Management of Fall armyworm (*Spodoptera frugiperda*), with emphasis on Bt Transgenic Technology

Galen Dively  
Emeritus Professor  
Department of Entomology  
University of Maryland  
galen@umd.edu
Outline

FAW population distribution
Identification, life cycle, and damage
Biocontrol agents
Cultural control options
Biopesticides
Conventional insecticides
Host plant resistance with native genes
Bt transgene-based resistance
Integrated management of the Fall Armyworm on maize
A guide for Farmer Field Schools in Africa

Food and Agriculture Organization of the United Nations, Rome, 2018

For fact sheets and management decision guides, visit: www.plantwise.org/fallarmyworm
Why FAW is a serious pest in Africa:

- high reproductive rate.
- feeds on many different crops.
- strong flyer, disperses long distances.
- continuous generations throughout the year.
- natural enemies do not act effectively enough to prevent crop injury.
Africa: 43
North America: 41
Central America: 28
South America: 32
Recently detected in India

For countries with FAW, value at risk is over $13.3 billion and a major threat to food security.
Life cycle of the fall armyworm
30 – 40 days

Adult moth blows in on storm fronts, migrating 100s of km
Larvae, which emerge in 14-28 days, may tunnel directly into the maize ear

Adult lays eggs on immature plants, hatching in 3-5 days

Pupation ends and the cycle repeats in warmer climates

The moth lives as an adult for 11-14 days
After development it crawls to the ground to pupate in the soil for 7-14 days

Note: Graphic is adapted from Pioneer® materials.
Inverted ‘Y’:

4 spots that form a square:

Fall armyworm
Host plants:
- Wider host range than African armyworm
- Over 80 plants recorded, but prefers grasses

Preferred food:
- Sweet maize
- Field maize
- Sorghum
- Bermuda grass
- Grass weeds (crabgrass)
### Field crops:
- Alfalfa
- Barley
- Bermuda grass
- Buckwheat
- Cotton
- Clover
- Maize
- Oat
- Millet
- Peanut

### Vegetable crops:
- Rice
- Ryegrass
- Sorghum
- Sugarbeet
- Sudangrass
- Soybean
- Sugarcane
- Timothy
- Tobacco
- Wheat

### Sweet corn
- Sweet potato
- Turnip
- Spinach
- Tomato
- Cabbage
- Cucumber

### Other crops:
- Apple
- Grape
- Orange
- Papaya
- Peach
- Strawberry
- Some flowers
- Usually one late larva per whorl.
- Can compensate for significant leaf feeding and still produce ears.
- High infestations can kill the growing tip and prevent ear formation.
Insecticides are applied to sweet maize in the southeastern U.S., sometimes daily to control FAW.
Biological Control Agents: Parasitoids and Predators

- **Lady beetle spp.**
- **Telenomus sp.**
- **Chelonus sp.**
- **Trichogramma parasitizing FAW eggs**
- **Campoletis flavicincta**
- **Tachinid fly, Winthemia trinitatis**
- **Earwing spp.**
- **Ground beetles**
- **Predaceous bugs**
Biological Control Agents: Pathogens

- *Metarhizium anisopliae*
- *Metarhizium rileyi*
- *Beauveria bassiana*

**Bacterial diseases**
- *Bacillus thuringiensis*

- Viruses, *Spodoptera Frugiperda Multicapsid Nucleopolyhedrovirus (SfMNPV)*

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- Often too late to prevent economic damage.
- Efficacy influenced by weather conditions.
- Commercial virus biopesticide is being developed.
- Biopesticides with strains of *Bt aizawai* are available.
- Must be applied at the early larval stages
Cultural Management:

- **Plant early or use early maturing varieties** (higher armyworm densities occur later in the season).
- **Maintain healthy plants** with adequate moisture to allow better compensation of the damage.
- “Push-Pull” companion cropping show some potential but requires an investment of labor and extra cost.
  - intercropping maize with a pest-repellent (“push”) plant (*Desmodium* spp.), surrounded by a border pest-attractive trap (“pull”) plant (napier grass (*Pennisetum purpureum* or *Brachiaria* spp.))
- Deep tillage and plant residue after harvest may interfere with FAW but need further research.
Regular Monitoring for early detection is essential for FAW management.

Use FAW pheromone traps to detect the presence of moth activity.

Check fields several times weekly starting at seedling stage.
Fall Armyworm – When to Spray?

**USAID ADVANCE**

Attacks Seedlings

Clusters of small, round "windows"  
Spray 1-2 weeks after emergence

Spray at tassel

Attacks Ears

Long narrow "windows"

Completes lifecycle in 30-40 days

Egg  
Larva or caterpillar  
Pupa  
Adult

FAW Action Thresholds
For African farmers

<table>
<thead>
<tr>
<th>Stages</th>
<th>Thresholds</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Whorl Stages</td>
<td>10 - 30%</td>
<td>Spot treatments if infestations are clumped in the field.</td>
</tr>
<tr>
<td>Late Whorl and Pretassel Stages</td>
<td>30 - 50%</td>
<td></td>
</tr>
<tr>
<td>Tassel, Silking and Ear Stages</td>
<td>10 - 30% (not recommended for small farmers)</td>
<td></td>
</tr>
</tbody>
</table>

Thresholds used on sweet maize in US: Treat for FAW during the early whorl stage when more than 15% of the plants are infested. During mid- to late-whorl stages, treatment for FAW may be necessary if more than 30% of the plants are infested.
Infestation of older larvae is too advanced to control.

Larvae may be too deep in the whorl.
Local Management Options:

- Probably most practical option for small farmers is simply to **monitor fields carefully and crush egg masses** and young larvae.
- Use of lime, soaps, ash, sand, sawdust or dirt placed into whorls.
- Sugar water sprayed into whorls to attract ants.
- **Neem** botanical insecticide made from chopped up leaves and crushed seeds (azadirachtin), stewed in water for several days, strained, and formulated with cooking oil and dish soap as a foliar spray (acts as an antifeedant and IGR).
- Other **botanical extracts** with potential use include: velvet bean (*Mucuna pruriens*), Persian lilac (*Melia* sp.) and Pyrethrum (*Tanacetum cinerariifolium*), Fish-poison bean (*Tephrosia vogelii*) (rotenoids).
- **Viruses from infected worms can be made into a local spray** or wettable powder. See USAID/CIMMYT IPM Guide for Small-Scale Production of Baculoviruses Infecting FAW
Conventional Insecticides

Currently the main control option in response to FAW outbreaks.

Old and new classes of insecticides are available and used in Africa. Some are more toxic than others.

**IPM approach is recommended, using low-risk insecticides or biopesticides as the best option but only when necessary.**

Control efficacy against FAW depends on:

- Choosing the right pesticide (more toxic is not better)
- Right labelled dose (sprayer calibration is important)
- Timing the treatment (stage of FAW larvae, time of day)
- Spray coverage (type of applicator and spray volume)
- Water used (higher pH can degrade many insecticides)
<table>
<thead>
<tr>
<th>Product Name</th>
<th>Active Ingredient(s)</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lannate</td>
<td>methomyl*</td>
<td>Available in Africa</td>
</tr>
<tr>
<td>Lorsban</td>
<td>chlorpyrifos*</td>
<td>Pyrinex (+SP)</td>
</tr>
<tr>
<td>Asana</td>
<td>esfenvalerate*</td>
<td>Available in Africa</td>
</tr>
<tr>
<td>Perm-UP</td>
<td>permethrin*</td>
<td>Available in Africa</td>
</tr>
<tr>
<td>Baythroid,</td>
<td>beta-cyfluthrin*</td>
<td>Thunder (+neo)</td>
</tr>
<tr>
<td>Declare</td>
<td>gamma cyhalothrin</td>
<td></td>
</tr>
<tr>
<td>Bifenture, Capture,</td>
<td>bifenthrin*</td>
<td>Available in Africa</td>
</tr>
<tr>
<td>Sniper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hero</td>
<td>zeta-cypermethrin* + bifenthrin*</td>
<td></td>
</tr>
<tr>
<td>Warrior, Capture,</td>
<td>lambda-cyhalothrin*</td>
<td>Super Top (+neo)</td>
</tr>
<tr>
<td>generics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mustang Maxx</td>
<td>zeta-cypermethrin*</td>
<td>Chemaprid</td>
</tr>
<tr>
<td>Tombstone</td>
<td>cyfluthrin*</td>
<td>Available in Africa</td>
</tr>
<tr>
<td>Avaunt</td>
<td>Indoxacarb</td>
<td>Avatar, Viper (+SP)</td>
</tr>
<tr>
<td>Besiege</td>
<td>lambda-cyhalothrin* + chlorantraniliprole</td>
<td></td>
</tr>
</tbody>
</table>

*Restricted use products, have 12-48 hrs re-entry and 1-7 days harvest intervals. All classified highly hazardous or require mitigation measures to reduce risks.
## Foliar Treatments - Soft Insecticides for FAW Control in the US

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<tr>
<th>Product Name</th>
<th>Active Ingredient(s)</th>
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<tr>
<td>Coragen, Premio</td>
<td>chlorantraniliprole</td>
<td>Available in Africa</td>
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<tr>
<td>Voliam Targo</td>
<td>chlorantraniliprole+abamectin</td>
<td>Available in Africa</td>
</tr>
<tr>
<td>Minecto Pro</td>
<td>cyantraniliprole</td>
<td>Available in Africa</td>
</tr>
<tr>
<td>Belt</td>
<td>flubendiamide</td>
<td>Available in Africa</td>
</tr>
<tr>
<td>Blackhawk, Entrust</td>
<td>spinosad</td>
<td>Available in Africa</td>
</tr>
<tr>
<td>Radiant, Exalt</td>
<td>spinetoram</td>
<td></td>
</tr>
<tr>
<td>Match</td>
<td>lufenuron</td>
<td>Available in Africa</td>
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<tr>
<td>Intrepid</td>
<td>methoxyfenozide</td>
<td></td>
</tr>
<tr>
<td>Rimon</td>
<td>novaluron</td>
<td></td>
</tr>
<tr>
<td>Dimilin</td>
<td>diflubenzuron</td>
<td>Available in Africa</td>
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<tr>
<td>Neemix, many others</td>
<td>azadiractin</td>
<td>Available in Africa</td>
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<tr>
<td>Able, Agree,</td>
<td>Bacillus thuringiensis</td>
<td>Bypel, Agoo</td>
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<tr>
<td>Virus products (Spobiol)</td>
<td>maybe available in near future</td>
<td></td>
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<td>Product Name</td>
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<tr>
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<td></td>
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</tr>
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Insecticide Effectiveness against FAW in the US and Brazil

- FAW resistance to pyrethroids has resulted in fair to good control of the leaf feeding injury but poor ear protection.
- Spinetoram, indoxacarb, and chlorantraniliprole are most effective to control older larvae.
- IGRs - novaluron, lufenuron, diflubenzuron and methoxyfenozide can effectively controlled early to mid stage larvae.
- Biological insecticides (Bt sprays, virus formulation) work well if applied to come in direct contact with 1\textsuperscript{st}-3\textsuperscript{rd} instars.
- Studies report high frequency of resistance to spinosad, lambda-cyhalothrin and lufenuron detected in Brazilian populations.
Field Application/Formulation of Bt Sprays

- Mainly applied as liquid sprays, used by organic farmers.
- Formulated of just crystal protein, crystal protein + spores, or the entire dead bacteria.
- Degraded in sunlight- usually persist less than a few days; requires complete spray coverage, must be ingested, and does not kill all insect stages.
- Use of Bt insecticides has been limited because field performance is not consistent.
- Shelf life- 1-3 years in cool dry place.
# Bacterial Insecticides

<table>
<thead>
<tr>
<th>Species</th>
<th>Trade Name</th>
<th>Use</th>
<th>Interesting notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bacillus sphaericus</em></td>
<td>VectoLex ®</td>
<td>mosquito larvacide</td>
<td>Bt spray applied to water</td>
</tr>
<tr>
<td></td>
<td>VectoBac®</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Bacillus thuringiensis</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>spp. aizawai</em></td>
<td>XenTari®</td>
<td>Lepidoptera</td>
<td>Cry 1 and Cry 9 protein</td>
</tr>
<tr>
<td></td>
<td>Agree ®</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>spp. kurstaki</em></td>
<td>Dipel®</td>
<td>Lepidoptera</td>
<td>Cry 1 protein</td>
</tr>
<tr>
<td></td>
<td>Deliver ®</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>spp. tenebrionis</em></td>
<td>Novodor ®</td>
<td>Coleoptera</td>
<td>Cry 3A protein</td>
</tr>
<tr>
<td><em>spp. israelensis</em></td>
<td>Thuricide ®</td>
<td>Diptera</td>
<td>Cry 4 protein</td>
</tr>
<tr>
<td></td>
<td>Gnatrol®</td>
<td></td>
<td></td>
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<tr>
<td><em>spp. japonensis</em></td>
<td></td>
<td>Coleoptera</td>
<td>Cry 3B protein</td>
</tr>
<tr>
<td><em>spp. galleriae</em></td>
<td>grubGONE!</td>
<td>Coleoptera</td>
<td>Cry 1cb1 and Cry 9 like</td>
</tr>
<tr>
<td><em>Chromobacterium subtsugae</em></td>
<td>Grandevo®</td>
<td>insects and mites</td>
<td>2012 new biological</td>
</tr>
</tbody>
</table>
Host Plant Resistance

- Easiest to implement, safe to use, and environmentally friendly.

Native Resistance

Transgenic Resistance
Native Maize Resistance

- Particularly needed in open-pollinated varieties, because small African farmers have limited access to safe and affordable FAW control options.

- Breeding programs in Mexico, Brazil, and the USA have incorporated naturally occurring polygenic traits for insect resistance into several maize inbred lines and have developed a number of improved tropical/subtropical maize hybrids but only with partial resistance to FAW.

- No Africa-adapted maize varieties with documented levels of resistance to FAW.
Native Maize Resistance

- International research organizations are screening maize inbred lines to identify germplasm with potential levels of FAW resistance for medium- to long-term breeding development of African maize varieties.

- Given results of breeding efforts in Americas, it is unlikely that Africa maize varieties can provide high levels of resistance to FAW.
Transgenic Maize Resistance

Offers significantly more effective HPR traits to manage FAW than does native resistance.

Bt maize hybrids, expressing single and combinations of cry and vip genes, isolated from *Bacillus thuringiensis*, are grown globally, particularly in Brazil and North America, where over 80% of the total maize production is planted with Bt hybrids.
**Bacillus thuringiensis**

Most widely used biopesticide
Naturally occurring bacterium that was discovered over 100 years ago
Can be cultured on artificial media
Bacillus thuringiensis

The spore producing structure (sporangium) contains a spore (reproductive function) and a proteinaceous crystal (containing delta endotoxin, preferred to as Cry proteins)
**Bacillus thuringiensis** Growth Characteristics

- **Lag Phase**: Increasing metabolism, slow growth
- **Logarithmic Phase**: Rapid vegetative cell growth
- **Stationary Phase**: No growth, sporulation and vegetative cell death

VIPs excreted

Cry endotoxin produced as a crystalline protein
Mode of Action of Bt proteins

High gut pH (8-11) dissolves the Bt protein and activates toxin which attaches to specific midgut receptor sites cells.
Bt corn expresses the cry or vip proteins in all tissues throughout the crop cycle.

- **Corn Cells**
  - **Protoxin**
  - **Endotoxin**
  - **Pore formation**
  - **Cells in gut rupture**
  - **Death**

  - **Promoter turns on production**
  - **Gut enzymes activate toxin**
  - **Toxin binds to membrane**
  - **Perforated cells leak**
  - **Gut paralyzed**
Main caterpillar targets of Bt corn

- Corn earworm
- European corn borer
- Fall armyworm
- True armyworms
- Western bean cutworm
- Black cutworm
European corn borer:  Cry1Ab, Cry1F, Cry1A.105, and Cry2Ab2

Corn earworm:  Cry1Ab, Cry1F, Cry1A.105, and Cry2Ab2, VIP3A

Fall armyworm:  Cry1Ab, Cry1F, Cry1A.105, and Cry2Ab2, VIP3A

Black cutworm:  VIP3A and Cry1F

True armyworm:  VIP3A only

Western bean cutworm:  Cry1F, VIP3A only
Handy Bt Trait Table for U.S. corn production updated for 2018
http://msue.anr.msu.edu/news/handy_bt_trait_table

Table 1: Bt corn ‘events’ (transformations of one or more genes) and their Trade Names

<table>
<thead>
<tr>
<th>Trade name for trait</th>
<th>Event</th>
<th>Protein(s) expressed</th>
<th>Insect Target or Herbicide Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agrisure CB/LL</td>
<td>Bt11</td>
<td>Cry1Ab + PAT</td>
<td>corn borer + glufosinate tolerance</td>
</tr>
<tr>
<td>Agrisure Duracade</td>
<td>5307</td>
<td>eCry3.1Ab</td>
<td>rootworm</td>
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<tr>
<td>Agrisure GT</td>
<td>GA21</td>
<td>EPSPS</td>
<td>glyphosate tolerance</td>
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<tr>
<td>Agrisure RW</td>
<td>MIR604</td>
<td>mCry3A</td>
<td>rootworm</td>
</tr>
<tr>
<td>Agrisure Viptera</td>
<td>MIR162</td>
<td>Vip3A</td>
<td>broad lep control (but not corn borer)</td>
</tr>
<tr>
<td>Hercules 1 or CB</td>
<td>TC1507</td>
<td>Cry1Fa2 + PAT</td>
<td>corn borer + glufosinate tolerance</td>
</tr>
<tr>
<td>Hercules RW</td>
<td>DAS-59122-7</td>
<td>Cry34Ab1/Cry35Ab1 + PAT</td>
<td>rootworm + glyphosate tolerance</td>
</tr>
<tr>
<td>Roundup Ready 2</td>
<td>NK603</td>
<td>EPSPS</td>
<td>glyphosate tolerance</td>
</tr>
<tr>
<td>Yieldgard Corn Borer</td>
<td>MON810</td>
<td>Cry1Ab</td>
<td>corn borer</td>
</tr>
<tr>
<td>Yieldgard Rootworm</td>
<td>MON863</td>
<td>Cry3Bb1</td>
<td>rootworm</td>
</tr>
<tr>
<td>Yieldgard VT Pro</td>
<td>MON89034</td>
<td>Cry1A.105 + Cry2Ab2</td>
<td>broader lep control</td>
</tr>
<tr>
<td>Yieldgard VT Rootworm RR</td>
<td>MON88017</td>
<td>Cry3Bb1 + EPSPS</td>
<td>rootworm + glyphosate tolerance</td>
</tr>
</tbody>
</table>
• 100% prevention of whorl and stalk damage due to European corn borer.

• Eliminates yield losses and number of marketable ears.
Attribute GSS0966 (Bt)       Prime Plus (nonBt)
From Burtet et al. Managing fall armyworm with Bt maize and insecticides in southern Brazil. Pest Manag Sci 2017
Economic Benefits of Bt Corn

• Reduced costs of using insecticides

• Improves farmer efficiency; easy-to-use, no re-entry intervals, or pre-harvest intervals.

• Increases high yields & food quality
Health and Environmental Benefits

- Reduces risks of pesticide use: worker exposure, pesticide residues, spray drift, non-target effects.
- Prevents pollution: groundwater contamination, fossil fuel consumption, spills, pesticide containers and waste.
- Preserves beneficial populations; can help keep other pests in check.
Kernel damage and larval frass create conditions in the ear that favor ear mold pathogens, such as *Fusarium* and *Aspergillus flavus*, that produces mycotoxins which are poisonous to humans and livestock.
Reduces Pest Populations on Other Crops

Bt corn provides 100% control of corn borers.

No evidence of resistance development after 23 years. Reduced use of insecticides and increased yields.

Wide adoption of Bt corn has resulted in corn borer declines expanding beyond the planted transgenic crops.
ECB recruitment in field corn is the major source of moths colonizing other host crops.
HIGH-DOSE expression in Bt corn prevents ECB reproduction and population recruitment.
Pest Resistance is the major threat to the sustainability of the Bt transgenic technology

- Bt corn in the US is regulated at a higher standard than conventional insecticides.
- Conditions for registration approval require resistance monitoring and the high dose-refuge strategy.
High Dose - Refuge Strategy

All offspring are RS which are killed by the high dose

Many SS moths emerge

SS x RR

All RR moths mate with SS moth

Very less moths emerge but all RR

Refuge

Bt Crop
Current Situation of Pest Resistance to Bt Corn

- Widespread adoption and lack of refuges have led to FAW resistance to Cry1F maize in Puerto Rico, Brazil and Argentina.

- In the USA, Cry1Ab toxin expressed in events MON810 and BT11 in maize also have lost some control efficacy against FAW.

- Genetic analyses and field trials of Bt maize suggest resistance alleles may not be present in FAW populations currently in Africa.
Refuge and High Dose Issues

**Issue #1** - Toxin expression in Bt maize is not high dose for all target insects (particularly FAW), so some heterozygous individuals (with one R allele) can survive.

**Issue #2** – Susceptible and resistant adults may not mate at random; refuge too far away from the Bt crop. Should it be within 0.5 km away?

**Issue #3** – Farmers are required by the seed contract to plant a refuge of non-Bt corn but compliance has been declining.
Multiple Proteins Pyramided in Corn

- Most Bt hybrids grown in the US express multiple proteins for the same insect pests.
- Broaden the spectrum of control and makes it more difficult to develop resistance.
- Many hybrids express two Cry3 proteins for rootworms and four Cry and/or Vip3A proteins for caterpillars.
Transgenic Resistant Maize in Africa

- Currently commercially available only in South Africa, where two Bt products provide protection against FAW.

**MON810 event (cry1Ab)** for stem borer control but also confers partial resistance to FAW (since 1997).

**MON89034 event (cry1A.105 and cry2Ab2)** for control of both FAW and stem borers (since 2010).

Most effective against FAW is the **MIR162 event (vip3A)** pyramided with multiple cry proteins provides broad lepidopteran control.
Transgenic Resistance Efforts in Africa

Public-private partnerships (i.e. WEMA project), working with research organizations of South Africa, Kenya, Tanzania, Uganda, and Mozambique, are currently testing the performance, yield benefit and safety of Bt maize under African conditions.

In confined field trials, MON810 event (cry1Ab) is showing effective control of stem borers and partial control of FAW in Kenya, Mozambique, and Uganda.

Applications for regulatory approval are pending or will be submitted in a number of Africa countries.
Challenges for deployment of Bt Maize in Africa

- Lack of regulatory and biosafety framework to ensure sustainability of the technology.
- Lack of education about GMOs at the consumer level.
- Single Bt traits may be loyalty-free from biotech companies, but who will develop the technology and how long until commercial availability in local varieties?
- Will there be enough maize production in a country to justify the costs of technology approval?
Challenges for deployment of Bt Maize in Africa

- Adding Bt traits into open-pollinated varieties will require education of farmers that keep seed.

- Performance of Bt maize could be affected FAW resistance already in the population.

- Are sufficient refugia around maize present in the Africa landscape to produce enough susceptible FAW moths to delay resistance?
Questions