

Resistance Management for Bt Crops: Global Lessons

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Insect Resistance Can Arise Rapidly

Colorado potato beetle

Insecticide	Introduction	1 st Failure
Arsenicals	1880	1940's
DDT	1945	1952
Dieldrin	1954	1957
Carbaryl	1959	1963
Azinphosmethyl	1959	1964
Carbofuran	1974	1976
Fenvalerate	1979	1981
Permethrin	1979	1981

Implications for Bt Crops: Issues and Opportunities

- High, season-long levels of insecticidal protein are possible
 - Provides a very high level of control throughout the life of the pest, unlike most conventional insecticides
 - **But strong selection for resistance**
- Defined in-plant distribution of insecticidal protein
 - Can control how much of the pest population is exposed
 - Better control of how farmers use the product

Consequences and Costs

- Potential costs of resistance evolution
 - Loss of product value (impact on product life)
 - Impact on company reputation
- Costs of resistance management
 - Development costs
 - Implementation costs

The Basic Need

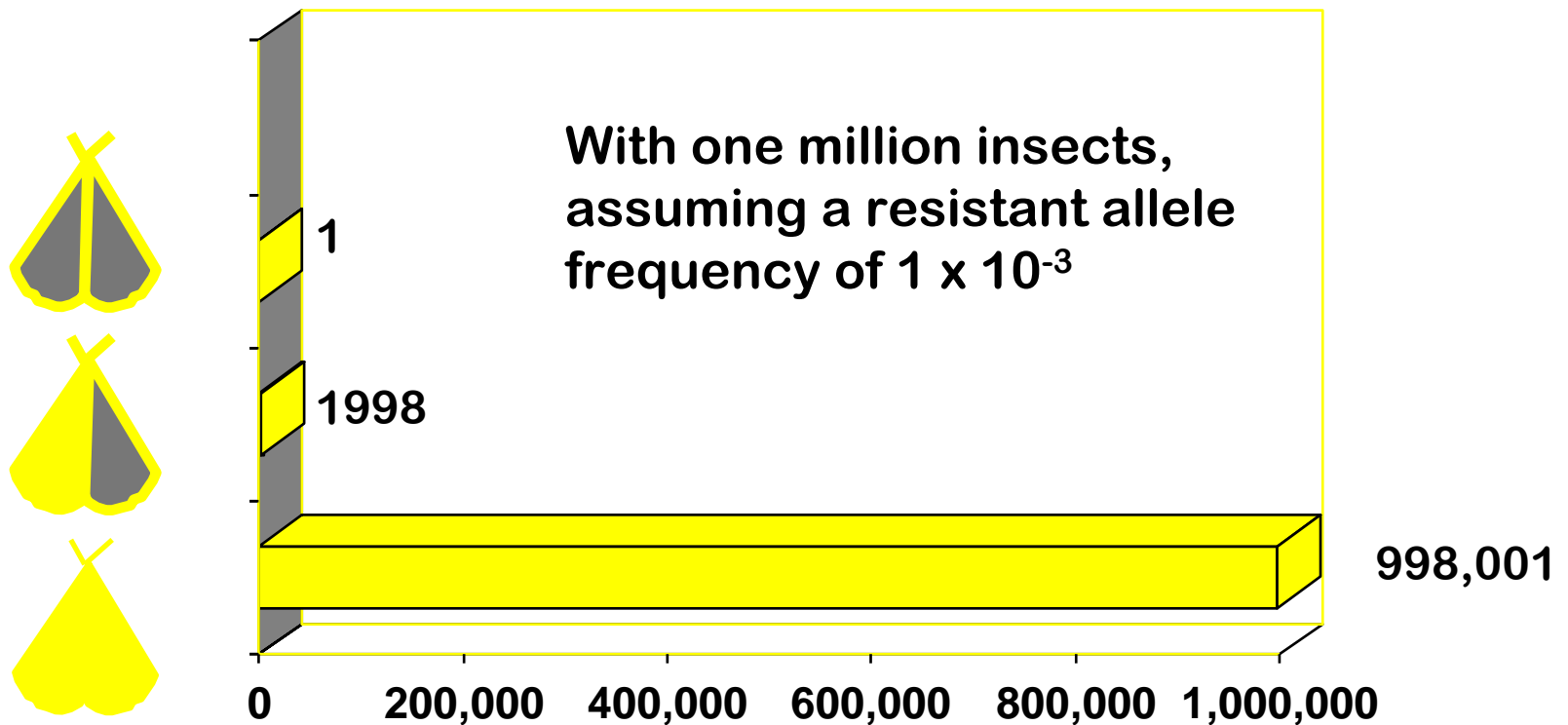
To develop IRM strategies that are:

- Effective in delaying resistance evolution
- Practical and implementable
- Cost-effective

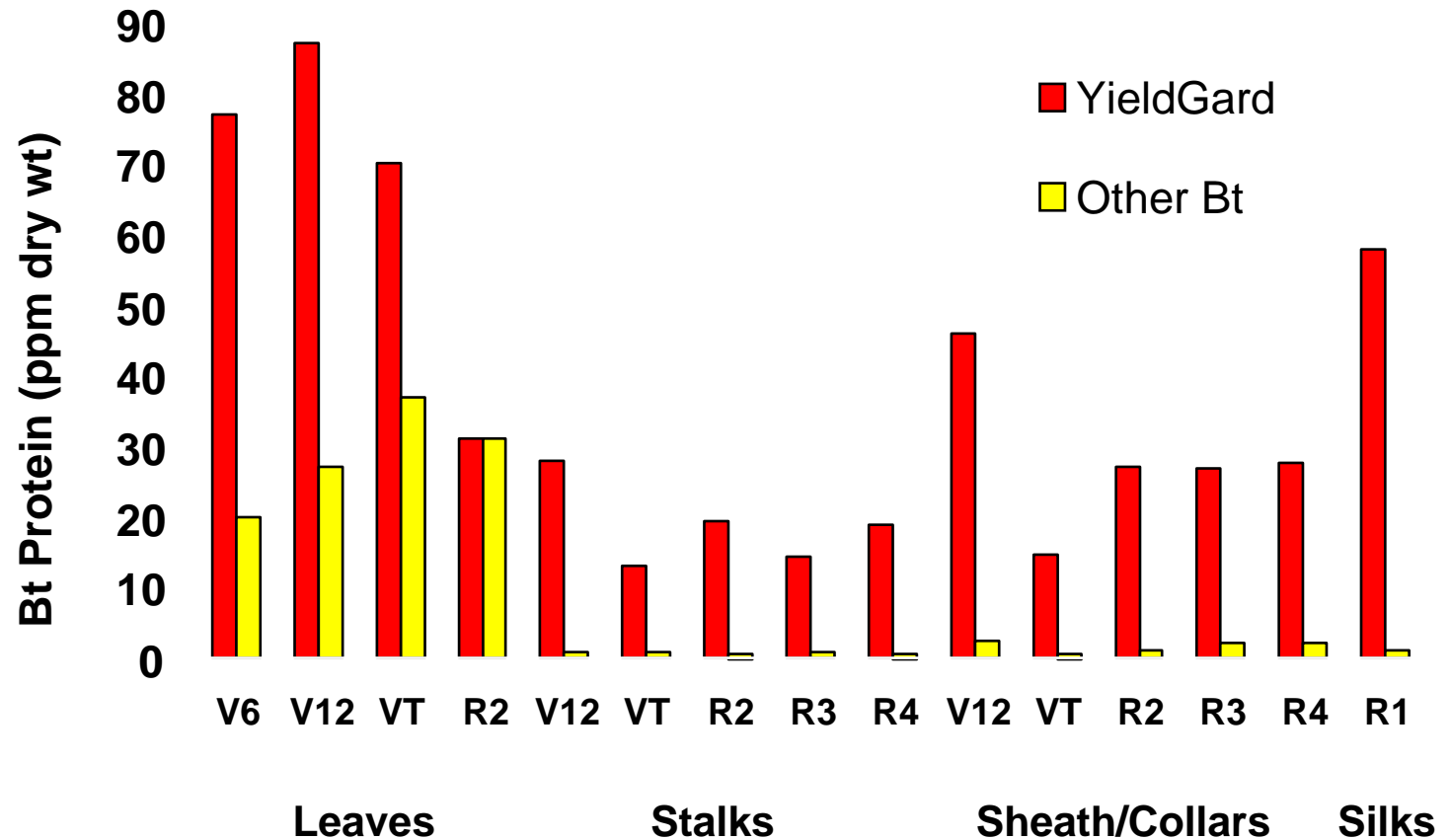
Approaches to IRM

- Minimize selection pressure
 - Limit product use and provide “refugia”
- Remove resistant alleles from the population
 - High doses of insecticide
- Multiple selection mechanisms

First Part of a Two-Pronged Strategy: Make Resistance Functionally Recessive



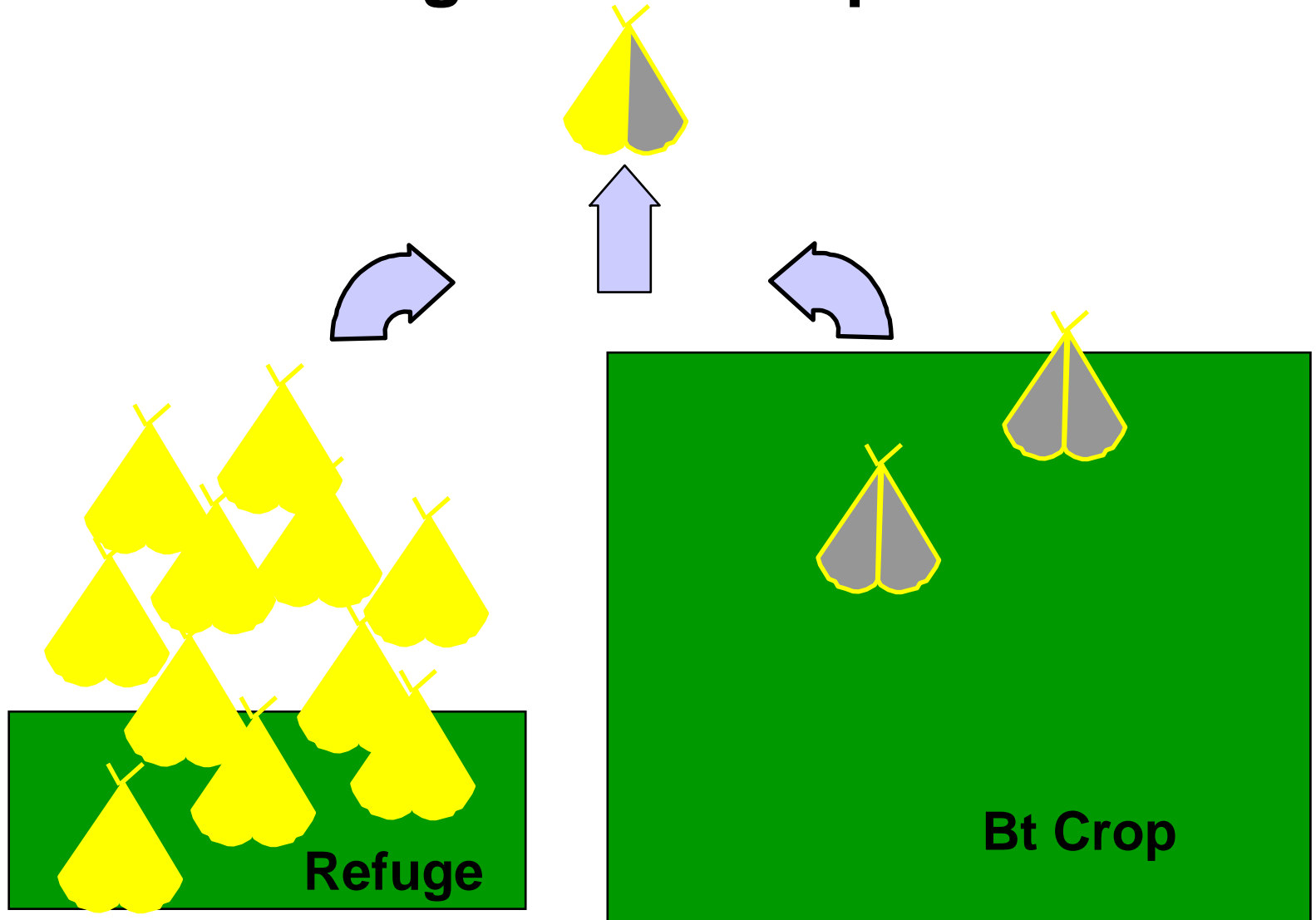
Cry1Ab Protein in Bt corn



Genetics of Bt Resistance

- Mechanisms of Bt resistance that give high-level resistance typically are recessive or largely recessive
- Alleles that confer this sort of Bt resistance typically appear to be rare (0.005 or much less)

Second Part of IRM Strategy: Provide Refuge for Susceptible Pests



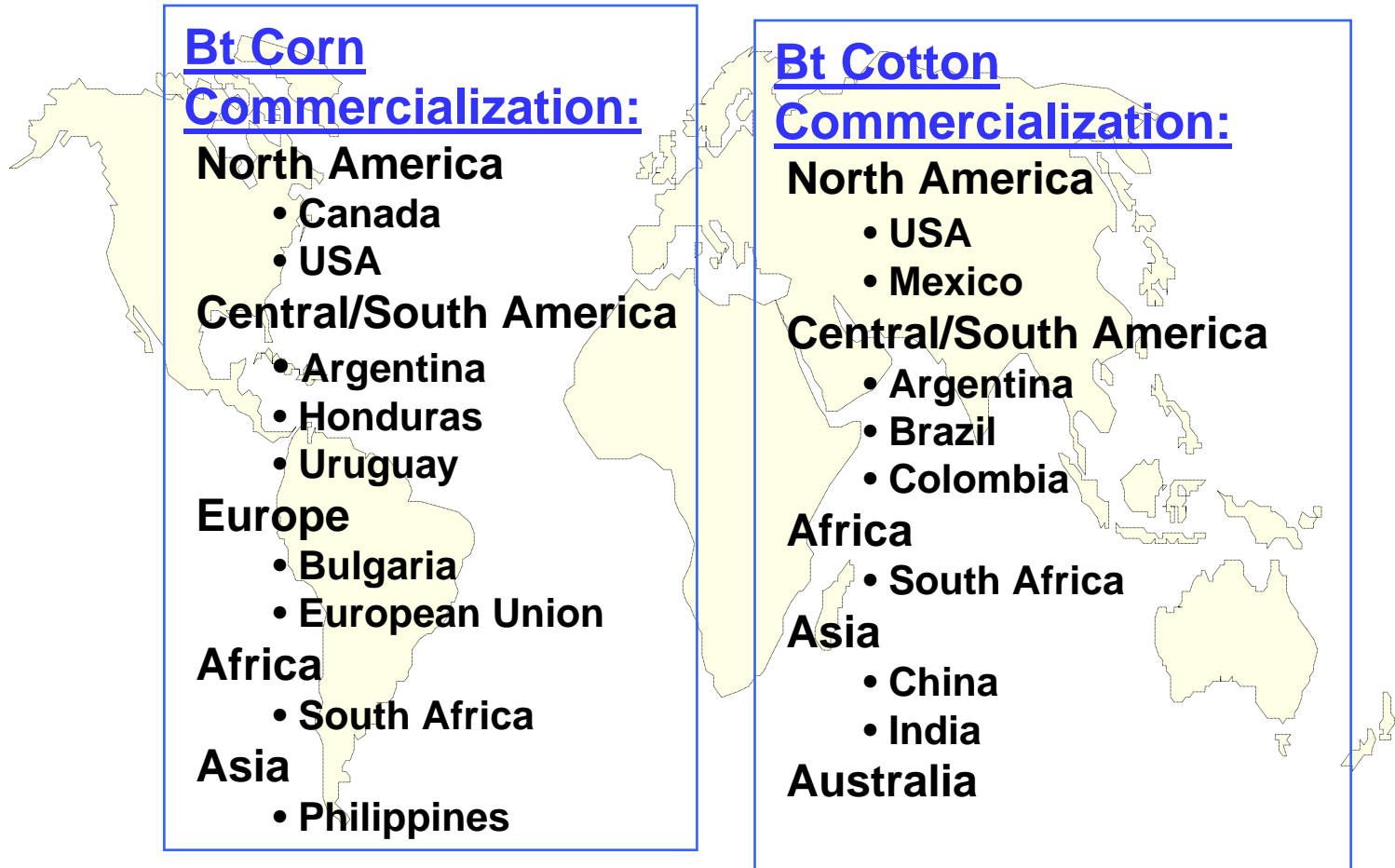
Combining Effective Dose and Refuge: Years to Resistance

% Refuge	No high dose	High dose
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0	3	1
0.1	3	<u>5</u>
1	5	22
5	<u>11</u>	83
10	19	>100
20	35	>100

(from Onstad & Gould 1998)

Global Adoption of Bt Crops



Resistance Management for Bt Crops

- An IRM plan is in place everywhere Bt crops have been commercialized
 - Developed as a collaboration between industry and academic scientists, regulators and farmers
 - A part of product stewardship and may be a regulatory requirement
- Standard components of IRM include:
 - An appropriate refuge that acts as a source of susceptible pest insects
 - Monitoring for resistance in the target pest species
 - An education program to ensure farmers are aware of, and support, IRM

IRM Should be Adapted to Local Conditions and Needs

- Designing an IRM plan
 - Appropriate IRM practices (for example, refuge size) consider local pest biology and agricultural practices
 - Refuge may be structured or unstructured (natural); unstructured refuge may be sufficient for pests with a broad host range

Product Design

Mode of action
Protein expression
Level of control

Pest Biology

Host range
Movement before
and after mating

**IRM Strategy:
product use**

Resistance Genetics

Degree of dominance
Allele frequency
Fitness cost

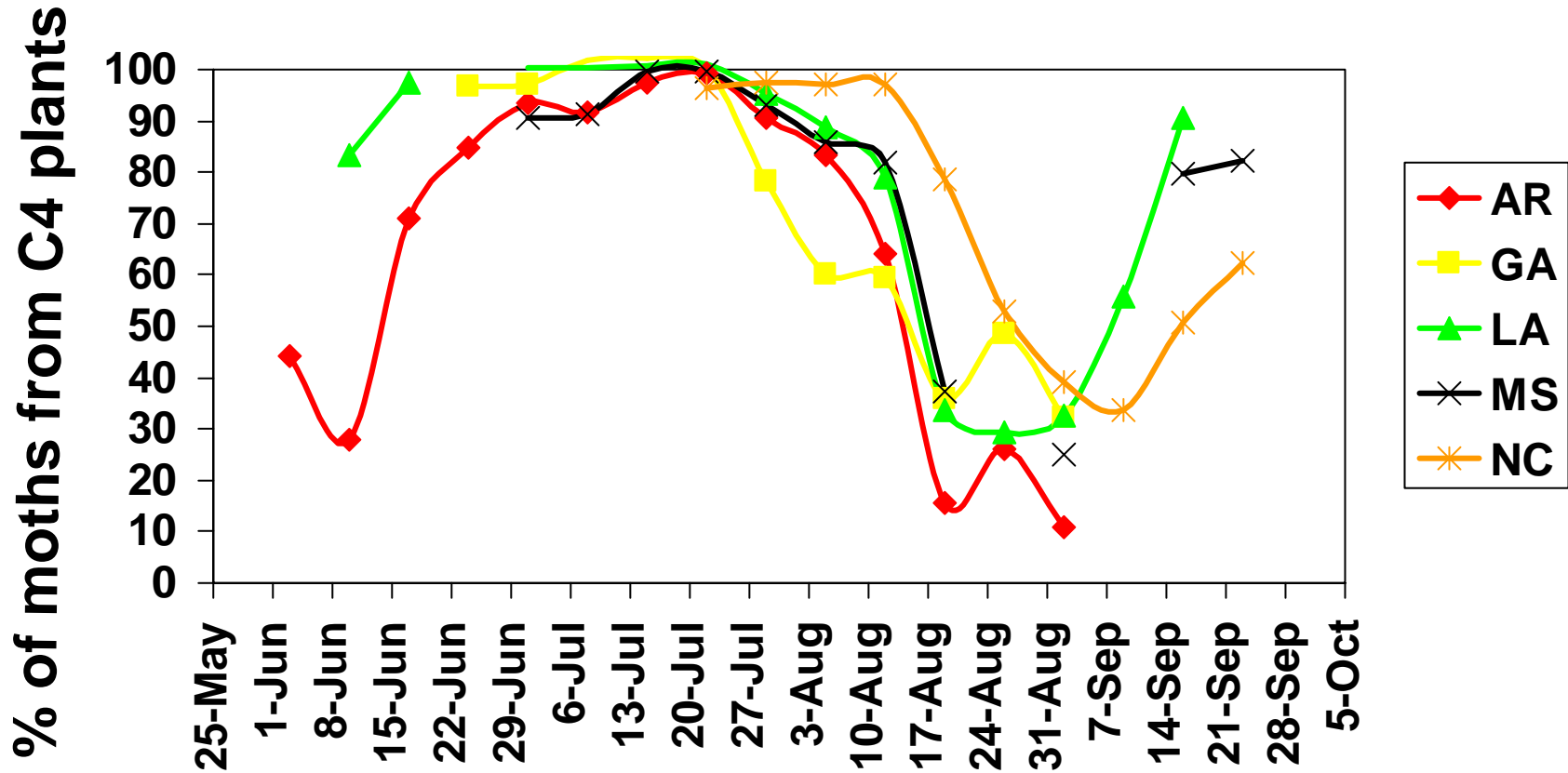
Farming Practices

Farm size
Diversity of farms
IPM practices

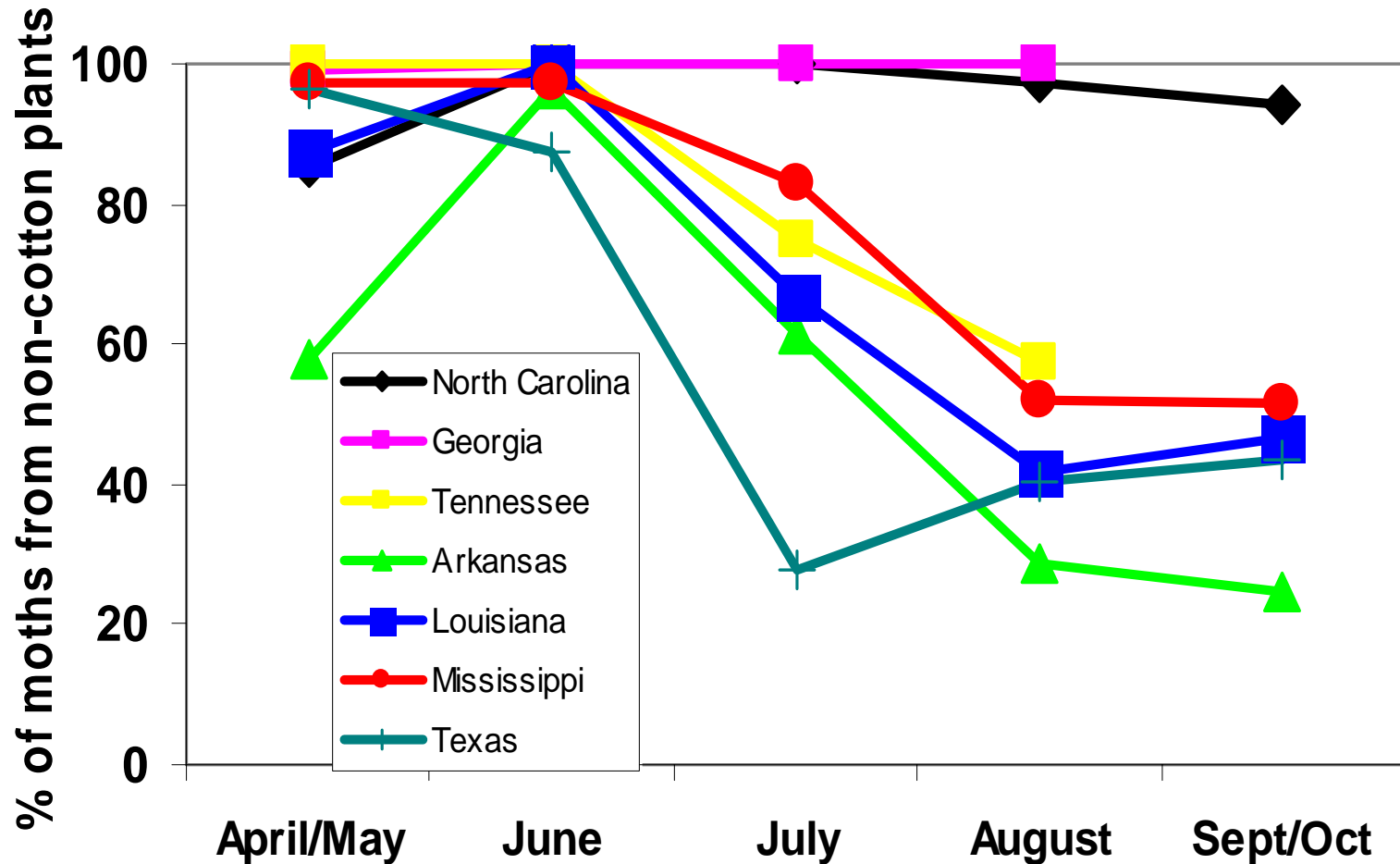
Critical Issues to Address for IRM

- Level of control of target pests
 - Better control means refuge can be smaller
 - “High dose” for single-Bt products
- Host range of pests and diversity of cropping system
 - Greater diversity (smaller farm sizes) means structured refuge can be smaller
- Pest movement and farming practices determine refuge design

% of *Helicoverpa zea* Moths from C4 Plants (corn and grasses)



Can Identify Higher Risk Areas: *Heliothis virescens* in the US



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 - Refuge may be structured or unstructured (natural); unstructured refuge may be sufficient for pests with a broad host range
- IRM implementation
 - Contracts can provide a legal basis for requiring farmers to plant a refuge, but may not be accepted by farmers
 - IRM education is most effective if coordinated across all stakeholders

Bt Corn IRM

Country	Structured Refuge Options	Implementation Approach	Regulatory Status
US	20% except where cotton is grown then 50%	Farmer contract; Broad education	Required
Canada	20%	Farmer contract; Auditing; Broad education	Required
Argentina	10%	Broad education	Voluntary
Philippines	20% if adoption >80%; otherwise none	Broad education	Required

Bt Cotton IRM

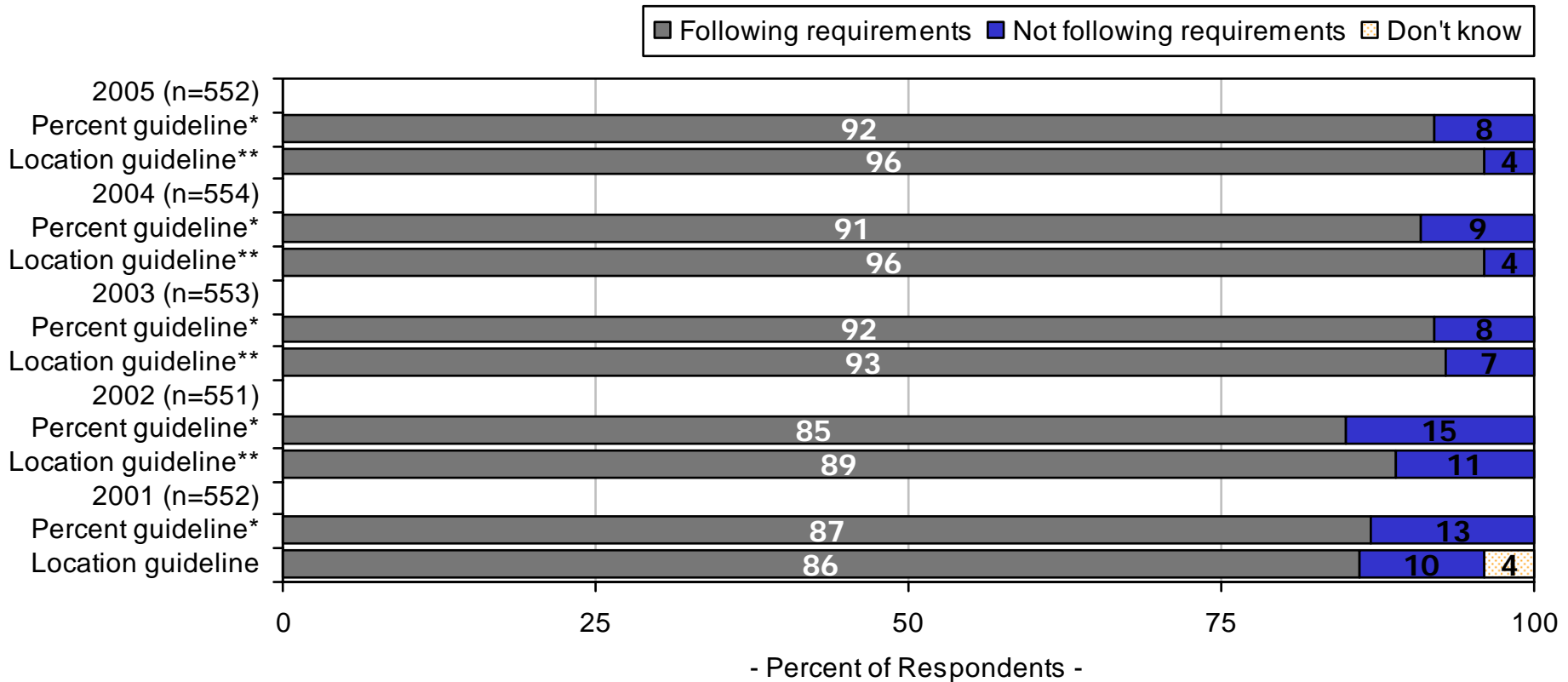
Country	Structured Refuge Options	Implementation Approach	Regulatory Status
US	BG: 20% S; 5% NS BG II: None*	Grower contract; Broad education	Required
Australia	BG II: 10% NS; 5% pigeonpea NS; 15% sorghum NS; 20% corn NS	Grower contract; Auditing; Broad education	Required
China	BG: None	-	Voluntary
India	20% S	Bundling	Required
South Africa	5% NS	Bundling	Voluntary

* In regions where TBW and CBW are the key target pests

No Evidence of Resistance to Bt Corn or Bt Cotton

- Bt corn and Bt cotton first commercialized 10 years ago, and now used in about 15 countries
 - Adoption is >80% in large parts of the US, China and Australia
- No instances of resistance in any country
 - Resistance monitoring programs are in place for the primary target pests in each country
- Suggests that IRM programs work
- Greater knowledge of insect biology and Bt resistance indicates that the risk of resistance evolving to Bt crops not as high as first thought

The Role of Farmers in IRM: Refuge Compliance in the USA

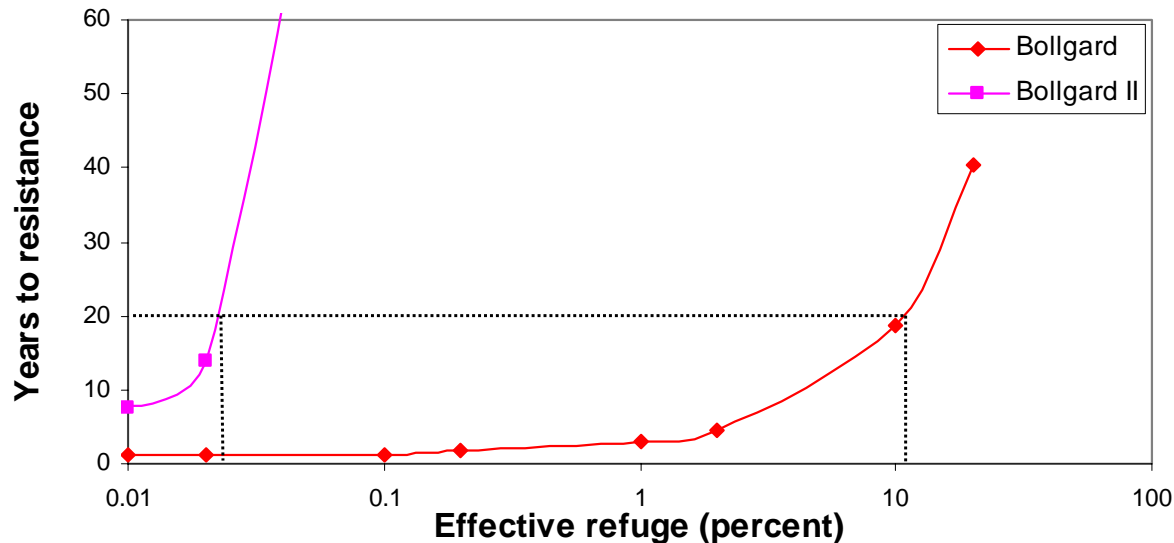


*Assumes 50% in cotton belt and 80% in corn belt

**Among growers who know the distribution of Bt cornfields on their operation

Trends for the Future

- More pyramided Bt products
 - Bollgard II cotton, WideStrike cotton, various corn products in the pipeline
 - Require less refuge, creating potential for different products having very different refuge requirements



Using Different Modes of Action

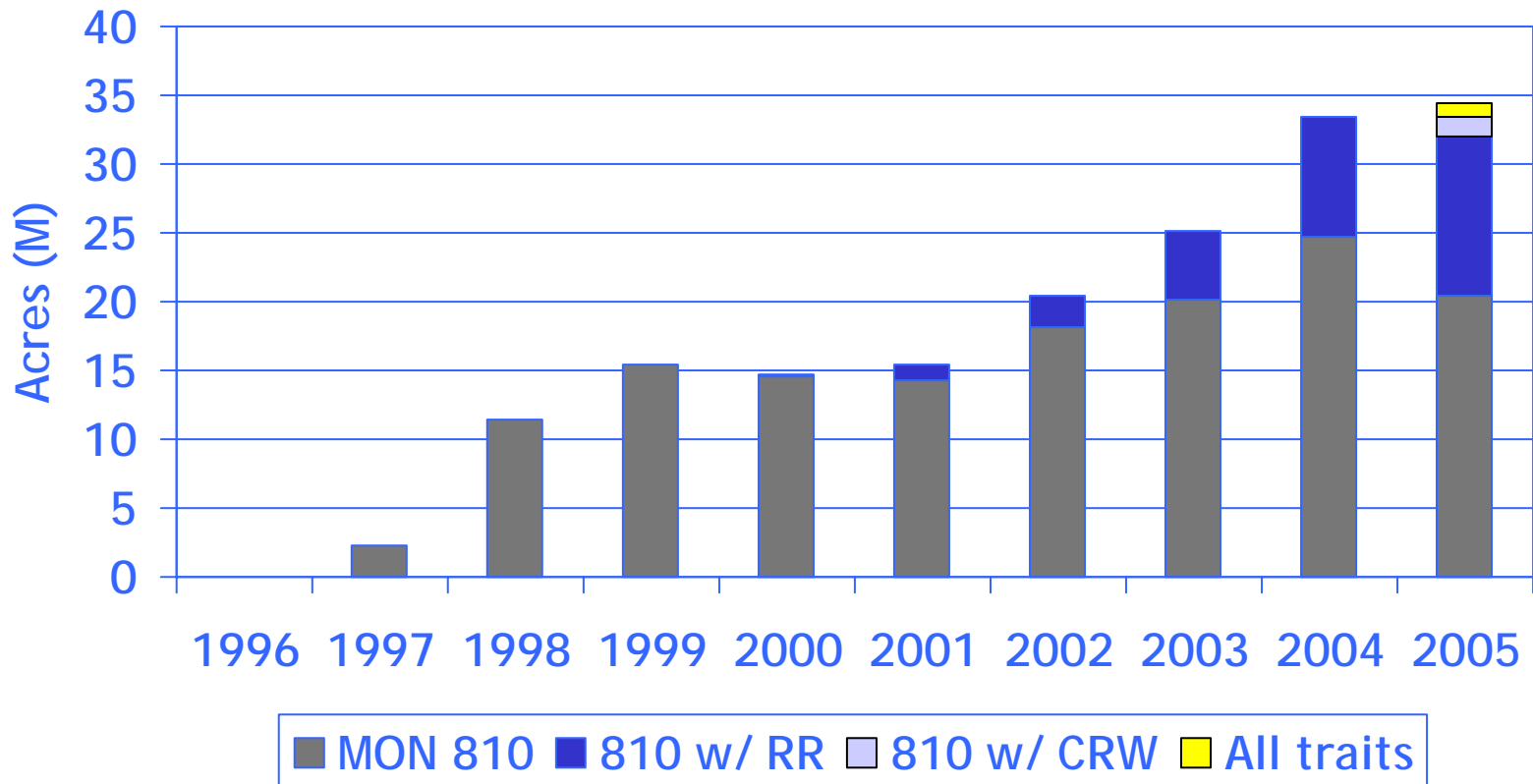
- Forces pests to develop multiple resistance mechanisms and a higher level of resistance

Target Pest	Control	Cry1Ac	Cry1Ac + Cry2Ab
<i>Heliothis virescens</i>	90	95	0
<i>Helicoverpa zea</i>	47.0	19.0	5.0
<i>Pectinophora gossypiella</i>	17.5	22.2	0

Trends for the Future

- More pyramided Bt products
 - Bollgard II cotton, WideStrike cotton, various corn products in the pipeline
 - Require less refuge, creating potential for different products having very different refuge requirements
- More stacked trait products, requiring that IRM strategies for the different pest complexes be reconciled

Bt Corn Adoption in the US



Conclusions

- IRM strategies can and must be adapted to local needs and practices, considering the nature of different Bt crops, pest biology, and farming systems
- IRM strategies must balance technical needs with logistical constraints

