</td>
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<tr>
<td></td>
<td>Aztec 4.67G</td>
<td>0.10</td>
<td>200.7</td>
</tr>
<tr>
<td></td>
<td>L.S.D.</td>
<td></td>
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</tr>
</tbody>
</table>

Means followed by the same letter do not differ (p=0.05)
What to do? When “Simple” is Gone

**KEY = IPM**

**Objective:**
Manage Corn Rootworm Populations!
2012 Problem Field – Springfield MN

Dual Challenges:
Trait Resistance &
Corn Rootworm
Density

Photos by Bruce Potter
Trait Performance in Bt-RW Problem Field: Root Injury (Ostlie - Springfield MN)

# Roots Pruned < 1.5"

Bt-RW Trait(s)

- None
- Single
- Pyramid

Preliminary Data
Trait Performance in Bt-RW Problem Field: Beetle Emergence *(Ostlie - Springfield MN)*

```
<table>
<thead>
<tr>
<th>Bt-RW Trait(s)</th>
<th>PO448R</th>
<th>P0448</th>
<th>AMX</th>
<th>P0407</th>
<th>AMXT</th>
<th>DKC52-62 RR2</th>
<th>DKC52-59 VT3</th>
<th>DKC53-56 GSSX</th>
<th>N53W3 GT</th>
<th>N53W3000GT</th>
<th>2K591 RR2</th>
<th>2K592 HXX</th>
<th>2K594 SSX</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>459.0</td>
<td>283.0</td>
<td>1100.0</td>
<td>1080.0</td>
<td>463.0</td>
<td>576.0</td>
<td>421.0</td>
<td>432.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyramid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>
```

Preliminary Data

Beetles/A (1000s)
Trait Effect on Corn Rootworm Beetle Production: 2014-5 Springfield MN

<table>
<thead>
<tr>
<th>Variety</th>
<th>Beetles (1000s) per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>DKC 52-62 RR</td>
<td>156.6</td>
</tr>
<tr>
<td>DKC 52-59 VT3P</td>
<td>559.2</td>
</tr>
<tr>
<td>NK N53-3122</td>
<td>18.6</td>
</tr>
<tr>
<td>DKC 52-61 VT2P</td>
<td>25.9</td>
</tr>
<tr>
<td>DKC 46-20 VT3P</td>
<td>99.1</td>
</tr>
<tr>
<td>DKC 53-56 GENSS</td>
<td>91.3</td>
</tr>
<tr>
<td>NK N53-3122</td>
<td>56.0</td>
</tr>
<tr>
<td></td>
<td>72.3</td>
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</table>
Resistance Taking Us Back to School on the Basics
<table>
<thead>
<tr>
<th>Control Tactic</th>
<th>Considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop Rotation</td>
<td>Reduces pressure – watch variants, volunteer corn, weeds. Grain / forage demands (livestock), contracts (ethanol)</td>
</tr>
<tr>
<td>Pyramid traits</td>
<td>Resistance ??; Performance may be partially compromised by prior trait use, refuge less effective, selection pressure continues, rotate to avoid resistance</td>
</tr>
<tr>
<td>Single traits</td>
<td>Resistance confirmed (primarily VT3 / VT3 Pro). Cross-resistance w/ Agrisure, rotate to avoid resistance</td>
</tr>
<tr>
<td>Layer insecticide on refuge corn</td>
<td>Environmental/health issues, 40-60% kill, protection declines w/ pressure</td>
</tr>
<tr>
<td>Layer insecticide over pyramid</td>
<td>Masks resistance issues. Insurance use – benefit???. Depends on pressure, RIBs benefit under heavy pressure</td>
</tr>
<tr>
<td>Layer insecticide over single trait</td>
<td>Masks resistance issues. Benefit only under heavy pressure on refuge or if Bt-RW performance problem.</td>
</tr>
<tr>
<td>Spray beetles</td>
<td>Reduces pressure, multiple sprays needed, scouting costs &amp; challenges, fungicide tankmix??, environment concerns</td>
</tr>
</tbody>
</table>
CRW Management: What’s a Guy to Do?

- This is a classic resistance situation => Be prepared to change management after 3-4 years in same trait.
- Preferred option – Crop rotation!!!! Watch for rotational resistance with western corn rootworm!
- If you can’t rotate, be prepared to invest more money in corn rootworm management
  - Switch to different single trait or pyramid
  - Layer with a soil insecticide (bandaid)
  - Foliar sprays (multiple, well-timed) may be required to knock-down heavy populations
- Get a handle on corn rootworm pressure and trait performance => Scout!
- Take IPM (Integrated Population Management) approach
Western Corn Rootworm Injury to First-Year Bt-RW Corn (*Gray - IL*)
Any Questions?