Seeds of Change: Can Mutant Rootworms Defeat Our Current Efforts to Control Them with Bt Corn?

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Background

• Host plant resistance has always been considered one of the foundations of IPM

• Transgenic insecticidal corn allows us to achieve some of our traditional goals

• The problem is that stakeholders must wisely and rationally use Bt corn
New Strategies

• Blocks of single-toxin Bt and non-toxic seed have been planted by growers for several years

• Now growers and seed companies are about to experiment with two-toxin pyramids and seed mixtures.
Background

- WCR has evolved resistance to chemical insecticides and to crop rotation.

- The more effective the pest control, the greater the probability of resistance evolution

- Don’t bet against the rootworm!
Background

• Since 2001, Onstad has modeled and analyzed WCR IRM using both block and seed-blend refuges in areas with and without rotation-resistant WCR.

• Now SmartStax double-toxin corn has been approved by EPA (with block refuge) and seed blends of single-toxin corn have been proposed by Pioneer Hi-Bred.
Objectives

- Analyze models of WCR that will infest approved and proposed transgenic insecticidal corn hybrids
- Evaluate resistance management (IRM) strategies for delaying evolution of resistance to Bt corn
First Model

- Corn with two insecticidal traits (pyramid) (some corn may be older hybrids with single toxin)

Refuge varies from 5% currently approved for Monsanto/Dow SmartStax to 20% currently required for single trait corn (Refuge has no Bt toxin in plants)
First Model Assumptions

USEPA estimates of Bt mortality for SS

Cry34/35Ab1 0.9420-0.9918,
Cry3Bb1 is 0.962 - 0.9996,
both traits 0.9822-0.9997.

Thus we modeled SS|SSS mortality as the maximum of two in pyramid and made each 0.999
Why don’t toxins work independently and completely?

- Interference during expression in plant?
- Inadequate energy in plant?
- Interference of one toxin with another in insect?
- Limited target sites in insect?
Assumptions of First Model

• Initial resistance-allele frequency=0.0001
• Resistance confers 100% survival on Bt corn
• Insecticide mortality is 70% if used
• 100% compliance with refuge requirements
• Uniform distribution of adult beetles in every block of corn (either Bt corn or refuge)
• Female beetles mate before they disperse
• Female beetles disperse to lay eggs
Single-Trait Bt Corn

- Years to 50% R-allele frequency with block refuges

<table>
<thead>
<tr>
<th>Refuge</th>
<th>0.01</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>No insecticide use in refuge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5%</td>
<td>35</td>
<td>4</td>
</tr>
<tr>
<td>10%</td>
<td>38</td>
<td>5</td>
</tr>
<tr>
<td>20%</td>
<td>43</td>
<td>6</td>
</tr>
<tr>
<td>Insecticide use every year</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5%</td>
<td>18</td>
<td>4</td>
</tr>
<tr>
<td>10%</td>
<td>34</td>
<td>4</td>
</tr>
<tr>
<td>20%</td>
<td>43</td>
<td>5</td>
</tr>
</tbody>
</table>
Pyramided Bt Corn

- Years to 50% R-allele frequency with block refuges
- Dominance is always 0.5 (additive)
- No insecticide use in refuge
  - 5% 12
  - 20% 15

- Insecticide use
  - 5% 8 same as sequential use
  - 20% 14
Pyramided Bt Corn
Independent Toxins

- Years to 50% R-allele frequency with block refuges
- Dominance is always 0.5 (additive)
- No insecticide use in refuge
  - 5% 18 instead of 12
  - 20% 23 instead of 15

- Insecticide use
  - 5% 11 instead of 8
  - 20% 22 instead of 14
Pyramided and Single Trait
Bt Corn in Landscape

・ Years to 50% R-allele frequency with block refuges
・ Dominance is always 0.5 (additive)
・ Half of cornfields remain single-trait

・ Pyramid  Single-trait  Years to resistance
・ refuge   refuge
・ 20%       20%             15 and 8
・ 5%        20%             14 and 7

・ Faster evolution with inadequate compliance
Conclusions from First Model

• We must understand dominance of resistance as well as the mortality caused by more than one toxin trait in Bt corn.
• Insecticide use in refuges becomes more important as refuge size decreases.
• It is possible sequential use of Bt toxins over years may be just as good for IRM as pyramiding toxin traits.
Conclusions from First Model

• Planting significant amounts of single-trait Bt corn (expressing one of pyramided toxins) in same region as pyramided Bt corn, may reduce durability of pyramided corn.

• Rootworm evolves resistance to single-trait first then only must overcome second trait to defeat pyramid.
Second Model

- Created by Pioneer Hi-Bred team that included Onstad as consultant. (Pan, Stanley, Flexner et al.)

- Seed blend of single-toxin corn (Cry34Ab1/Cry35Ab1) mixed with refuge seed.

- Comparisons to block refuge scenarios
Second Model

• Model of WCR differs from First Model by explicitly modeling adult dispersal and daily emergence and behavior of beetles.

• This model was used to evaluate management of single resistance gene with major effect (gene confers 100% survival)
Second Model Assumptions

- Mortality of susceptible WCR=0.9875
- Dominance of resistance allele=0.05
- Initial resistance-allele frequency=0.001
- Female beetles mate before they disperse
- Female beetles disperse to lay eggs
- 0.75% of seeds in Bt cornfield are not Bt
## Results of Second Model

- **Resistance** – Number of years until 50% R allele frequency in WCR population

<table>
<thead>
<tr>
<th>Refuge type</th>
<th>Compliance</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>5% blended refuge</td>
<td>100%</td>
<td>10 years</td>
</tr>
<tr>
<td>20% block moved annually</td>
<td>70%</td>
<td>7 years</td>
</tr>
<tr>
<td>No refuge,</td>
<td>0%</td>
<td>5 years</td>
</tr>
</tbody>
</table>
Results of Second Model

- Results are sensitive to refuge location and farmer compliance
- 20% Block refuge, Compliance
  - Fixed 100% >20 years
  - Fixed 70% 10 years
  - Moved every 2 years, 100% 9 years
  - Moved annually 100% 8 years

- Note male dispersal is greater in these simulations than in standard simulations
Conclusions of Second Model

• Based on the results produced by the Pioneer/Onstad team, we concluded that a 5% seed blend (refuge-in-the-bag) was just as good if not better than a 20% block refuge for delaying resistance to single-toxin (Cry34Ab1/Cry35Ab1) corn.

• Compliance by growers and dispersal of beetles across cornfields are important.
Summary

• Seed blend simplifies compliance and equalizes quality of refuge and Bt corn plants.
• 5% refuge is reasonable given typical insensitivity of WCR evolution to refuge levels.
• Block refuge location and insecticide use in block refuges remain important issues for WCR IRM.
Acknowledgements

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