49th Meeting IRAC International
17-20 March 2014

Challenges to control lepidopteran pests in a multi-crop environment in Brazil

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IRAC-BR
Comitê Brasileiro de Ação a Resistência a Inseticidas

OUTLINE

- **Brazilian agriculture: implications for IPM**
- **Changes in insect population dynamics and crop management practices with Bt crops and recent detection of *Helicoverpa armigera***
- **Major challenges for implementing IRM in Brazil**

Spodoptera frugiperda

Major crop season

Before 1990's

OCT NOV DEC JAN FEV MAR APR MAY JUN JUL AUG SEP

The miracle of Cerrado

The Economist

Available at: http://www.economist.com/node/16886442

Corn-Growing Seasons in Brazil

OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEP

Cotton

≈ 0.893 million ha

Soybean

≈ 27.7 million ha

Source: Conab / IBGE (2013)

Irrigation

Cross-Crop Pests

Soybean

Spodoptera frugiperda
S. eridania
S. cosmioides
Helicoverpa spp.
Heliothis virescens
Chrysodeixis includens
Stink bugs and other bugs
Whiteflies
Spider mites

Corn

Spodoptera frugiperda
Helicoverpa spp.
Stink bugs and other bugs
Aphids

Cotton

Spodoptera frugiperda
S. eridania
S. cosmioides
Helicoverpa spp.
Heliothis virescens
Chrysodeixis includens
Stink bugs and other bugs
Whiteflies
Spider mites

Chrysodeixis includens in soybean and cotton

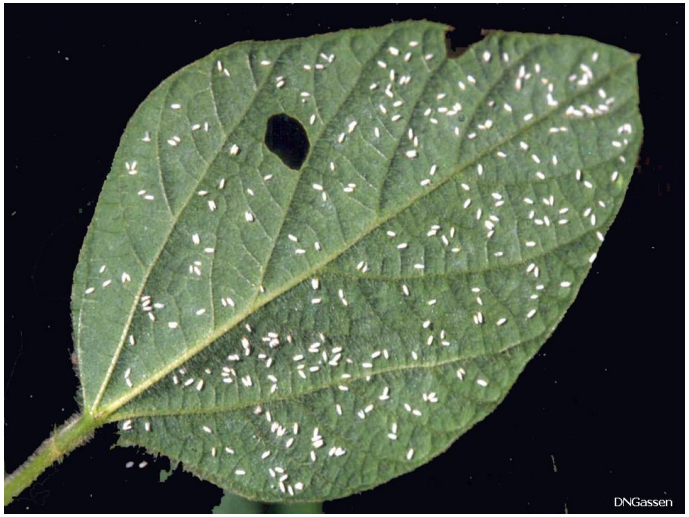
Credit: Paulo E. Saran

Tetranychid mites in soybean and cotton

Credit: Flávio Moscardi

Credit: Paulo E. Saran

Bemisia tabaci Biotype B



Stink bugs in cotton

Credit: Paulo E. Saran

Dysdercus spp.

Soybean

Maize

Millet

Credit: Paulo E. Saran

S. frugiperda
in cotton and soybean crops

Credit: Paulo E. Saran

Increase problem of *Spodoptera* spp. in cotton and soybean crops

Increase problem of *Heliothis virescens* in soybean

Credit: Paulo E. Saran

Helicoverpa spp.
in cotton and soybean crops

Credit: Paulo E. Saran & Pedro Brugnera

Credit: Barbosa

Helicoverpa armigera in citrus

Credit: Pedro T. Yamamoto

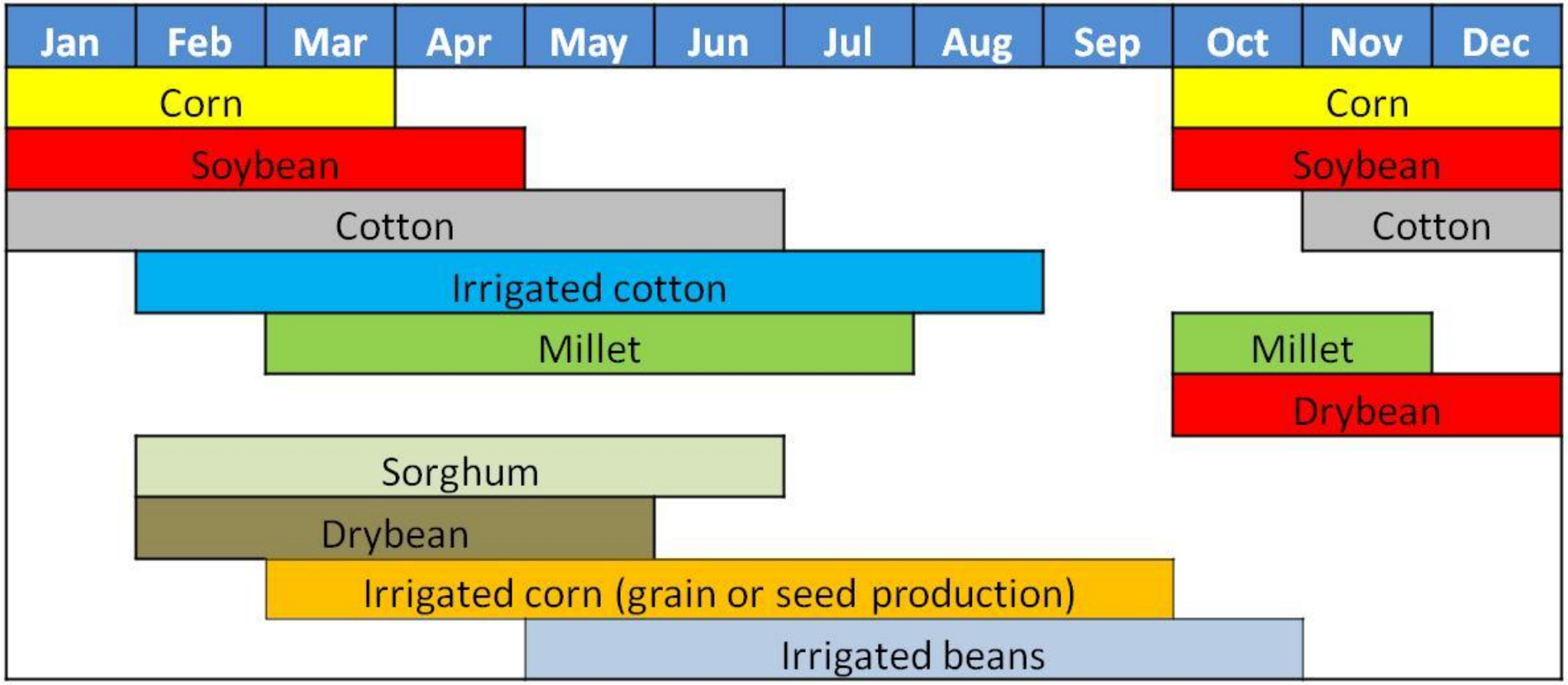
Helicoverpa armigera in coffee

Credit:: Evely Alves Sampaio

Helicoverpa armigera in Conyza bonariensis

Credit: Fernando Mignoso

Major Cropping Systems in Western Bahia, Brazil



Source: Círculo Verde

Soybean in Western Bahia

- 1980´s ➔2 to 4 insecticide sprays

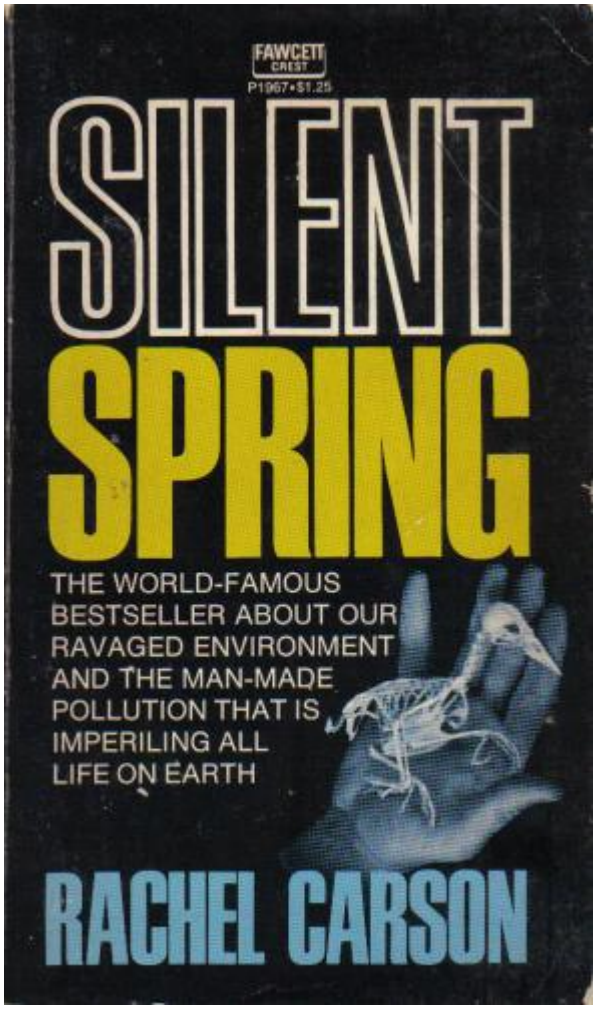
  Production cost: US$ 300-400/ha
- 1990´s ➔ 5 to 7 insecticide sprays

  Production cost: US$ 500-600/ha
- 2000´s ➔ 6 a 8 insecticide sprays

  Production cost: US$ 800/ha
- 2012/13 ➔ > 10 insecticide sprays

  Production cost: ≈ US$ 950/ha

Source: ADAB, ABAPA, AIBA, Fundação BA



1962

Pesticide Treadmill

Resistance Monitoring 1996-2013

Spodoptera frugiperda

Mato Grosso

Bahia

Goiás

Minas Gerais

Mato Grosso do Sul

São Paulo

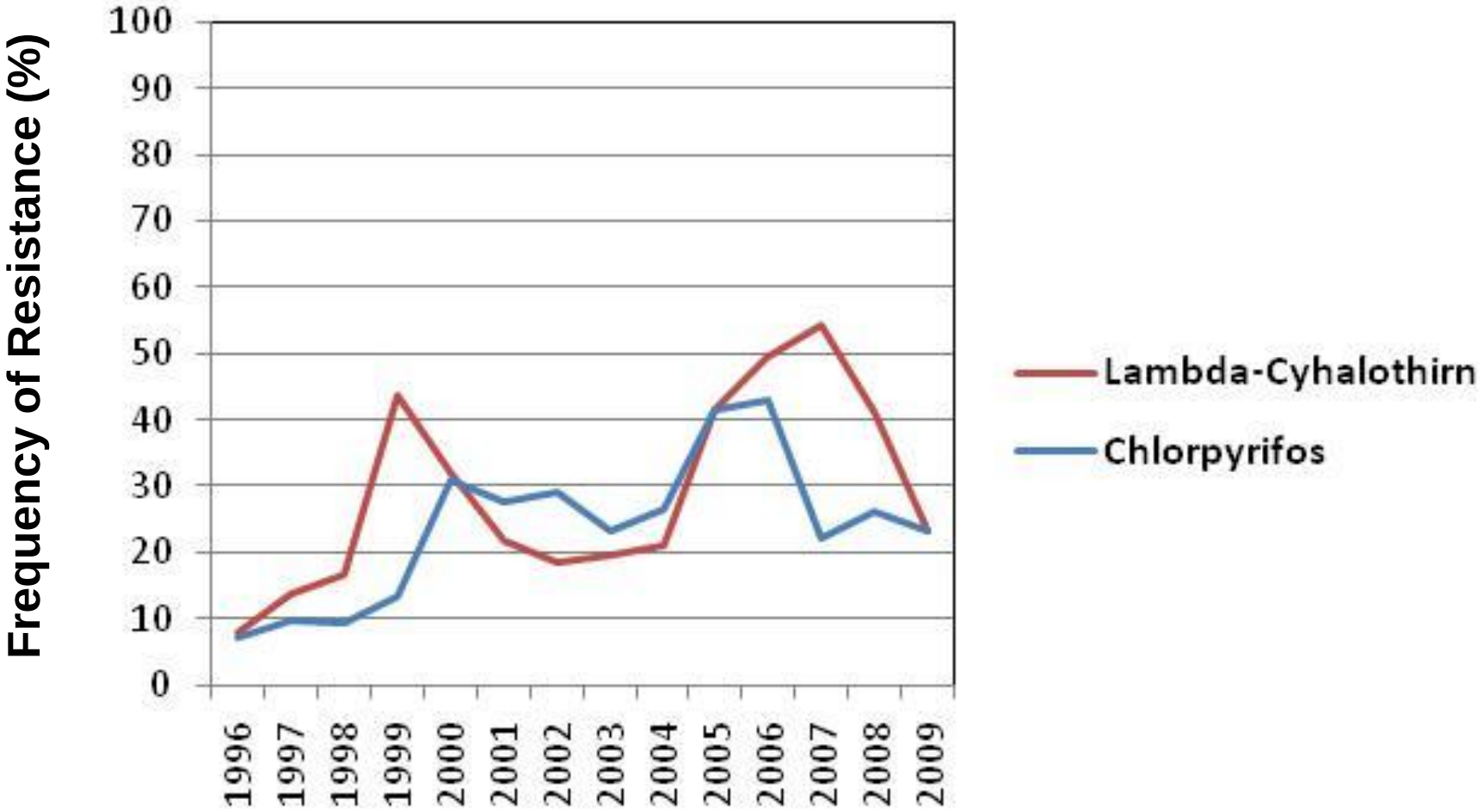
Paraná

Rio Grande do Sul

IRAC-BR

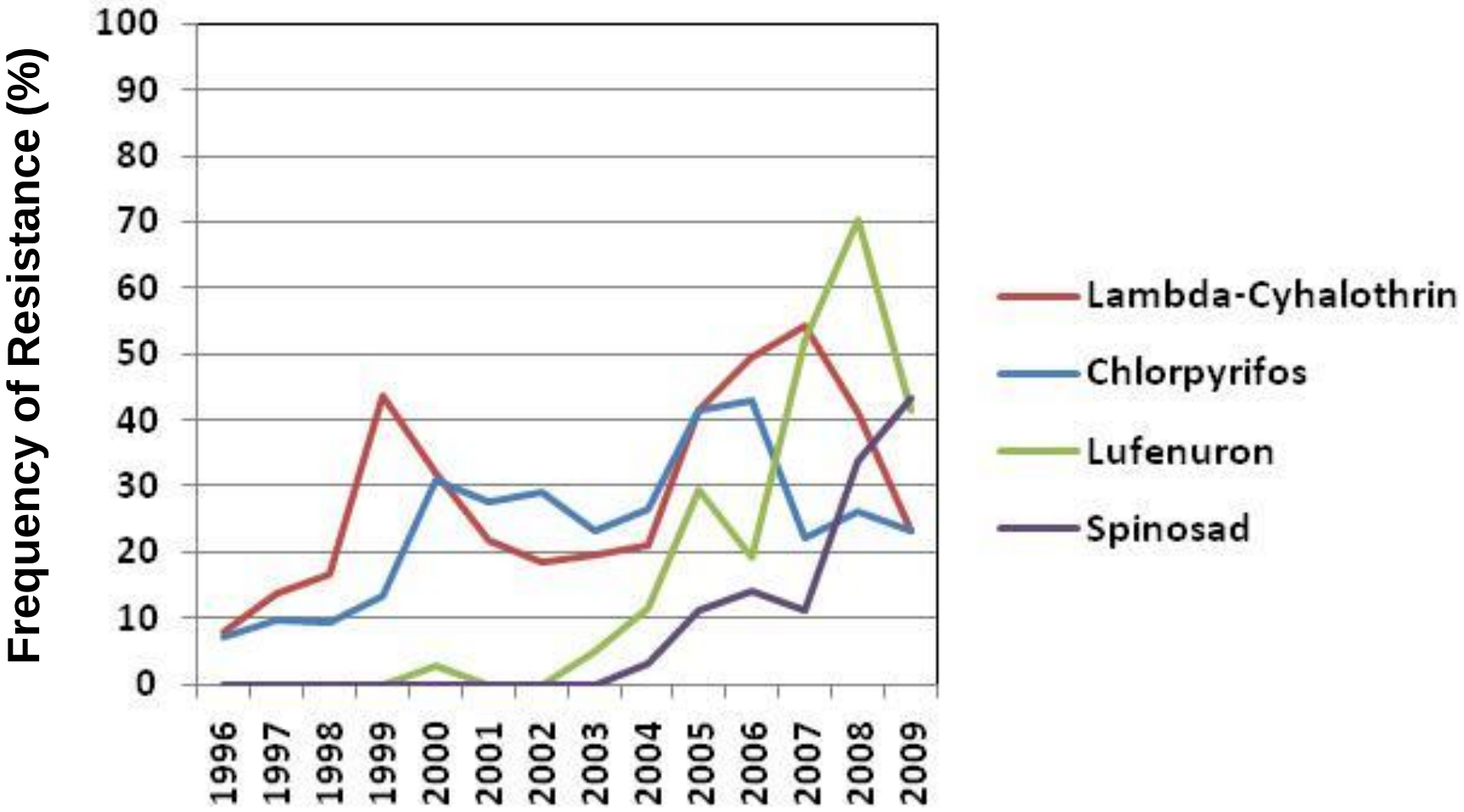
Comitê Brasileiro de Ação a Resistência a Inseticidas

Insecticide Resistance Monitoring in Rio Verde, Goiás State, Brazil



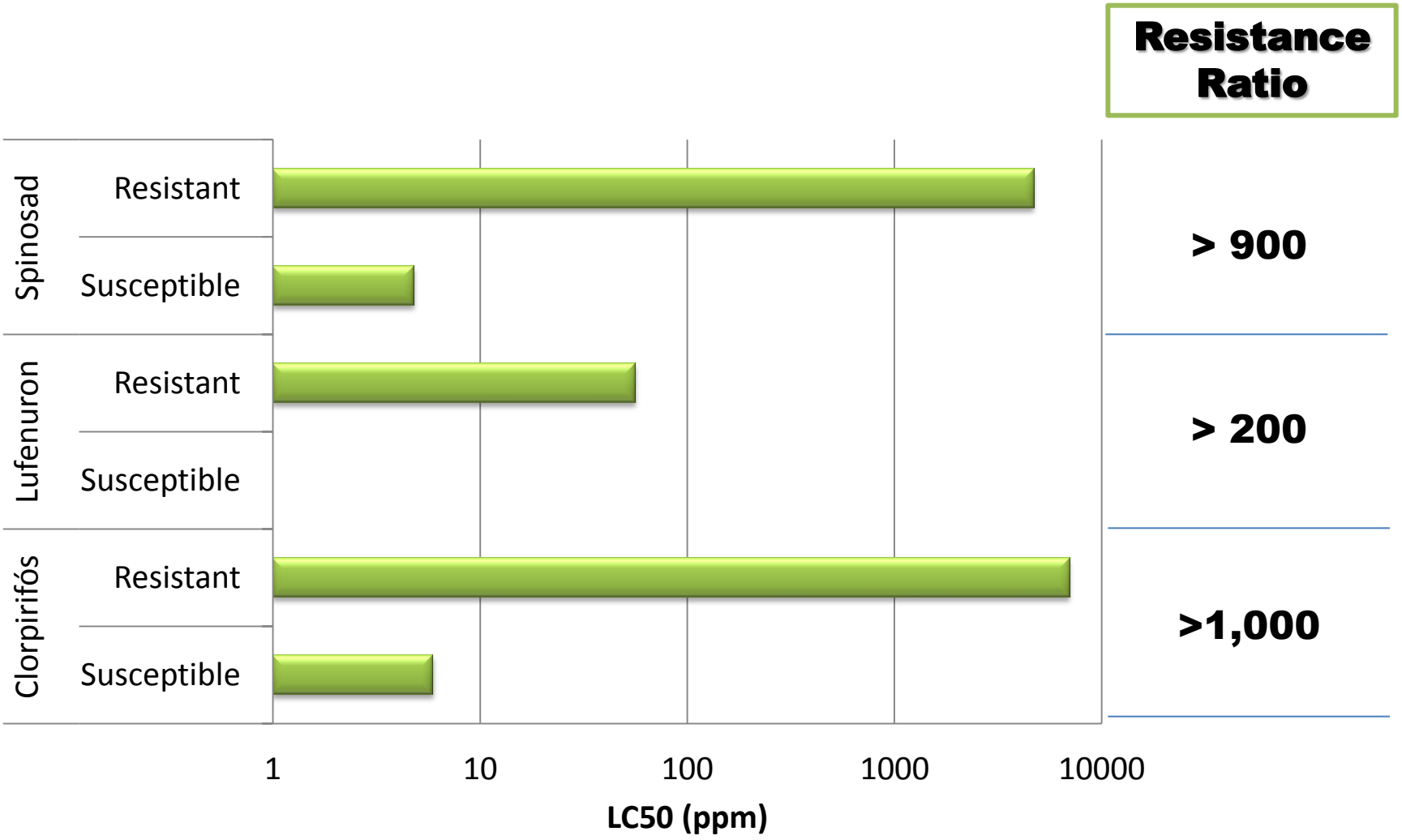
Omoto et al. (in prep.)

Insecticide Resistance Monitoring in Rio Verde, Goiás State, Brazil



Omoto et al. (in prep.)

Resistance of *Spodoptera frugiperda* to Insecticides



Investigating the molecular mechanisms of organophosphate and pyrethroid resistance in the fall armyworm *Spodoptera frugiperda*

Renato A Carvalho[1], Celso Omoto[2], Linda M Field[1], Martin S Williamson[1], Chris Bass[1¥]

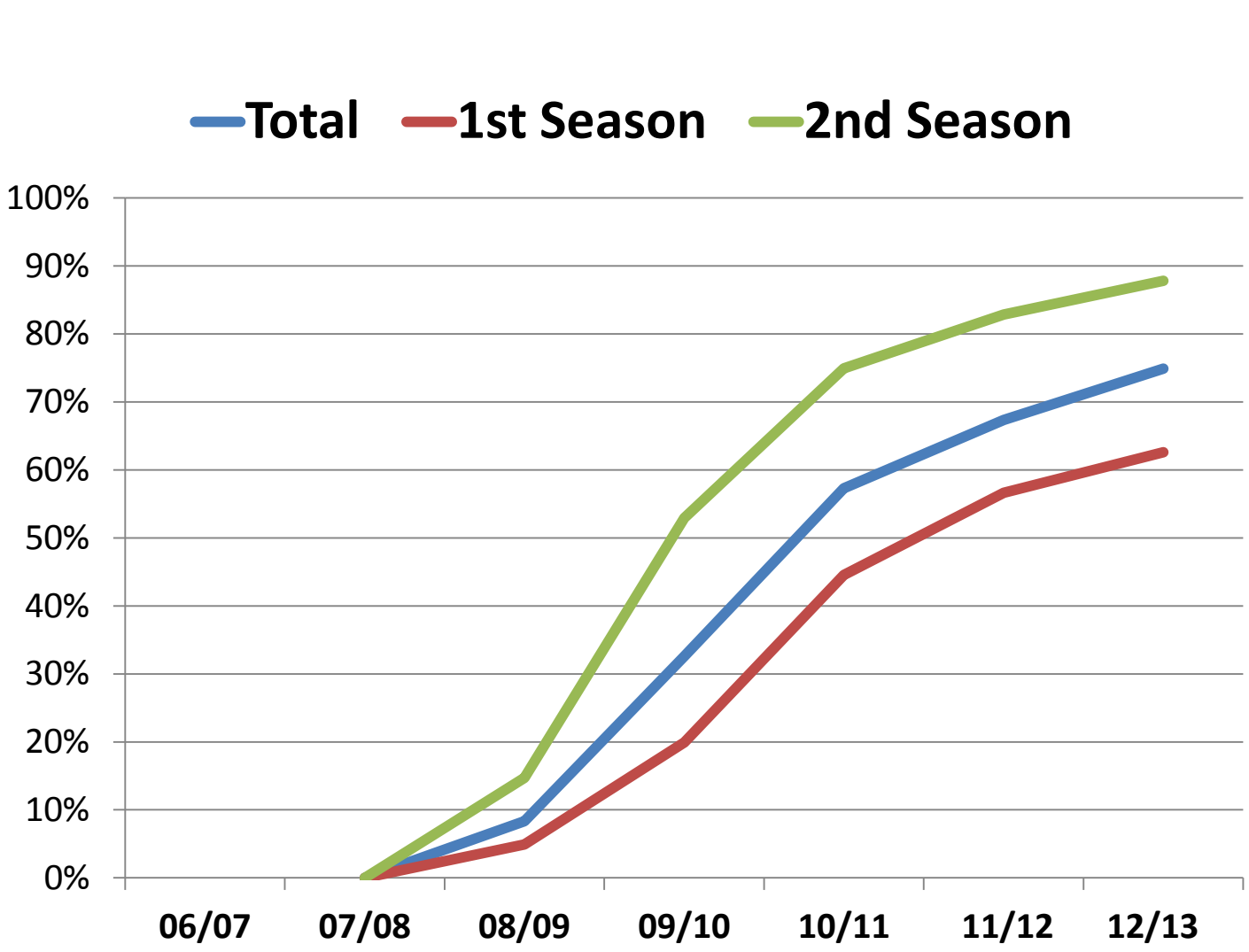
[1]Biological Chemistry Department, Rothamsted Research, Harpenden, Hertfordshire, AL5 2JQ, UK

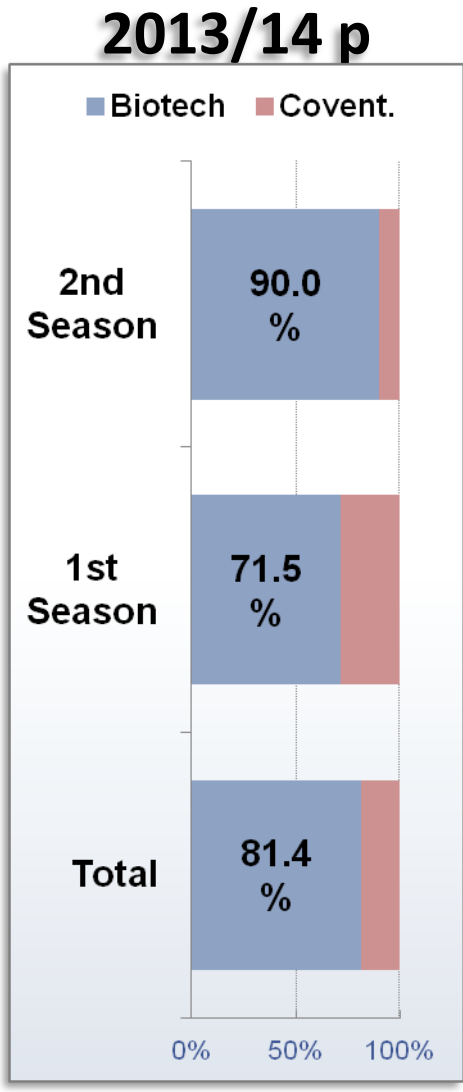
[2]Department of Entomology and Acarology, University of São Paulo (ESALQ/USP)-Piracicaba, São Paulo, Brazil.

Insecticide Resistance Status of *Spodoptera frugiperda* in Brazil

	Chemical Class	IRAC Classification
High f(R)	Organophosphates	1B
	Pyrethroids	3
	Benzoylureas	11
Low to intermetiate f(R)	Spinosyns	5
	Carbamates	1A
?	Indoxacarb	22A
	Diamides	28
	Bacillus thuringiensis	16

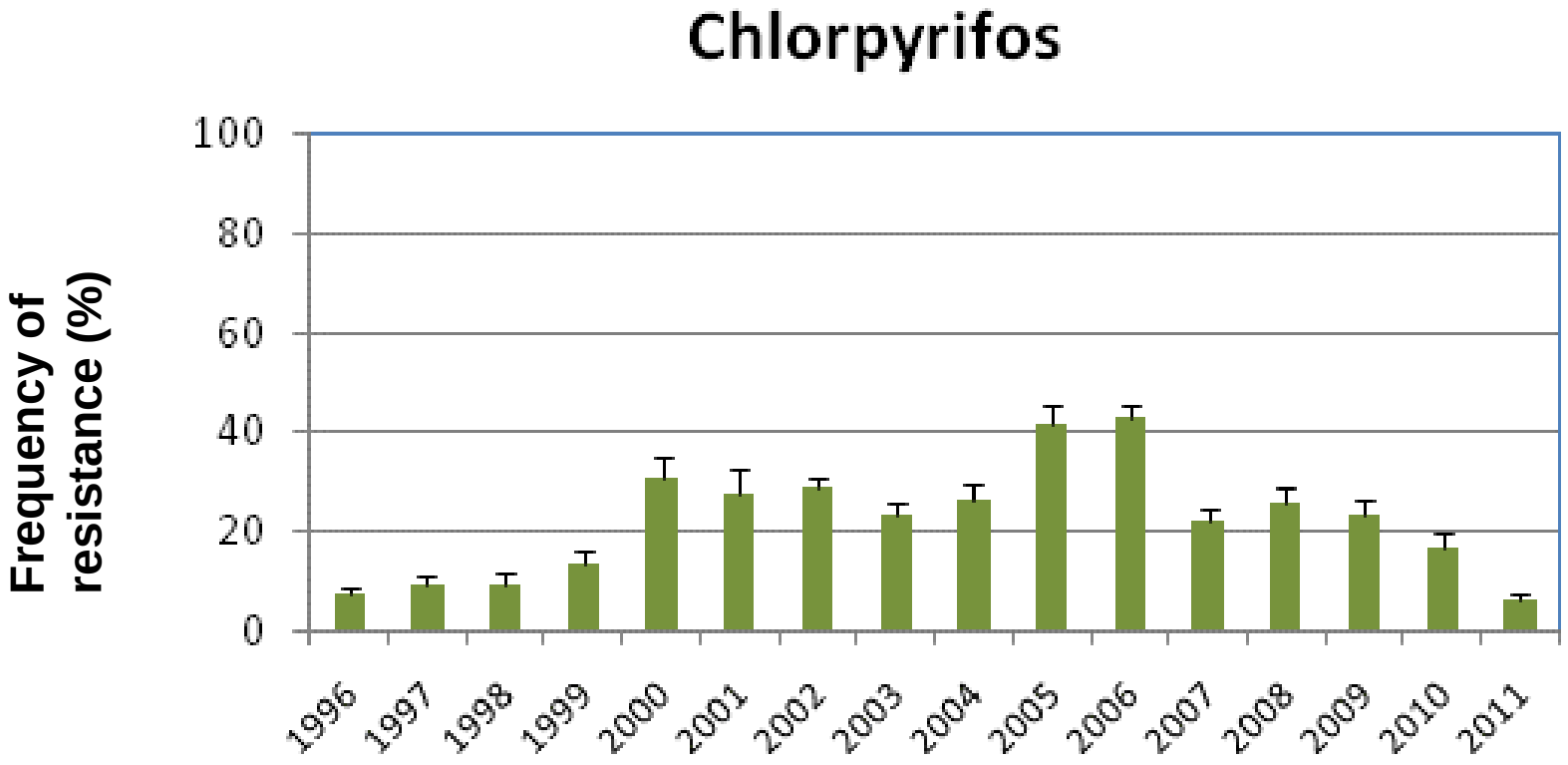
Adoption of transgenic maize technology in Brazil (% cultivated area)



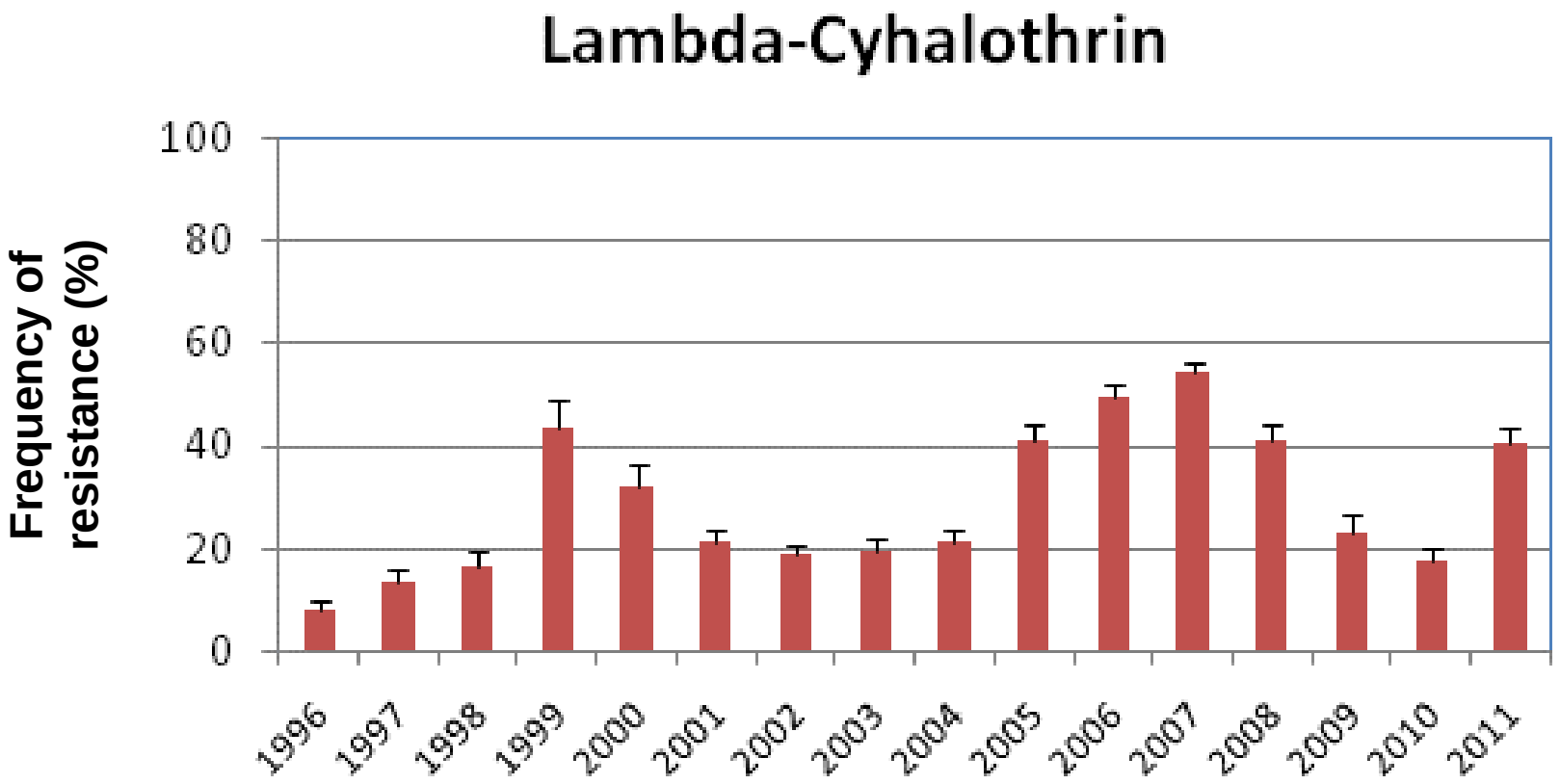


Source: CÉLERES® | % of total maize area | Updated in August 2013

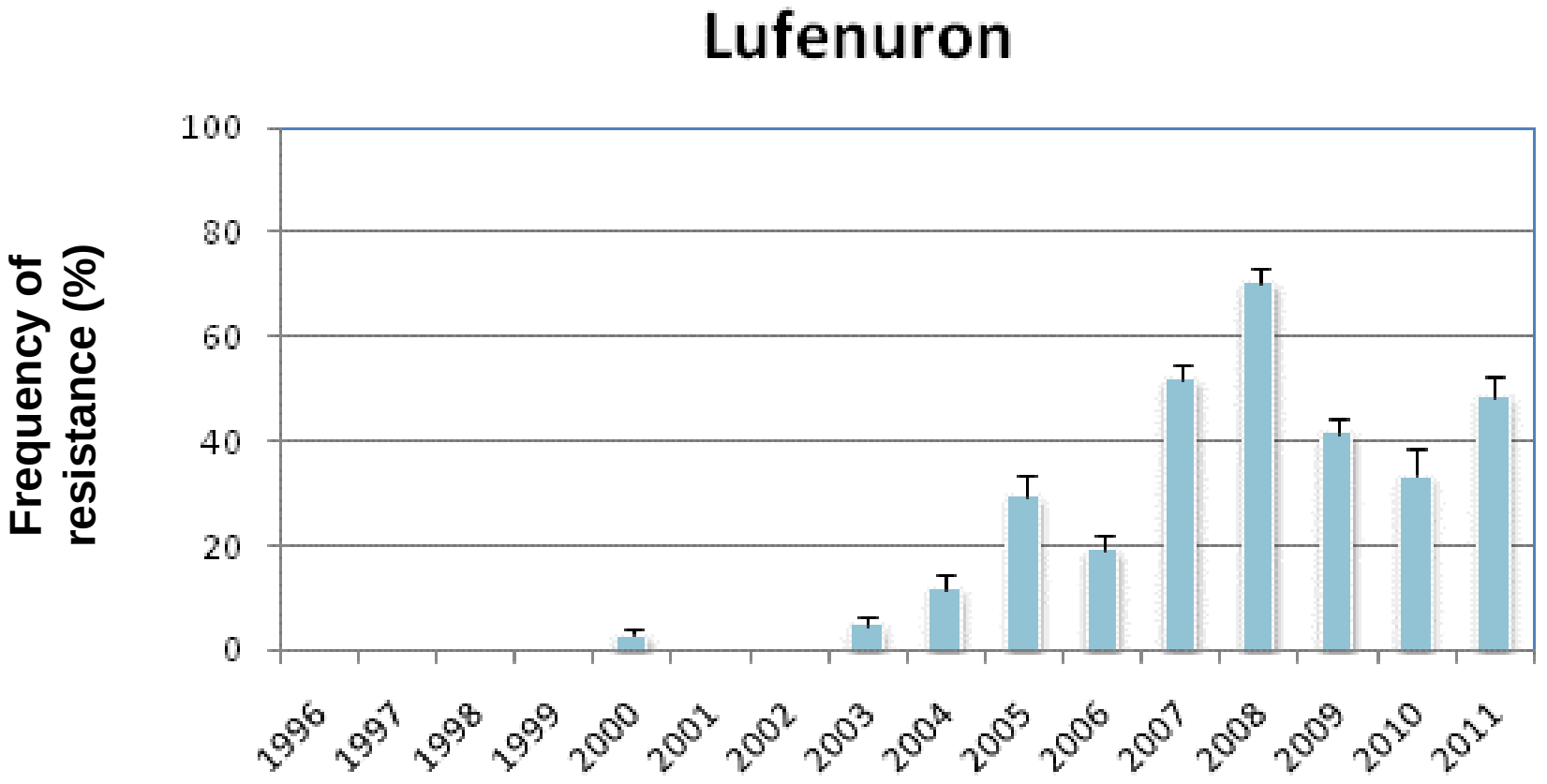
Frequency of Resistance – *S. frugiperda*
Rio Verde, Goiás



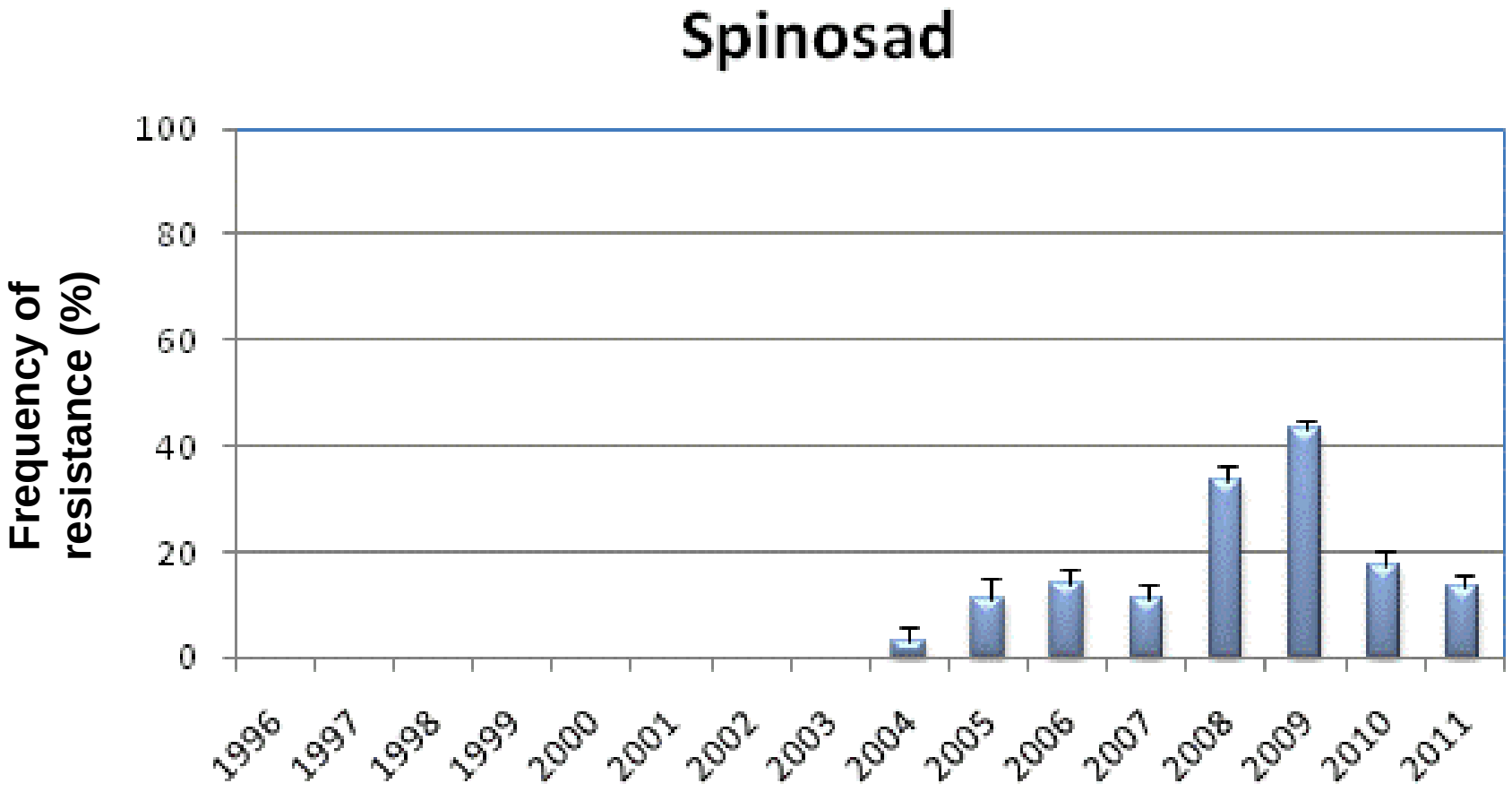
Frequency of Resistance - *S. frugiperda*
Rio Verde, Goiás



Frequency of Resistance - *S. frugiperda*
Rio Verde, Goiás



Frequency of Resistance - *S. frugiperda*
Rio Verde, Goiás



Bt crops in Brazil

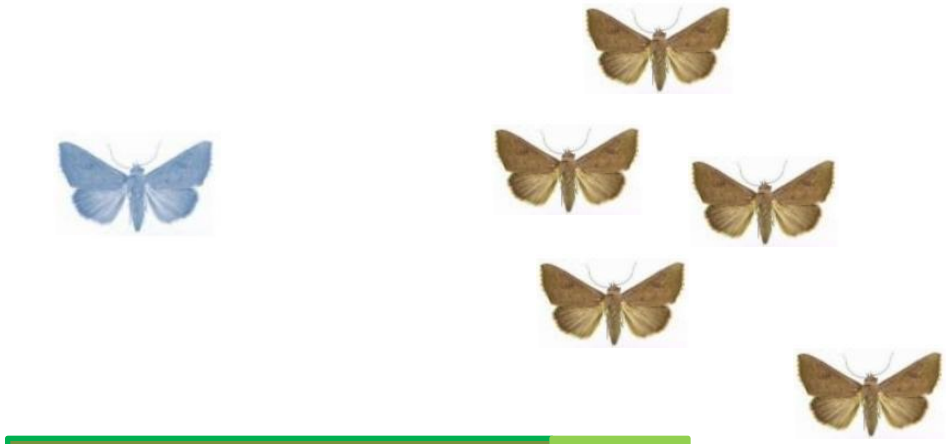
Crop	Bt protein(s)
Cotton	Cry1Ac
	Cry1Ac/Cry1F
	Cry1Ac/Cry2Ab2
	Cry1Ab/Cry2Ae
Corn	Cry1Ab
	Cry1F
	Cry1A.105/Cry2Ab2
	VIP3Aa20
	Cry1Ab/VIP3Aa20
	Cry1A.105/Cry2Ab2/Cry1F
	Cry1Ab/Cry1F
	Cry1A.105/Cry2Ab2/Cry3Bb1
Soybean	Cry1Ac

Source: CTNBio (2013)

High Risk of Resistance Evolution

- Not a high-dose event to major target pests
- Low refuge compliance
- Intense selection pressure with different Bt crops

Refuge Area



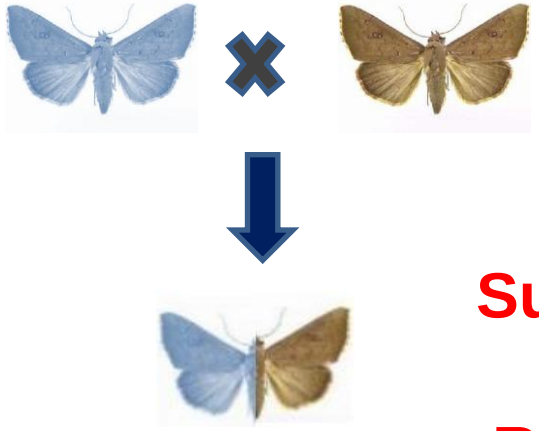
Bt crop

Refuge

Suscetível

Resistente

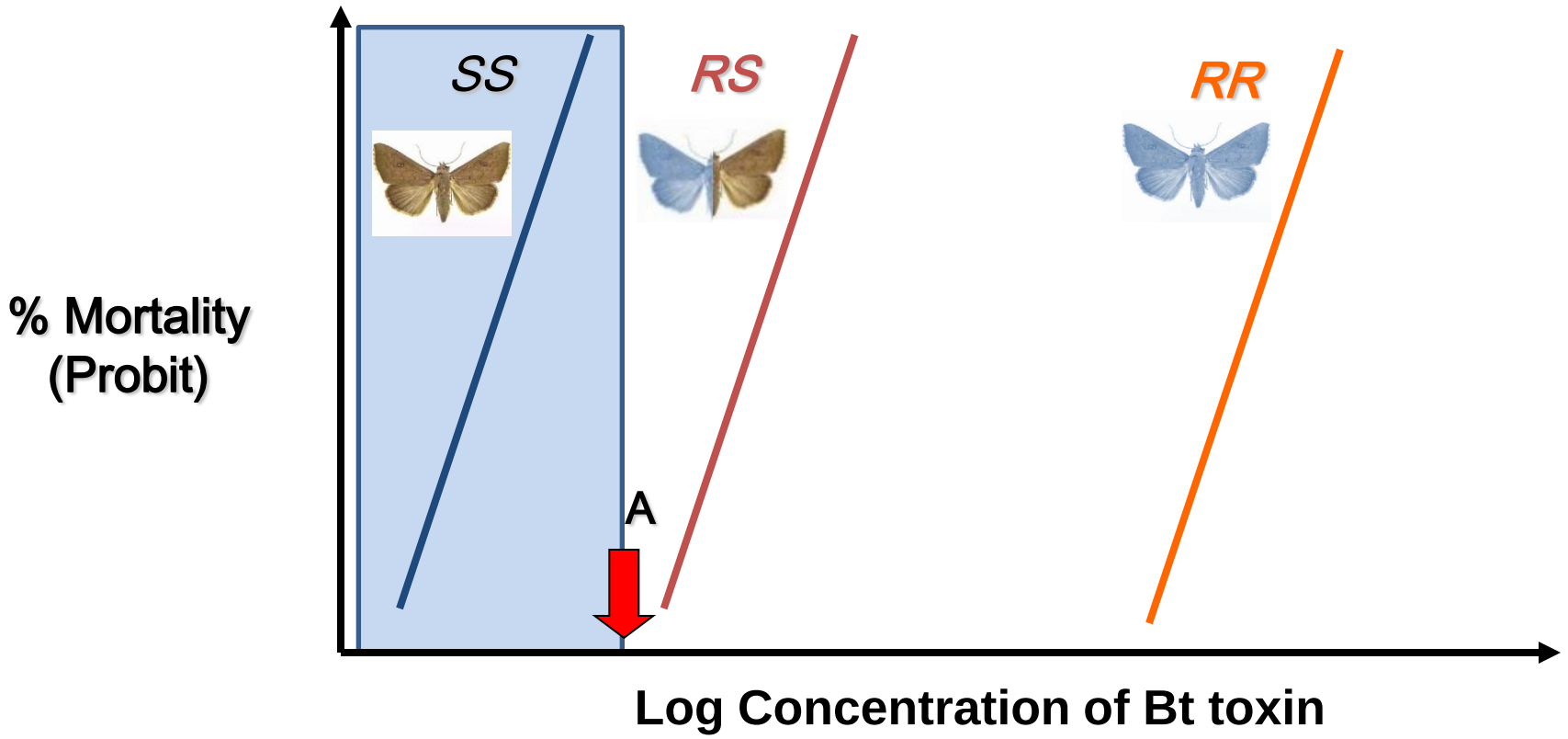
Resistant **Susceptible**



Susceptible or Resistant?

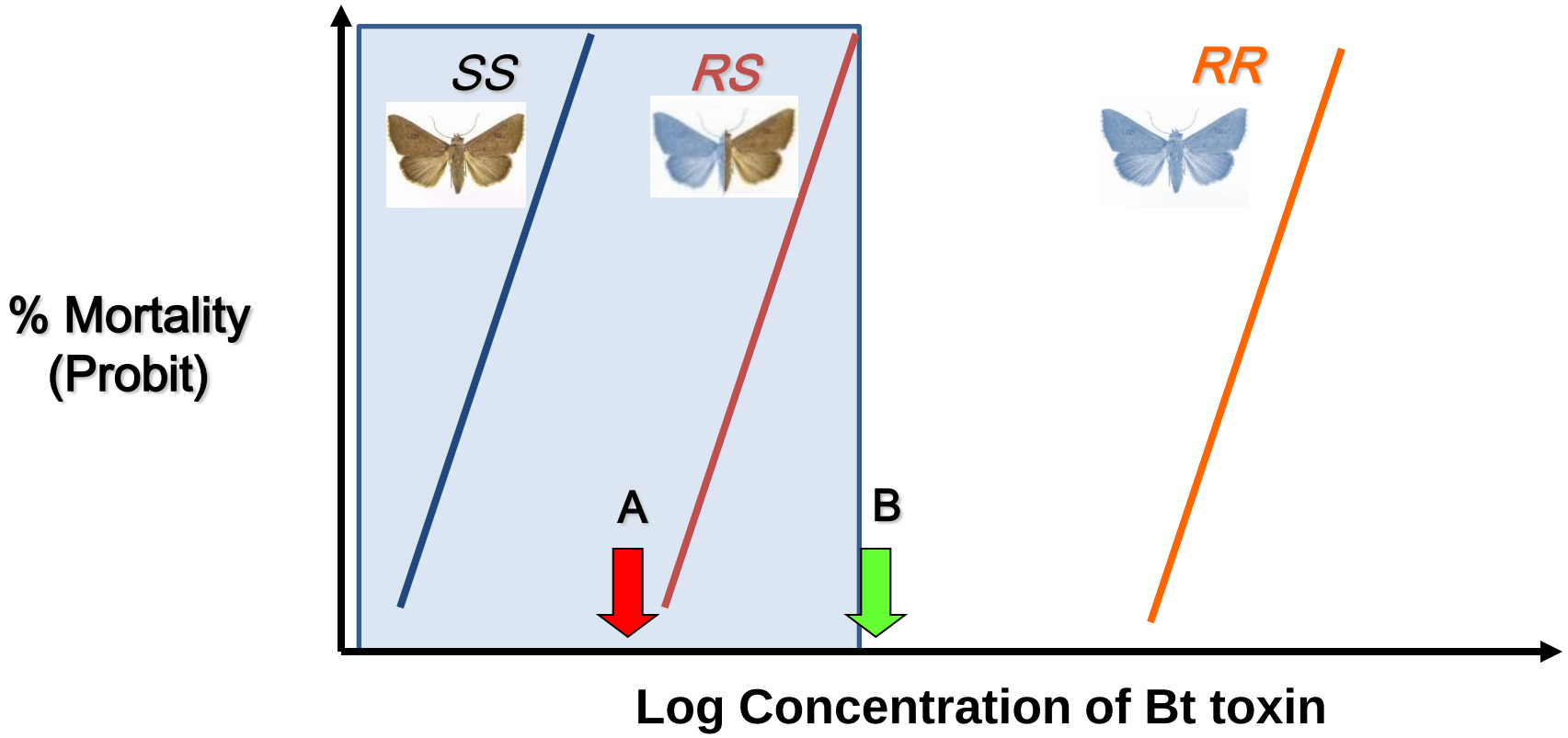
➔ **Depend on the Bt protein and concentration expressed in the plant**

Low or High Dose



Concentration A ➡ Resistance is functionally DOMINANT

Low or High Dose



Concentration A ➡ Resistance is functionally DOMINANT

Concentration B ➡ Resistance is functionally RECESSIVE

Assuming Hardy-Weinberg equilibrium

Allele frequency:

$f(R) = p = 0.001\ (10^{-3})$
$f(S) = q = 0.999$

Genotypic frequency:

in 1 million

$f(RR) = p^2 = 0.000001$ — 1

$f(RS) = 2pq = 0.001998$ ← — 1,998

$f(SS) = q^2 = 0.998001$ — 998,001

Bt maize in Brazil: Key Target Pests at Risk

Spodoptera frugiperda
Fall armyworm

Helicoverpa zea
Corn earworm

Diatraea saccharalis
Sugarcane borer

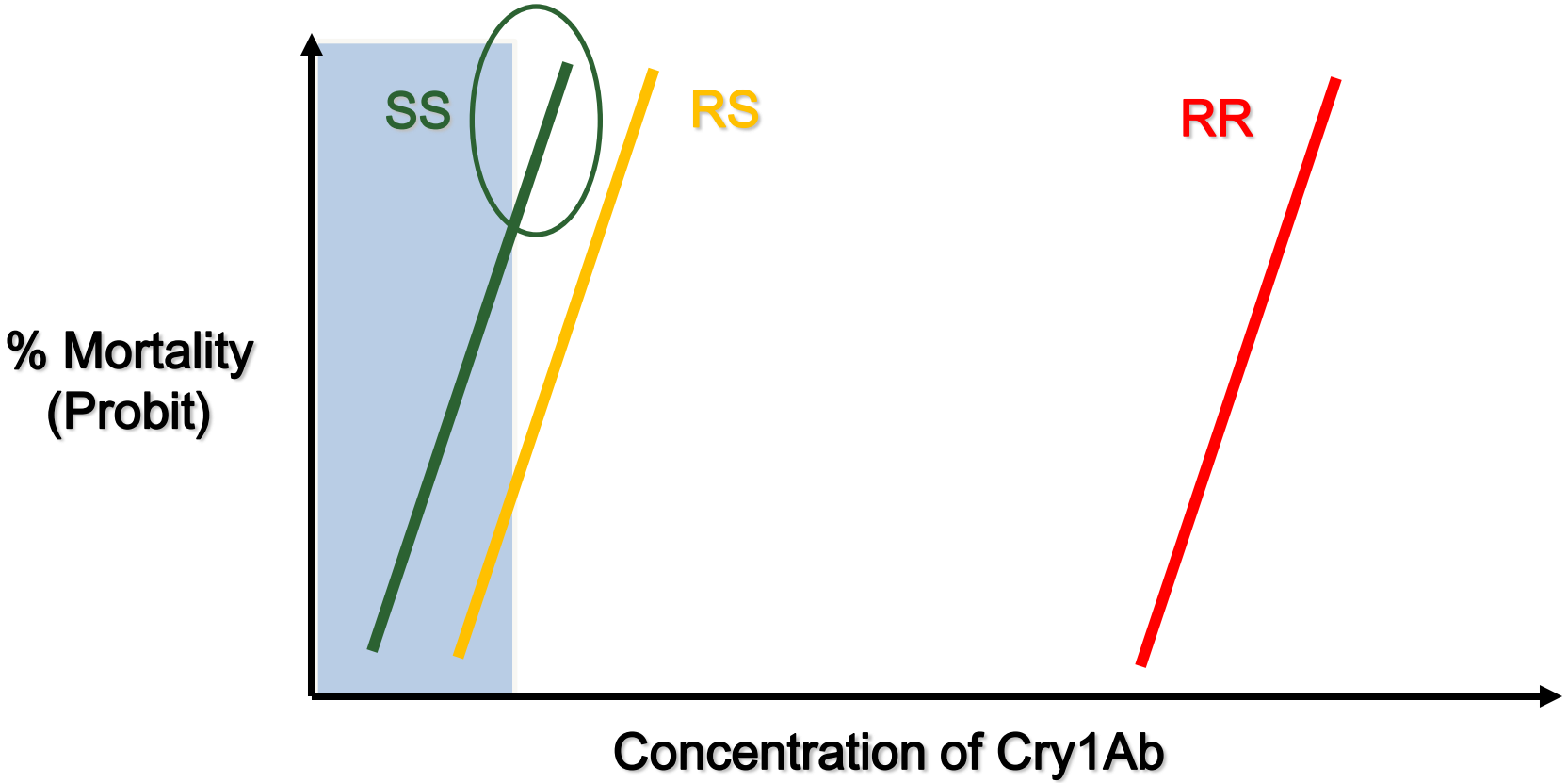
- **Cry1Ab (2007)**
- **Cry1F (2008)**
- **Vip 3A (2009)**

10% refuge area

- **Cry1A.105 + Cry2Ab2 (2009)**
- **Cry1Ab + VIP3Aa20 (2010)**
- **Cry1A.105 + Cry2Ab2 + Cry1F (2010)**
- **Cry1Ab + Cry1F (2011)**

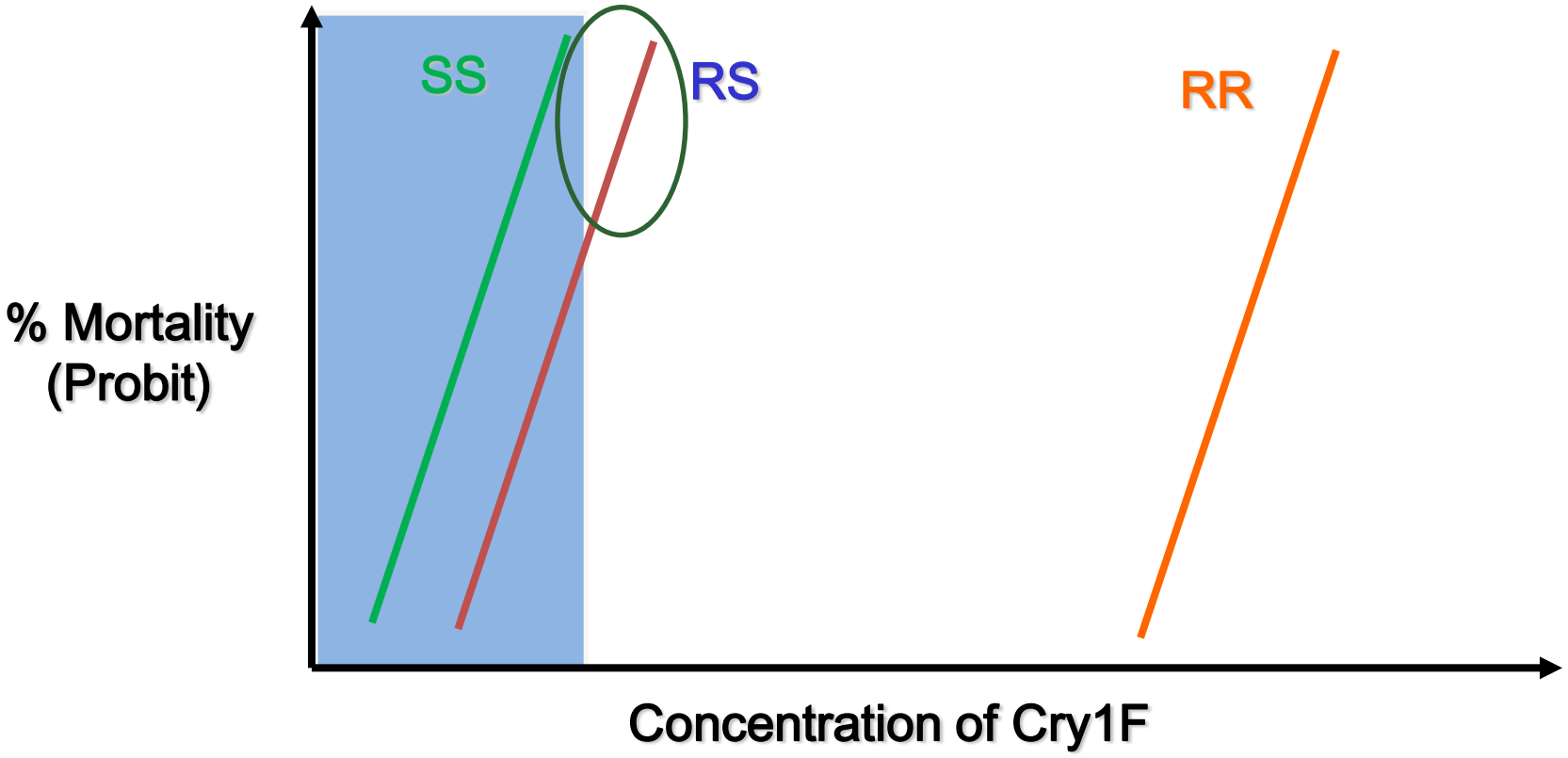
5% refuge area

Spodoptera frugiperda
Cry1b ➔ Low Dose and Moderate Efficacy



IRM by Moderation ➔ some SS individuals can survive on MON810 / Bt11

Spodoptera frugiperda
Cry1F ➔ High Efficacy



High Efficacy➔ kill 100% of SS individuals but is not a high-dose event
Some RS individuals can survive on Bt maize plants

Farias (2014)

FORUM

Discovery and Characterization of Field Resistance to Bt Maize: *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in Puerto Rico

NICHOLAS P. STORER,[1] JONATHAN M. BABCOCK, MICHELE SCHLENZ, THOMAS MEADE, GARY D. THOMPSON, JAMES W. BING, AND RANDY M. HUCKABA

Dow AgroSciences LLC, 9330 Zionsville Road, Indianapolis, IN 46268

J. Econ. Entomol. 103(4): 1031–1038 (2010); DOI: 10.1603/EC10040

➔**High intensity of resistance to Cry1F**

➔**Moderate cross-resistance to Cry1Ac and Cry1Ab**

OPEN ACCESS Freely available online

PLOS ONE

Shared Midgut Binding Sites for Cry1A.105, Cry1Aa, Cry1Ab, Cry1Ac and Cry1Fa Proteins from *Bacillus thuringiensis* in Two Important Corn Pests, *Ostrinia nubilalis* and *Spodoptera frugiperda*

Carmen Sara Hernández-Rodríguez[1], Patricia Hernández-Martínez[1], Jeroen Van Rie[2], Baltasar Escriche[1], Juan Ferré[1]*

1 Departamento de Genética, Universitat de València, Burjassot, Spain, **2** Bayer CropScience N.V., Ghent, Belgium

Bt corn

- **Cry1A.105 + Cry2Ab2**
- **Cry1Ab + VIP3Aa20**
- **Cry1A.105 + Cry2Ab2 + Cry1F**
- **Cry1Ab + Cry1F**

Phil. Trans. R. Soc. Lond. B (1998) **353**, 1777–1786

THE ROYAL SOCIETY

Two-toxin strategies for management of insecticidal transgenic crops: can pyramiding succeed where pesticide mixtures have not?

R. T. Roush

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Bt cotton in Brazil: Key Target Pests at Risk

Alabama argillacea
Cotton leafworm

Pectinophora gossypiella
Pink bollworm

Heliothis virescens
Tobbaco budworm

- **Cry1Ac (2005)**

} **20% refuge area**

Bt cotton in Brazil: Key Target Pests at Risk

Alabama argillacea
Cotton leafworm

Pectinophora gossypiella
Pink bollworm

Chrysodeixis ncludens
Soybean looper

Heliothis virescens
Tobacco budworm

Spodoptera frugiperda
Fall armyworm

Helicoverpa armigera

- **Cry1Ac + Cry2Ab2 (2009)**
- **Cry1Ac + Cry1F (2009)**
- **Cry1Ab + Cry2Ae (2011)**

5% refuge area

Bt soybean in Brazil: Key Target Pests

Anticarsia gemmatalis
Velvetbean caterpillar

Pseudoplusia includens
Soybean looper

Heliothis virescens
Tobacco budworm

Helicoverpa armigera

- **Cry1Ac (2010) ➔ 20% refuge area**

Research Article

SCI

Received: 16 September 2011 Revised: 16 December 2011 Accepted article published: 18 January 2012 Published online in Wiley Online Library: 7 March 2012

(wileyonlinelibrary.com) DOI 10.1002/ps.3271

Assessment of the high-dose concept and level of control provided by MON 87701 × MON 89788 soybean against *Anticarsia gemmatalis* and *Pseudoplusia includens* (Lepidoptera: Noctuidae) in Brazil

Oderlei Bernardi,[a*] Glaucia S Malvestiti,[b] Patrick M Dourado,[b] Wladecir S Oliveira,[b] Samuel Martinelli,[b] Geraldo U Berger,[b] Graham P Head[c] and Celso Omoto[a]

Research Article

SCI

Received: 6 January 2013 Revised: 5 May 2013 Accepted article published: 17 May 2013 Published online in Wiley Online Library:

(wileyonlinelibrary.com) DOI 10.1002/ps.3581

High levels of biological activity of Cry1Ac protein expressed on MON 87701 × MON 89788 soybean against *Heliothis virescens* (Lepidoptera:Noctuidae)

Oderlei Bernardi,[a*] Patrick M Dourado,[b] Renato A Carvalho,[b] Samuel Martinelli,[b] Geraldo U Berger,[b] Graham P Head[c] and Celso Omoto[a]

Low susceptibility of *Spodoptera cosmioides*, *Spodoptera eridania* and *Spodoptera frugiperda* (Lepidoptera: Noctuidae) to genetically-modified soybean expressing Cry1Ac protein

Oderlei Bernardi [a,*], Rodrigo J. Sorgatto [a], Alexandre D. Barbosa [a], Felipe A. Domingues [a], Patrick M. Dourado [b,1], Renato A. Carvalho [b,1], Samuel Martinelli [c,2], Graham P. Head [c,2], Celso Omoto [a]

Research Article

SCI

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(wileyonlinelibrary.com) DOI 10.1002/ps.3508

Expression of Cry1Ac in transgenic *Bt* soybean lines and their efficiency in controlling lepidopteran pests

Huilin Yu,[a] Yunhe Li,[a] Xiangju Li,[a] Jörg Romeis[a,b] and Kongming Wu[a]*

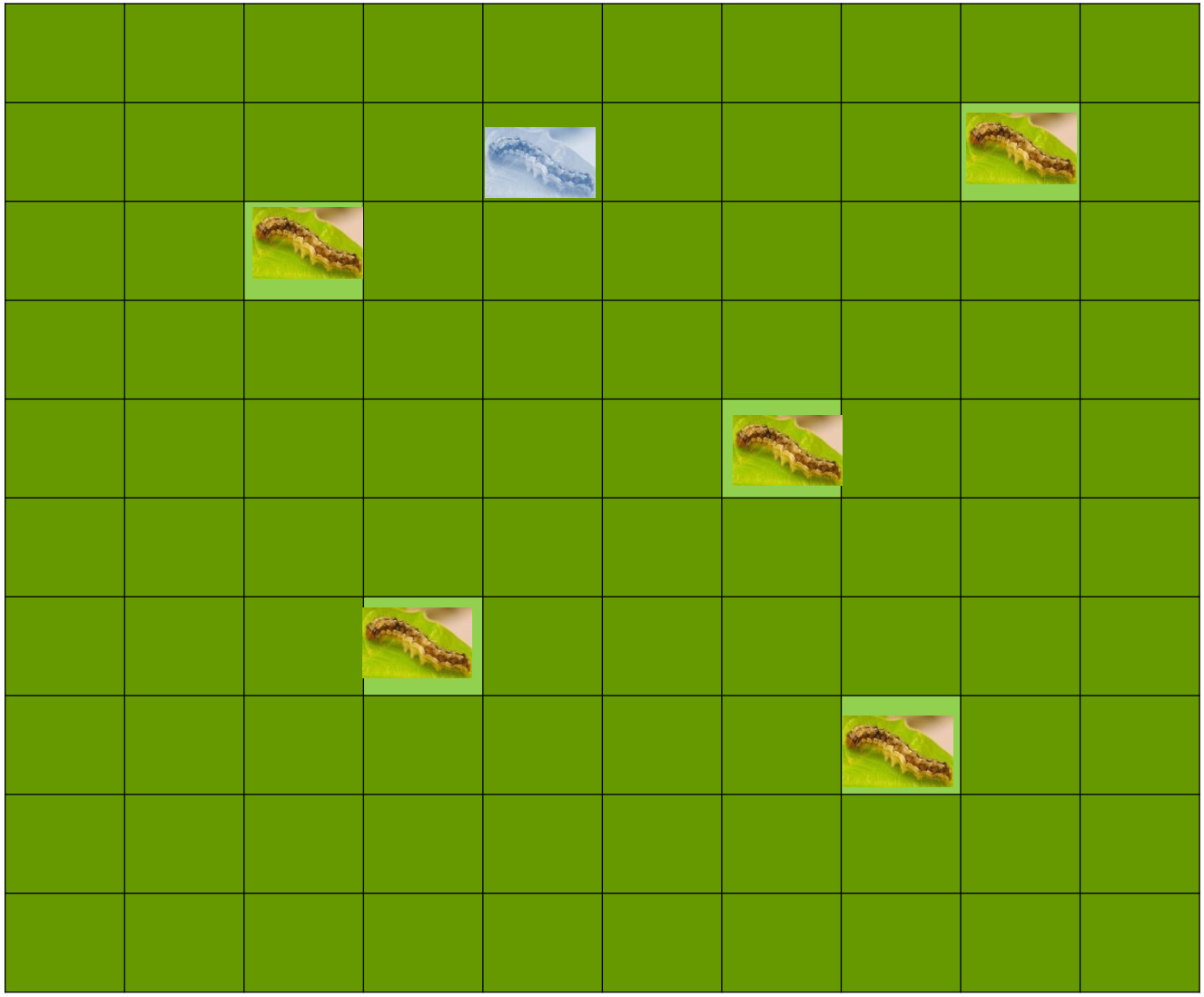
Bt crops in Brazil

Crop	Technology	Bt Protein		
		Cry1	Cry2	VIP
Corn	Yieldgard®; Agrisure TL®	Cry1Ab		
	Herculex®™	Cry1F		
	Viptera™			Vip3A
	Agrisure Viptera™	Cry1Ab		Vip3A
	Optimum™ Intrasect™	Cry1Ab + Cry1F		
	Yieldgard VT PRO™	Cry1A.105	Cry2Ab	
	PowerCore™	Cry1A.105 + Cry1F	Cry2Ab	
Cotton	Bollgard®	Cry1Ac		
	Bollgard II®	Cry1Ac	Cry2Ab	
	Widestrike™	Cry1Ac + Cry1F		
	TwinLink®	Cry1Ab	Cry2Ae	
Soybean	Intacta RR2 PRO™	Cry1Ac		

Bt crops in Brazil

Crop	Bt Proteins	Refuze Size*
Corn	Cry1Ab	10%
	Cry1F	10%
	Vip3A	10%
	Cry1A.105 + Cry2Ab2	5%
	Cry1Ab + Vip3A	5%
	Cry1A.105 + Cry2Ab2 + Cry1F	5% or RIB
	Cry1F + Cry1Ab	5%
	Cry1A.105 + Cry2Ab2 + Cry3Bb1	RIB
Cotton	Cry1Ac	20%
	Cry1Ac + Cry1F	5%
	Cry1Ac + Cry2Ab2	5%
	Cry1Ab + Cry2Ae	20%
Soybean	Cry1Ac	20%

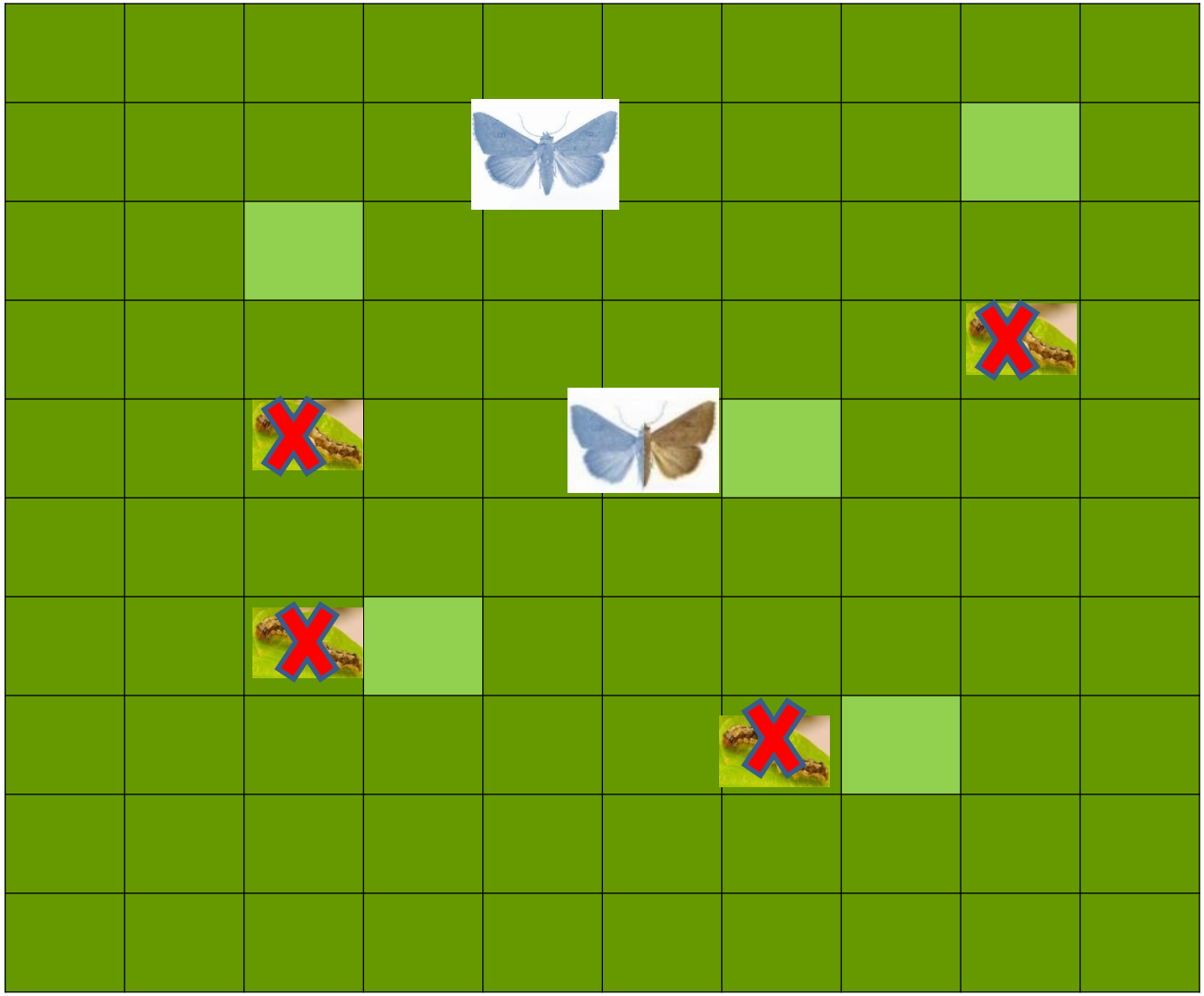
RIB



Bt crop

Non-Bt Crop

RIB



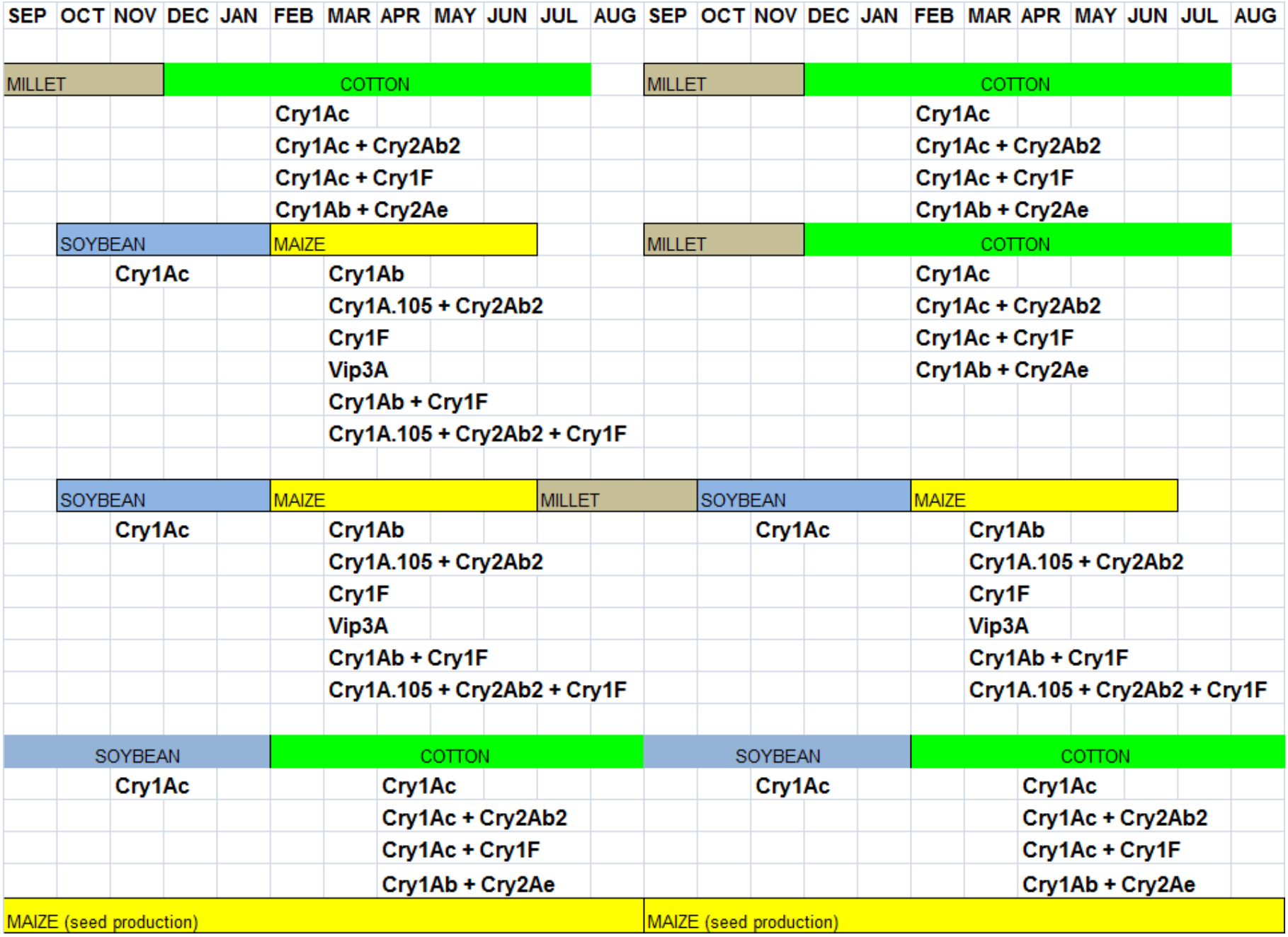
Susceptible

Resistant

Bt crop

Non-Bt crop

Cropping Systems in Mato Grosso, Brazil



Bt crops ➔ Changes in pest population dynamics

Bt Soybean

~~*Spodoptera frugiperda*~~
S. eridania
S. cosmioides
~~*Helicoverpa* spp.~~
~~*Heliothis virescens*~~
~~*Chrysodeixis includens*~~
Stink bugs & other bugs
Whiteflies
Spider mites

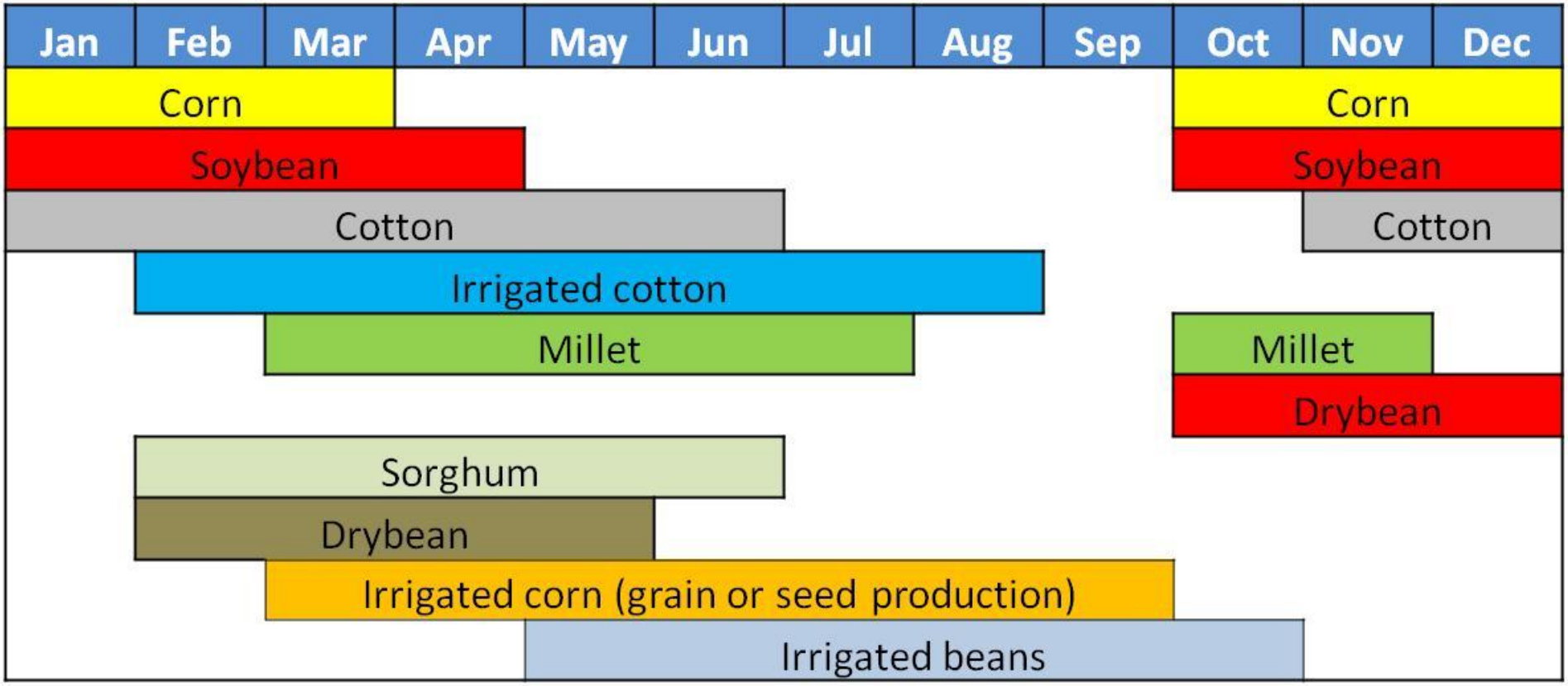
Bt Corn

~~*Spodoptera frugiperda*~~
~~*Helicoverpa* spp.~~
Stink bugs & other bugs
Aphids

Bt Cotton

~~*Spodoptera frugiperda*~~
S. eridania
S. cosmioides
~~*Helicoverpa* spp.~~
~~*Heliothis virescens*~~
~~*Chrysodeixis includens*~~
Stink bugs and other bugs
Whiteflies
Spider mites

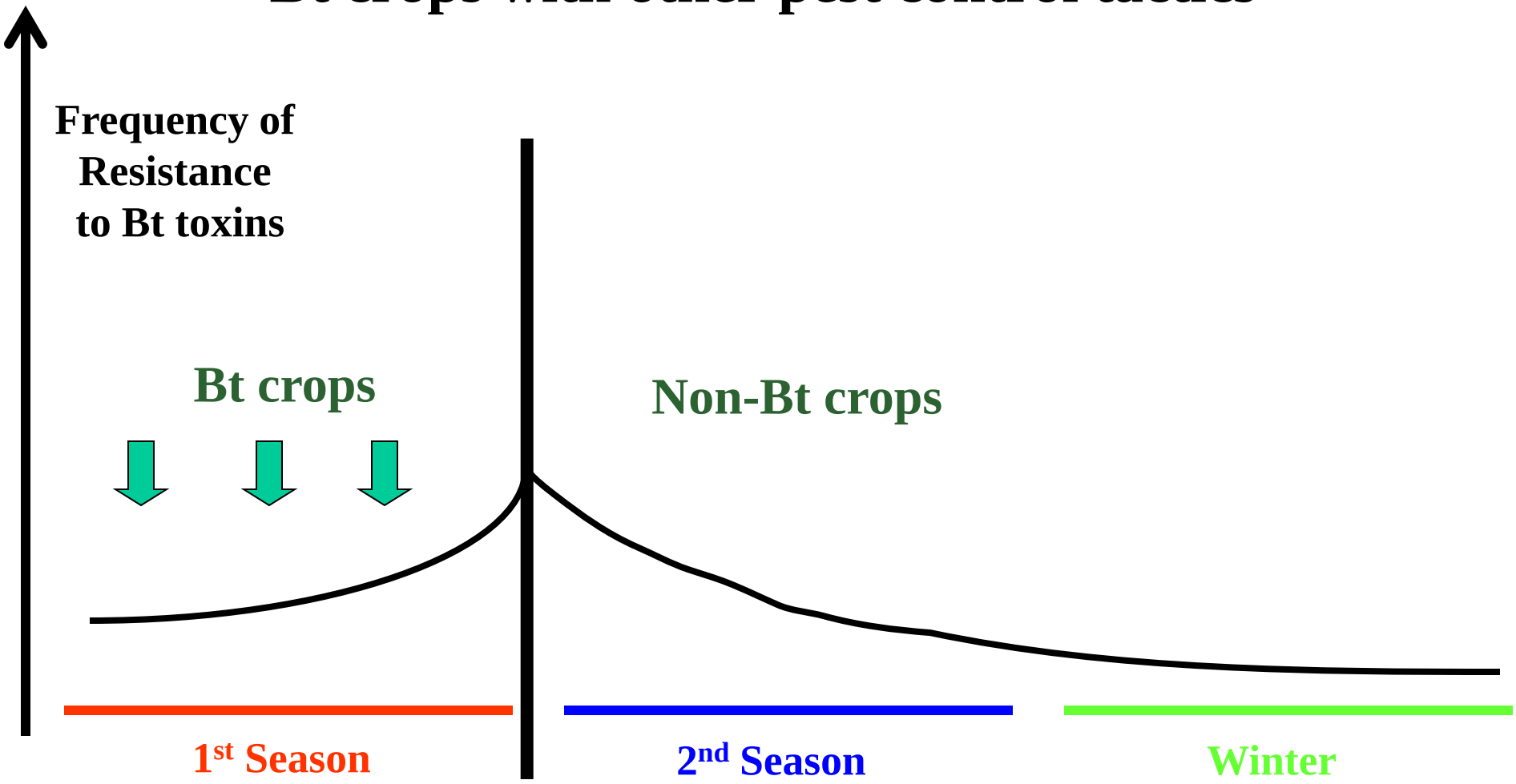
Major Cropping Systems in Western Bahia, Brazil



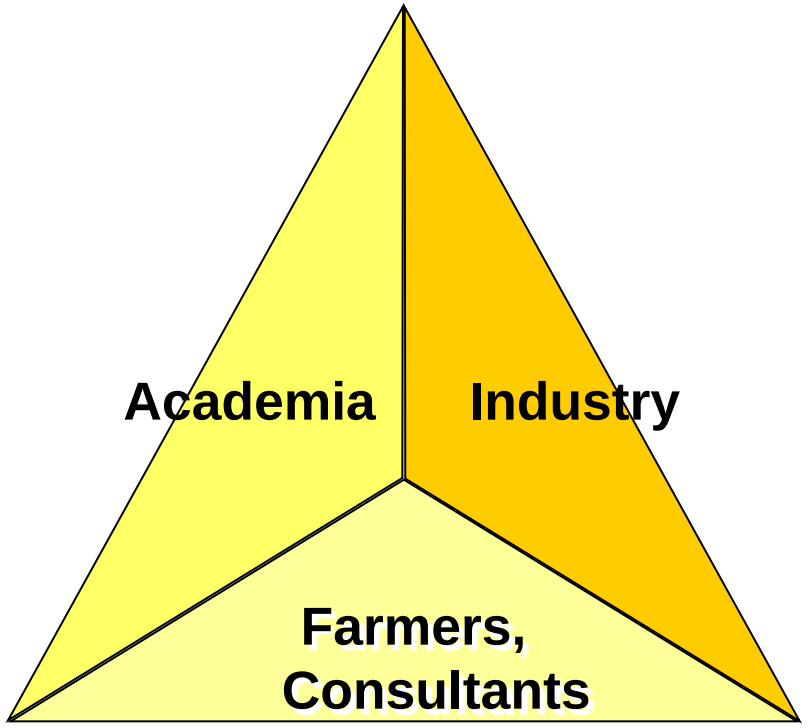
Plant Health Program for Western Bahia

- Crop Calendar (Crop-free Period)
- Insecticides (Emergency Use Permits)
- Biological Control
- Pupae busting (?)
- Irrigation

Need to reduce selection pressure by integrating Bt crops with other pest control tactics



Major Challenge: Implementation of IRM



➔ **Education, Research and Regulatory Issues**

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Thank you!