Area wide insecticide resistance management strategies for fall armyworm in corn in Puerto Rico

Hector E. Portillo¹, Henry Teran Santofimio², Caydee Savinelli³, Anthony Burd⁴, Jaime Sanchez², Sol Rosado-Arroyo⁵, Jim Johnson⁶, Graham P. Head⁷, Rodney N. Nagoshi⁸, David Mota-Sanchez⁹ and Christian Salcedo¹⁰

¹FMC Agricultural Solutions, Newark, DE, ²Corteva AgriScience, Salinas, PR, ³Syngenta Plant Protection, Greensboro, NC, ⁴Syngenta Crop Protection, Greensboro, NC, ⁵BASF Puerto Rico, Guanica, PR, ⁶Syngenta Crop Protection, Perry, MI, ⁷Bayer Crop Science, Chesterfield, MO, ⁸USDA - ARS, Gainesville, FL, ⁹Michigan State University, East Lansing, MI, ¹⁰Syngenta, Vero Beach, FL
Charter: Champion principles that reduce insecticide selection pressure on pest populations to sustain agriculture. Lead industry experts in sponsoring research and educational outreach on Insecticide Resistance Management.
IRAC-US Member Companies

- ADAMA
- Amvac
- BASF
- Bayer CropScience
- Corteva
- FMC
- ISK Biosciences
- Nichino
- Nisso America
- Syngenta
- Valent

www.irac-online.org
PRABIA Member Companies
Fall Armyworm as Pest in Puerto Rico

- Tropical island with favorable weather for crops and pest development
- Year round corn seed production, host crop availability
- Isolated Island Populations, 12 generations per year possible
- Rapid development of resistance:
  - Cry1F corn was introduced in 2003 in Puerto Rico, resistance in *S. frugiperda* documented in late 2006. (Storer et al., 2010 JEE 103:1031-1038).
  - Resistance or reduced susceptibility to many of the available insecticides reached a crisis in 2007-08
- Developing IRM and IPM strategies to manage fall armyworm was identified as critical for sustainable and continued profitable seed production
Fall Armyworm Becoming a Global Pest
Prior to 2016 only established in the America’s

Source: www.cabi.org/isc
Sequence analysis of segments from the presumptive coding region of the mitochondrial *Cytochrome Oxidase Subunit I (COI)* gene indicate that the h2 haplotype predominates in S. America, TX, and LA.

h4 is the majority form in Puerto Rico, Florida and U.S. east coast.

AL and GA are a mixture of migrants from TX and FL.
Putative Origin of FAW Invasion to Africa?

Fall Armyworm Global Spread

JaspreetSidhu
RangaswamyMuniappan
Virginia Tech
Genetic marker studies indicate that Florida-Caribbean are the likely source of the Africa FAW.

The migratory patterns of FAW have implications on impact of control practices and selection of resistance, thus this is an important project beyond Puerto Rico.

Summary of FAW COIB haplotype distribution
Seven Critical Workstreams Identified for the successful implementation of an area wide Resistance Management program in PR

1. Product efficacy and registration in corn
2. Development and maintenance of rotational program
3. Scouting and thresholds practices
4. Spraying techniques
5. Training
6. Resistance Monitoring
7. Communication
1. Product efficacy and registration in corn

**INSECTICIDE MOAs USEFUL FOR CONTROLLING LEPIDOPTERAN PESTS**

- **Nerve and Muscle Targets** - These insecticides are generally fast acting.
  - **Group 1** Acetylcholinesterase (AChE) inhibitors
    - inhibit AChE, causing hyperexcitation. AChE is the enzyme that terminates the action of the excitatory neurotransmitter acetylcholine at nerve synapses.
  - **Group 2** Carbamate insecticides
    - Carbamates (e.g. Methomyl, Thiodicarb)
  - **Group 3** Organophosphates (e.g. Chlorpyrifos)
  - **Group 4** Pyrethroids (e.g. Permethrin, Lambda-Cypermethrin)
  - **Group 5** Neonicotinoids
    - Niacinomimetic insecticides (e.g. Acetamiprid, Thiacloprid, Thiamethoxam)

- **Respiration Targets**
  - Mitochondrial respiration produces ATP, the molecule that energizes all vital cellular processes. In mitochondria, an electron transport chain uses the energy released by oxidation to charge a proton gradient across the mitochondrial ATP synthase. Several insecticides are known to interfere with mitochondrial respiration by the inhibition of electron transport and subsequent phosphorylation. Insecticides that act on mitochondrial targets in the system are generally fast-acting and toxic.
  - **Group 11** Thiodipropionyl biurets (e.g.[dimethoate](https://en.wikipedia.org/wiki/Methidathion)), a class of organophosphates that halt mitochondrial proton gradient and thus ATP synthesis.
  - **Group 12** Mitochondrial complex III electron transport inhibitors
    - **Folpet**, a triazole that inhibits complex III, preventing the utilization of energy by cells.

- **Midgut Targets**
  - Lepidopteran-specific microbial toxins that are sprayed or expressed in transgenic crops.
  - **Group 13** Microbial [bacteriophage](https://en.wikipedia.org/wiki/Bacteriophage) (e.g. Bacillus thuringiensis) and [insecticidal toxins](https://en.wikipedia.org/wiki/Ivra) (e.g. Bacillus thuringiensis and Bacillus sphaericus)

- **Growth and Development Targets**
  - Insect growth and development is controlled by the balance of two principal hormones: juvenile hormone and ecdysone. Insect growth regulators act by inhibiting one of these hormones or by directly affecting cell metabolism, such as in the synthesis of juvenile hormone.
  - **Group 7** [Juvenile hormone mimetics](https://en.wikipedia.org/wiki/Ivra)
    - Inhibitors of Ecdysone synthesis.
  - **Group 8** [Ecdysone agonists](https://en.wikipedia.org/wiki/Ivra)
    - Agonists that mimic the action of ecdysone.

- **Unknown**
  - Several insecticides are known to affect less well-described targets or functions.

---

- Eight MOA available in PR
- One MOA (Group 11, Bts) not used because of previous Bt resistance to GMO crops and some GMO crops being planted, so only 7 MOAs can be used
- Group 3A (pyrethroids) partially useful due to widespread resistance of larval stage
- Others groups have varied levels of efficacy, some related to resistance
1. Product efficacy and registration in corn

MOA ranking:

1. Group 6
2. Group 1A/1B
3. Group 28+4A
4. Group 22
5. Group 28
6. Group 18
7. Group 5
8. Group 3A
## 1. Product efficacy and registration in corn

### Potency of Insecticides Registered for Control of FAW

<table>
<thead>
<tr>
<th>Active ingredient</th>
<th>MOA</th>
<th>year</th>
<th>n</th>
<th>LD$_{90}$ (ug/ul)</th>
<th>Label max rate (oz/A)</th>
<th>Estimated rate to kill 90% (oz/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinetoram</td>
<td>5</td>
<td>2016</td>
<td>375</td>
<td>0.15</td>
<td>6</td>
<td>3.1</td>
</tr>
<tr>
<td>Emamectin benzoate</td>
<td>6</td>
<td>2016</td>
<td>300</td>
<td>0.01</td>
<td>4.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Permethrin</td>
<td>3A</td>
<td>2013</td>
<td>250</td>
<td>0.15</td>
<td>6</td>
<td>1.0</td>
</tr>
<tr>
<td>Methomyl</td>
<td>1A</td>
<td>2015</td>
<td>600</td>
<td>0.50</td>
<td>24</td>
<td>4.4</td>
</tr>
<tr>
<td>Carbaryl</td>
<td>1A</td>
<td>2015</td>
<td>298</td>
<td>6.41</td>
<td>64.0</td>
<td>34.2</td>
</tr>
<tr>
<td>Chlorpyrifos</td>
<td>1B</td>
<td>2016</td>
<td>154</td>
<td>1.60</td>
<td>32</td>
<td>8.5</td>
</tr>
<tr>
<td>Chlorantraniprole</td>
<td>28</td>
<td>2016</td>
<td>420</td>
<td>0.42</td>
<td>5</td>
<td>5.4</td>
</tr>
<tr>
<td>Methoxyphenozide</td>
<td>18</td>
<td>2015</td>
<td>300</td>
<td>1.49</td>
<td>16</td>
<td>15.9</td>
</tr>
<tr>
<td>Flubendiamide</td>
<td>28</td>
<td>2014</td>
<td>300</td>
<td>1.33</td>
<td>3</td>
<td>7.1</td>
</tr>
<tr>
<td>Bifenthrin</td>
<td>3A</td>
<td>2015</td>
<td>300</td>
<td>0.67</td>
<td>6</td>
<td>7.2</td>
</tr>
<tr>
<td>Zeta-cypermethrin</td>
<td>3A</td>
<td>2015</td>
<td>300</td>
<td>0.20</td>
<td>4</td>
<td>5.4</td>
</tr>
</tbody>
</table>

- Lab potency (field FAW population) data available for 6 MOAs, indoxacarb (Group 22) was not labeled until late 2017

- Note that lab dose for multiple MOAs is close to or greater than what is labeled in the field in most cases

MOA ranking based on lab bioassay:

1. Group 6
2. Group 5
3. Group 3A (permethrin only)
4. Group 1A/1B
5. Groups 28, 18, 3A
2. Development and maintenance of rotational program

Effect of strip cropping and adjacent farms on populations

Even if only treating one field, entire populations are exposed to the insecticide.

MOAs Rotation in time and space vs only space most likely to limit selection pressure

Possibility for exposure to every generation all year long
2. Development and maintenance of rotational program

<table>
<thead>
<tr>
<th>Month</th>
<th>Corn Acres Grown-2016</th>
<th>FAW Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>157.6</td>
<td>High</td>
</tr>
<tr>
<td>February</td>
<td>101.61</td>
<td>Medium</td>
</tr>
<tr>
<td>March</td>
<td>87.95</td>
<td>Medium</td>
</tr>
<tr>
<td>April</td>
<td>68.74</td>
<td>Medium</td>
</tr>
<tr>
<td>May</td>
<td>20.33</td>
<td>Low</td>
</tr>
<tr>
<td>June</td>
<td>33.77</td>
<td>Low</td>
</tr>
<tr>
<td>July</td>
<td>31.13</td>
<td>Low</td>
</tr>
<tr>
<td>August</td>
<td>27.71</td>
<td>Low</td>
</tr>
<tr>
<td>September</td>
<td>8.15</td>
<td>Low</td>
</tr>
<tr>
<td>October</td>
<td>162.75</td>
<td>Medium</td>
</tr>
<tr>
<td>November</td>
<td>358.27</td>
<td>High</td>
</tr>
<tr>
<td>December</td>
<td>431.09</td>
<td>High</td>
</tr>
</tbody>
</table>

Crop intensity and pest severity analysis was used to consider which MOs would fit best within a window.
## 2. Development and maintenance of rotational program

**Corn Window Rotation Program 2019/2020 Season**

- 2\textsuperscript{nd} year program is in place
- MOAs rotated on a 2 month window in 2\textsuperscript{nd} year vs 1 month window in 1\textsuperscript{st} year
- Factors considered:
  - MOA
  - Efficacy level
  - Pest pressure/scouting/timing
  - Total ai registered/crop season
  - Spray intervals, REI, PHI
  - Special labels requested: Proclaim (Group 6, emamectin benzoate) and Steward (Group 22, indoxacarb)

### Table: Development and maintenance of rotational program

<table>
<thead>
<tr>
<th>Month</th>
<th>MOA</th>
<th>Products</th>
<th># Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>October / November</td>
<td>28</td>
<td>Coragen®</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1A / 1B</td>
<td>Lannate® LV / Lorsban-4E®</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Radiant® SC</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>Intrepid® 2F</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>BIO</td>
<td>Capsanem®</td>
<td></td>
</tr>
<tr>
<td>December / January</td>
<td>3A</td>
<td>Perm Up® 3.2 EC / Brigade® 2EC / Baythroid® XL / Mustang Maxx®</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Proclaim®</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>Steward® EC</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>BIO</td>
<td>Capsanem®</td>
<td></td>
</tr>
<tr>
<td>February / March</td>
<td>28</td>
<td>Coragen®</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1A / 1B</td>
<td>Lannate® LV / Lorsban-4E®</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Radiant® SC</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>Intrepid® 2F</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>BIO</td>
<td>Capsanem®</td>
<td></td>
</tr>
<tr>
<td>April / May</td>
<td>3A</td>
<td>Perm Up® 3.2 EC / Brigade® 2EC / Baythroid® XL / Mustang Maxx®</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Proclaim®</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>Steward® EC</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>BIO</td>
<td>Capsanem®</td>
<td></td>
</tr>
<tr>
<td>June / July</td>
<td>28</td>
<td>Coragen®</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>1A / 1B</td>
<td>Lannate® LV / Lorsban-4E®</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Radiant® SC</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>Intrepid® 2F</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>BIO</td>
<td>Capsanem®</td>
<td></td>
</tr>
<tr>
<td>August / September</td>
<td>3A</td>
<td>Perm Up® 3.2 EC / Brigade® 2EC / Baythroid® XL / Mustang Maxx®</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Proclaim®</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>Steward® EC</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>BIO</td>
<td>Capsanem®</td>
<td></td>
</tr>
</tbody>
</table>
## Standardized scouting and Reporting and Thresholds

<table>
<thead>
<tr>
<th>Field size</th>
<th># sample sites</th>
<th># plants per site</th>
<th># total plants/field</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 acre</td>
<td>4</td>
<td>15</td>
<td>60</td>
</tr>
<tr>
<td>≥ 1 &lt; 5 acres</td>
<td>8</td>
<td>15</td>
<td>120</td>
</tr>
<tr>
<td>≥ 5 acres</td>
<td>10</td>
<td>15</td>
<td>150</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Observation</th>
<th>Site 1</th>
<th>Site 2</th>
<th>Site 3</th>
<th>Site 4</th>
</tr>
</thead>
<tbody>
<tr>
<td># Plants with larvae</td>
<td>5</td>
<td>3</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td># plants without larvae</td>
<td>10</td>
<td>12</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

% incidence = \( \frac{(5 + 3 + 7 + 0)}{(15 + 15 + 15 + 15)} \times 100 = \frac{15}{60} \times 100 = 25\%

### 3. Scouting and thresholds practices

Pest identification, scout for adults, eggs, larvae and damage

Photos courtesy of Andres Garcia Montero, FMC Mexico
4. Spraying techniques

- Timing: 1-2nd instar most susceptible life stage
- Once larvae gets in the whorls it is difficult to reach
- Proper calibration and choice of application equipment
- Nozzle selection for coverage and or penetration into the whorl
- Water volume and pressure, 200-300 L/ha minimum
- Use of adjuvants that aid in product movement into the whorl

Photos courtesy of Andres Garcia Montero, FMC Mexico
Multiple training sessions have been provided to PRABIA personnel by IRAC members as well as University experts since 2008 to cover relevant pest management topics with emphasis on IPM and IRM such as:

- Insecticides mode of action training
- Pest biology/pest management
- IPM/IRM

Photos courtesy of Henry Teran, Corteva. PRABIA, IRAC and Michigan State University personnel attending training on May 15-17, 2019
Most recently, May 15-17, 2019, a training-workshop was held at Corteva Agriscience, Salinas Puerto Rico where 22 employees from companies belonging to PRABIA working in IPM programs (BASF, Bayer, Corteva, ICIA, Rice Tec and Syngenta) were trained by Michigan State University and IRAC on bioassay methods to conduct resistance monitoring, including:

- Bioassay techniques to monitor resistance:
  - leaf disc (IRAC Method No. 007) and insecticide diet incorporation (IRAC Method No. 020)
- Evaluation of the larval mortality
- Use of Probit procedure from SAS and/or POLO program to analyze mortality data of the laboratory bioassays

Photos courtesy of Henry Teran, Corteva
Bioassays on FAW field populations in 2019 showed the following:

- Only 2 MOAs showed low/no resistance: Groups 6 and 1A

- Group 28 and Group 22 insecticides provide control in the field, but lab bioassay data show moderate to high levels of resistance

- While Groups 3A and 18 provide some control in the field, lab bioassay data show high levels of resistance

- These data is consistent with bioassays from previous years

- While Group 5 was not tested, some levels of resistance to this MOA have been observed in the past
7. Communication

• This is a critical task and includes the following:
  – Compile and distribute the annual IRM manual that includes a description of the program, the insecticide rotations per window, scouting techniques and other information
  – Organize meetings
  – Email members regarding any updates: new information on product efficacy, resistance monitoring bioassay results, pest pressure etc.
  – Other
Conclusions

• An area wide insecticide rotation program is the best long term option to prolong efficacy of available insecticides for FAW management in Puerto Rico

• Developing and implementing area wide programs requires a lot of effort and coordination

• Area wide programs are a hard sell, getting 100% compliance on a voluntary basis not easy

• Enforcing a fallow period may be necessary as rotation alone may not be enough to restore or maintain the efficacy of available MOAs

• Use of other management tools, i.e., cultural and biological control, need to be incorporated into the program

• This program benefits Puerto Rico/PRABIA, but it also has implications in other places given the migratory patterns of this pest
Thank You!