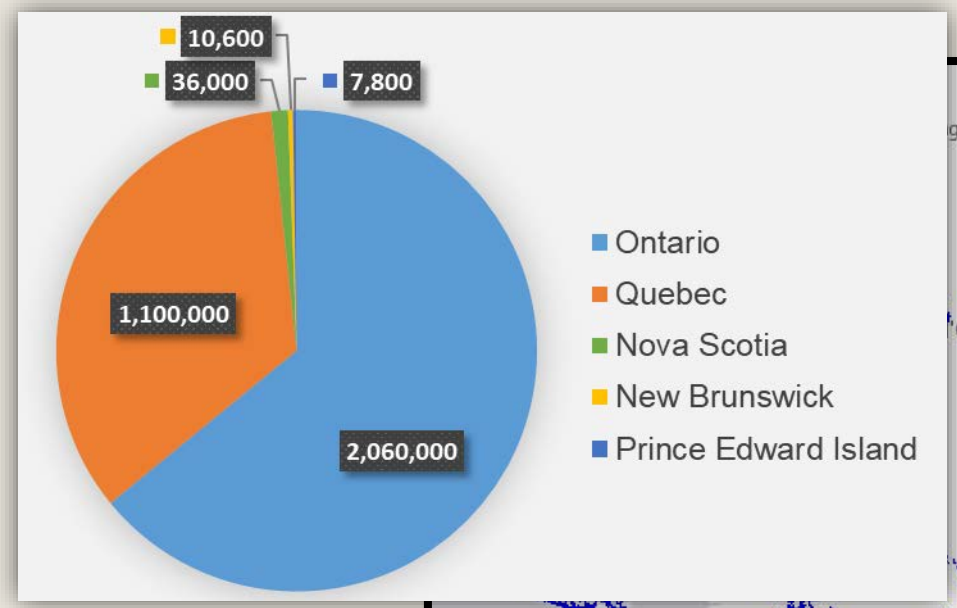
Bt Resistance in European Corn Borer in Nova Scotia, Canada

JOCELYN SMITH, YASMINE FARHAN, AND ART SCHAAFSMA

UNIVERSITY OF GUELPH RIDGETOWN CAMPUS, RIDGETOWN, ON

Indiana CCA Conference
Indianapolis, IN | December 17-18, 2019

Distribution and Density of Corn in Eastern Canada



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European Corn Borer

Figure 1. Approximate distribution of annual generations of European corn borer In the United States and Canada.

Mason, C.E., M.E. Rice, C.D. DiFonzo, R.P. Porter, and 20 others. 2018. *European Corn Borer Ecology, Management, and Association with Other Corn Pests*, NCR 0327. Ames: Iowa State University Extension and Outreach.

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Oct. 5, 1940 Canadian Countryman

J. Obermeyer

Calls for Officials to "Crack Down" on Careless Corn Growers

THE season of corn harvest is again at hand, and apparently we have quite an increase in corn borer infestation.

It is probable that weather conditions prevailing during the growing season will be blamed for this increase in borers. However, here is one farmer who believes that weather conditions are not the only cause of increased damage by this voracious insect. In many districts one sees evidence of laxity in the enforcement of the Corn Borer Act.

I have seen fields with almost one-third of the corn stubble lying on top of the ground after spring-seeding operations had been completed. On some farms corn stalks are allowed to become mixed with straw and litter, and the whole mass left lying in the barnyard until midsummer.

The farmer who fails to plow under his corn stubble is usually looked upon as being very delinquent. But is he a great deal worse than the farmer who carefully plows corn stubble under in the fall, and then tears half of it up again in the spring? Or is he much worse than the farmer who fails to burn, at the proper time, all corn stalks and other corn refuse that is lying about his premises?

It is the duty of those officials who have the responsibility of enforcing the Corn Borer Act to "crack down" on a few of these careless corn growers. Let them know that we have at least one law on the statute books that has teeth in it. If the Corn Borer Act were enforced to the limit, the damage done by borers in a year of normal weather conditions would be negligible.

Middlesex Co. DISSATISFIED CORN GROWER.

Schaafsma et al. 2002 Plant Disease

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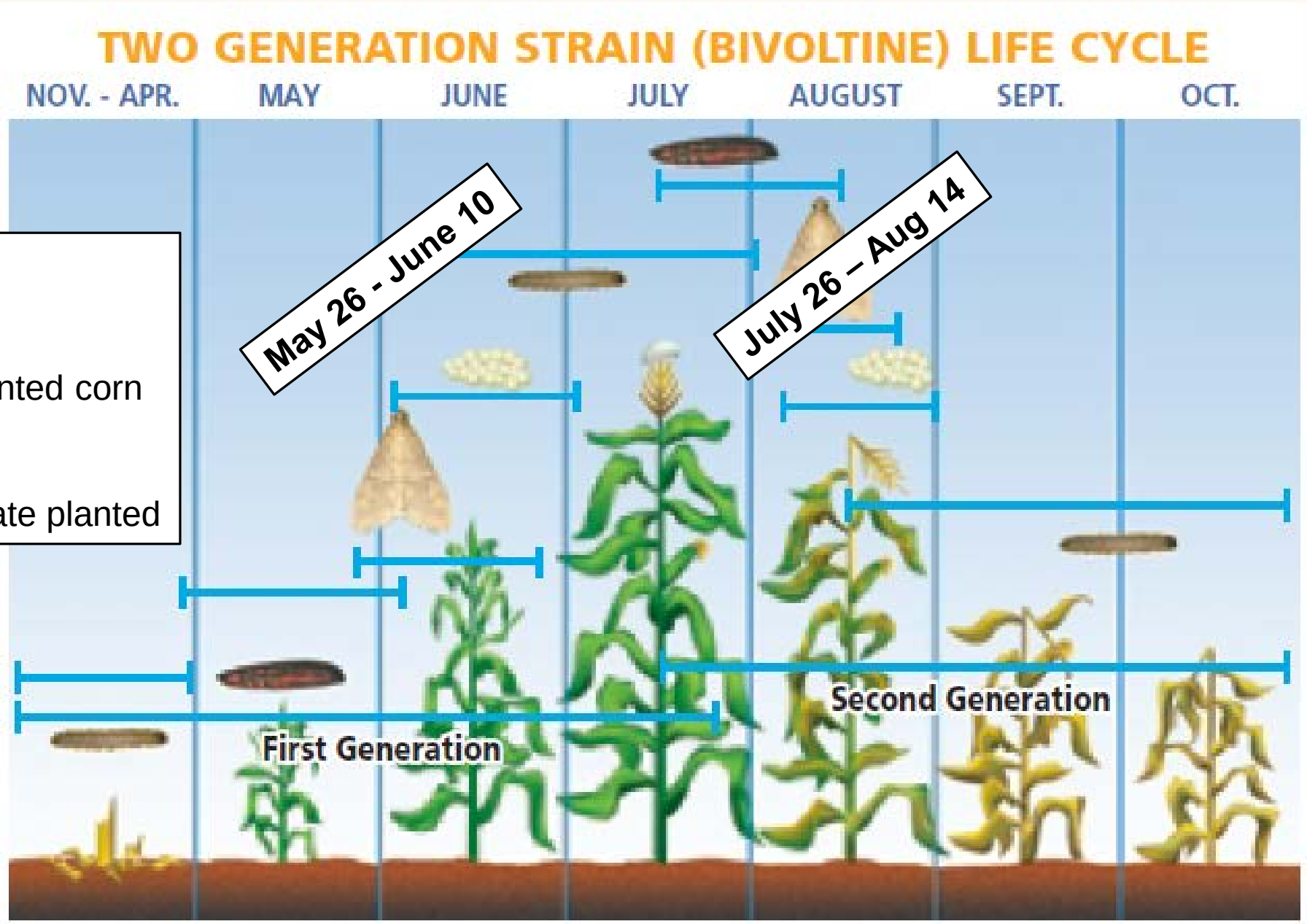
Risk Factors:

1st Generation:
- Tallest, early-planted corn

2nd Generation:
- Pollinating corn, late planted

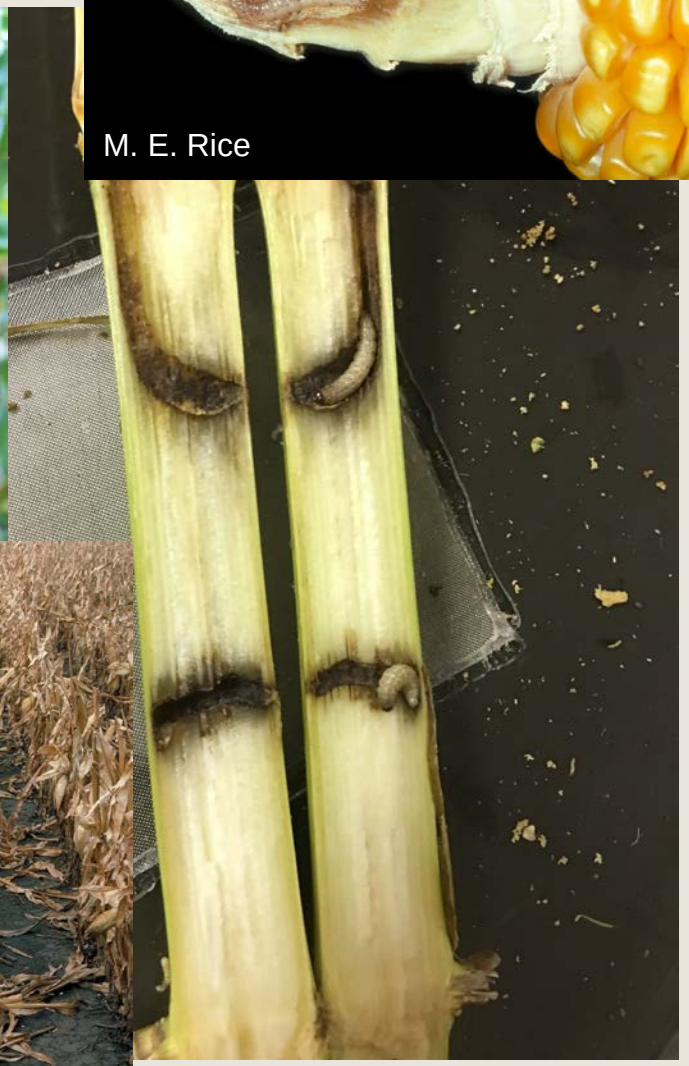


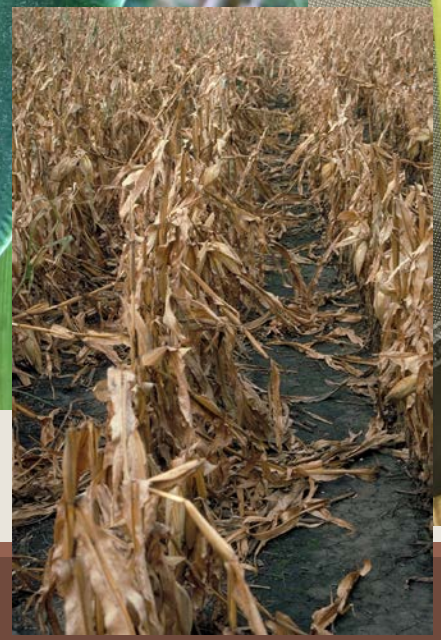
European Corn Borer Injury
1st Generation

- 1st instar – window paning, feeding within the whorl
- 2nd-3rd instar – shot holes in whorl leaves and boring into mid-rib
- Stalk boring, frass looks like sawdust near entry holes

European Corn Borer Injury 2nd Generation

- After VT, larvae move to leaf axils, leaf sheath and stalks
- 4th – 5th instars – stalk tunneling
- Ear drop, lodging, stalk rots, ear rots and mycotoxins
- 5-6% yield loss with 1 larva/plant





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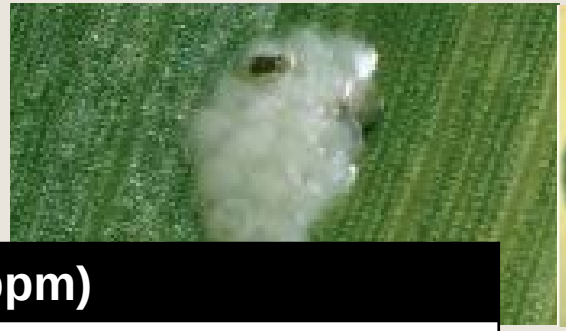
ECB Management

- Monitoring moth flights with pheromone traps
- Scouting for egg masses, small larvae, or feeding
- Insecticide application
- Natural enemies
- Bt corn



son S. Rao M. E. Rice

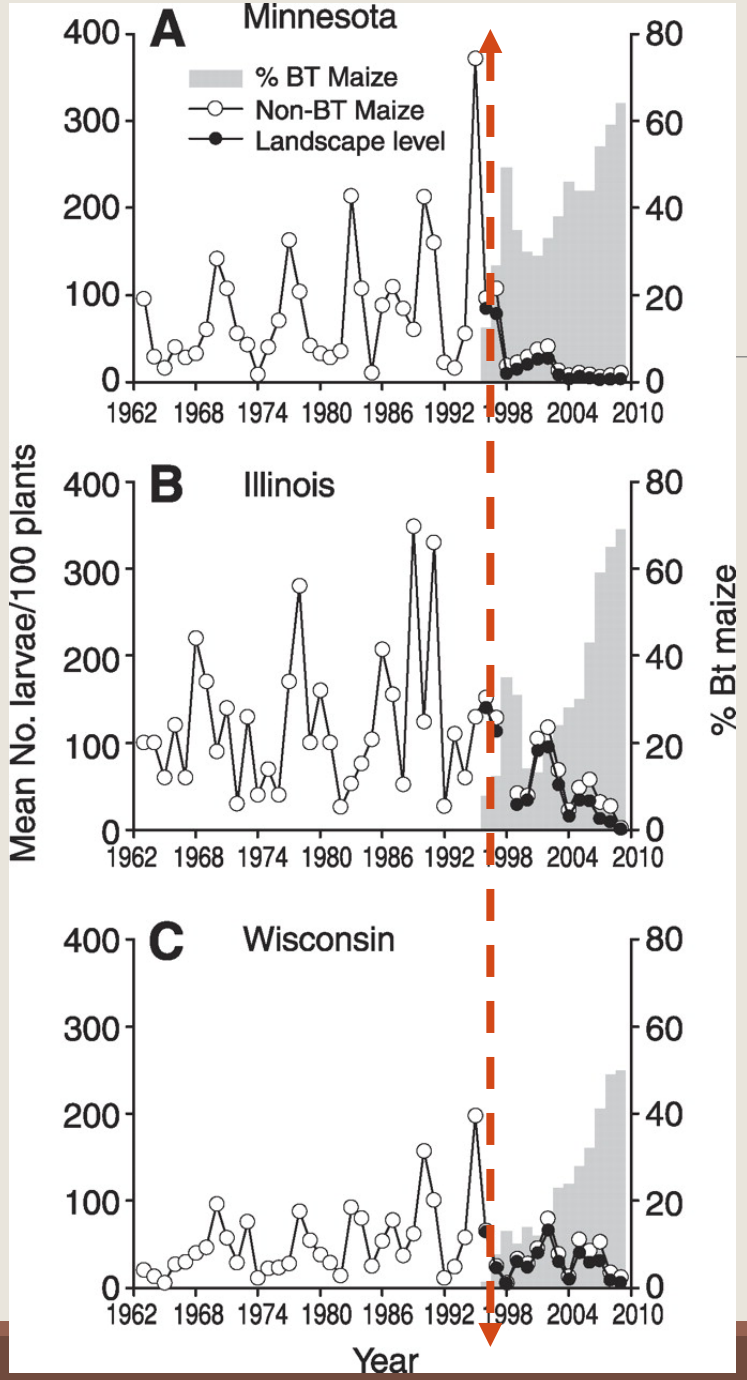
DON (ppm)					
	1996	1997	1998	1999	Avg
Non-Bt isoline	1.25	0.51	1.15	1.19	0.96
Bt	0.45	0.36	0.69	1.06	0.57
P-value	<0.0001	0.02	0.0019	0.51	<0.0001

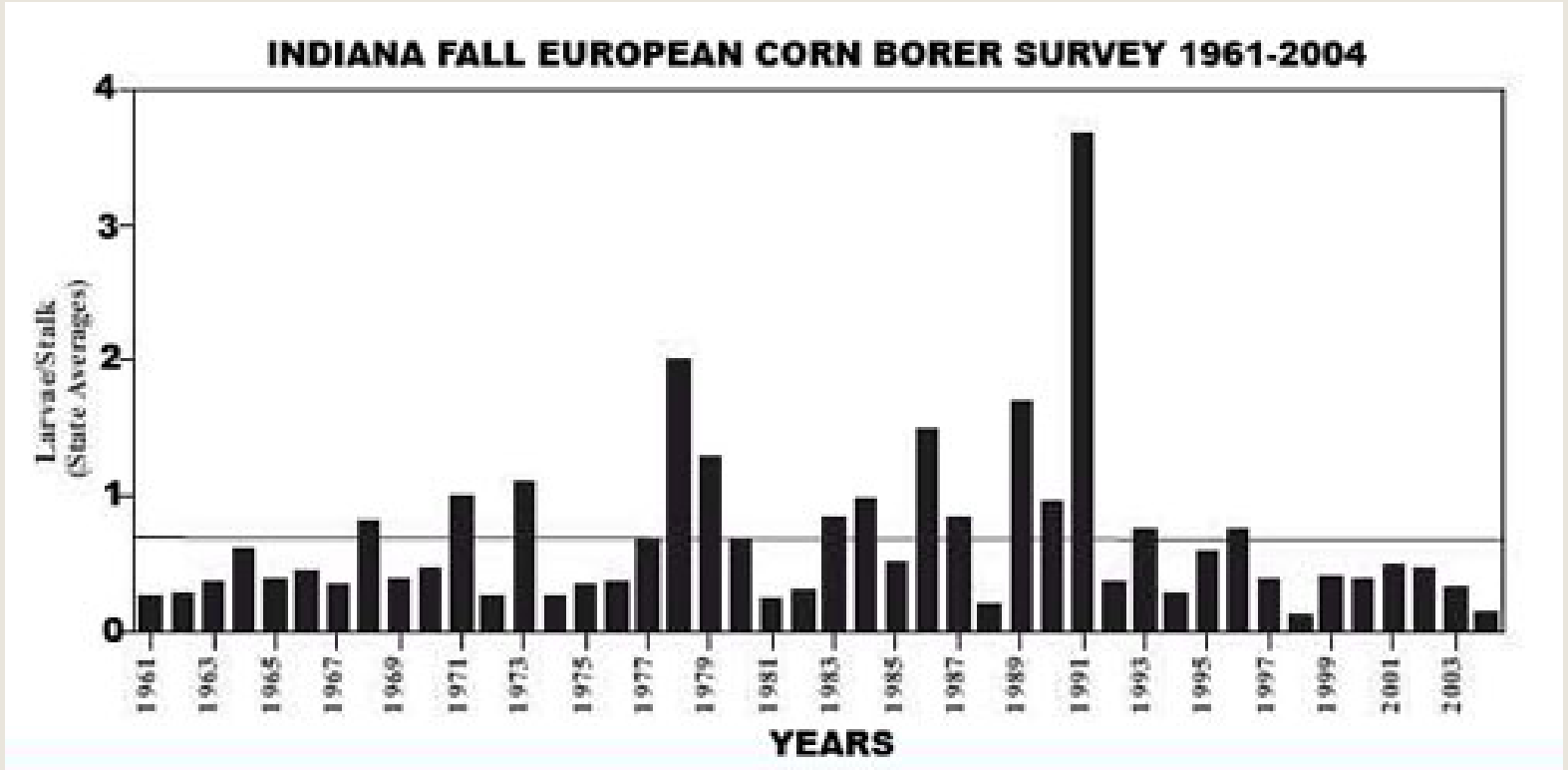
Schaafsma et al. 2002 Plant Disease

ECB Population Suppression

$3.2 billion for MN, IL, and WI corn growers

$2.4 billion for non-Bt corn growers





J. Obermeyer and L. Bledsoe, 2004

Areawide Suppression of European Corn Borer with Bt Maize Reaps Savings to Non-Bt Maize Growers
Hutchison et al. *Science* 08 Oct 2010:Vol. 330, Issue 6001, pp. 222-225

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GM Crops and Food: Biotechnology in Agriculture and the Food Chain 3:3, 184-193; July/August/September 2012; © 2012 Landes Bioscience

Understanding successful resistance management

The European corn borer and Bt corn in the United States

Blair D. Siegfried[1,*] and Richard L. Hellmich[2]

- **High dose/Refuge Strategy**
  - Multiple high dose Cry toxins targeting ECB: Cry1Ab (1996), Cry1F (2002), Cry1A.105 x Cry2Ab2 (2009)
    - Single toxin hybrids → Pyramided toxins in hybrids
    - Non-Bt refuge: 20% Structured → 10% → 5% RIB
- **Resistance Monitoring**

Table 2. No significant decrease in susceptibility to Bt crops: 19 cases involving five Bt toxins, 11 pest species, and seven countries (mean documented years of susceptibility[a] = 10.5 yr), updated from Tabashnik and Carrière (2017)

Insect	Crop	Toxin	Country	Year comm[b]	Years[a]	Reference[c]
O. nubilalis	Corn	Cry1Ab	Spain	1998	15	EFSA (2015)
O. nubilalis	Corn	Cry1Ab	United States	1996	15	Siegfried and Hellmich (2012)
O. nubilalis	Corn	Cry1Fa	United States	2003	8	Siegfried et al. (2014)

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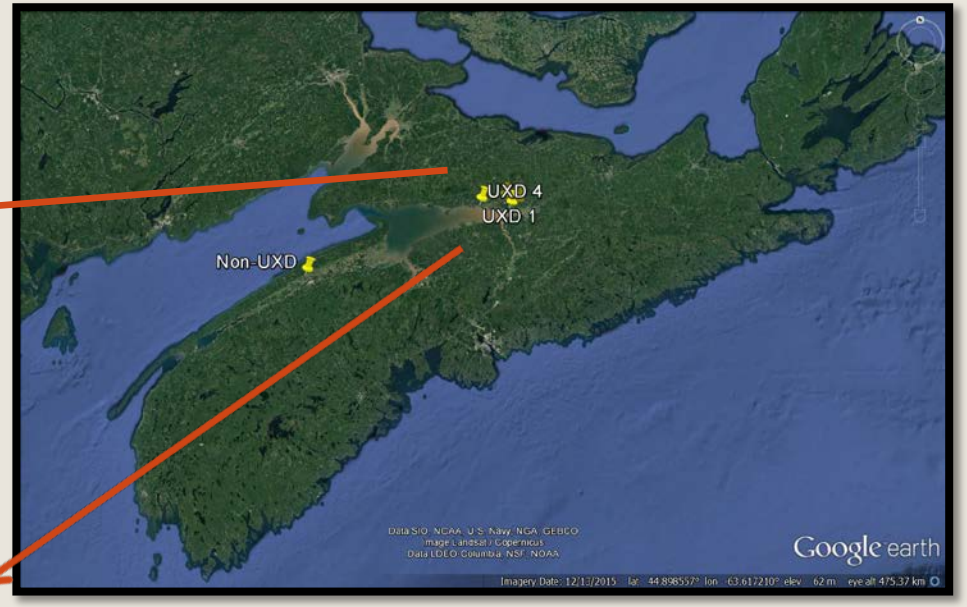

Field ID	Bt	Planting date	% ECB Damage	Collection date	Crop stage @ Collection	Beginning #ECB
UXI-1 – NS	Cry1F	16-May-18	70	04-Sept-18	R5	239
UXI-2 – NS	Cry1F	16-May-18	30	04-Sept-18	R5	75
UXI-3 – NS	Cry1F	09-May-18	40	04-Sept-18	R4	193
UXI-4 – NS	Cry1F	12-May-18	30	05-Sept-18	R4-R5	57
Non-UXI – NS	None	24-May-18	60	06-Sept-18	R4	131

Smith et. al. 2019 Scientific Reports

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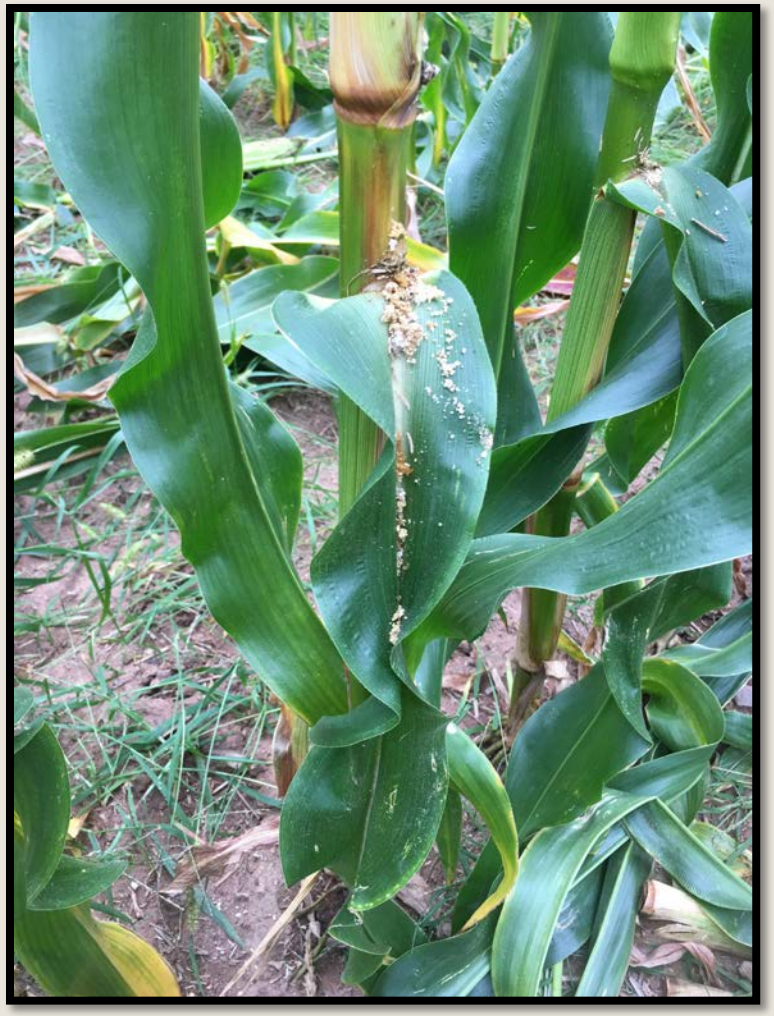
UXI-1, Truro, Nova Scotia
September 4, 2018



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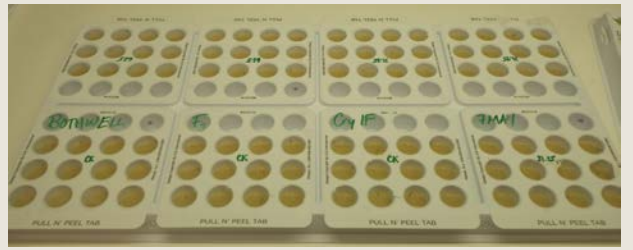
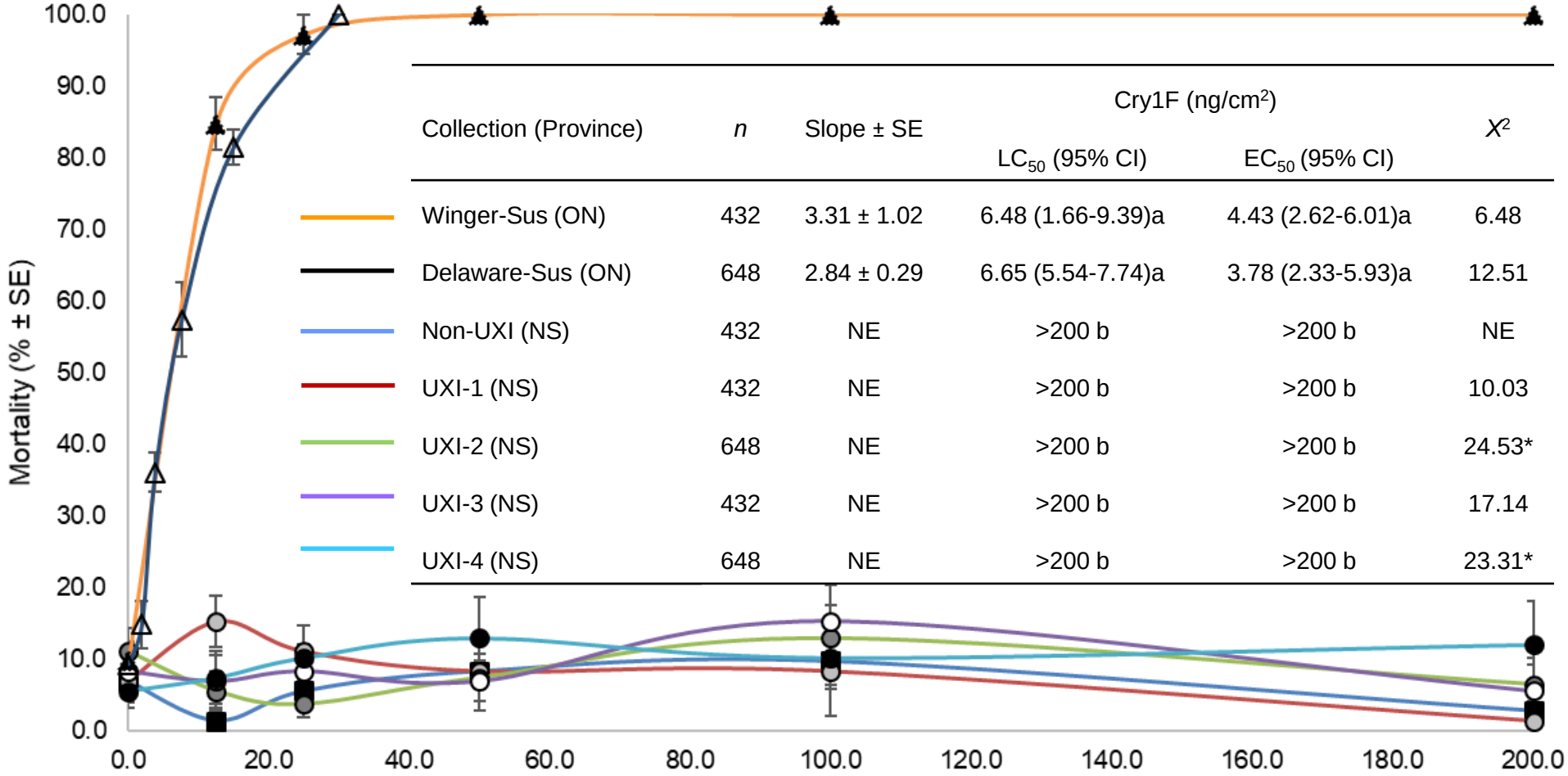
Diet overlay bioassay results





Collection (Province)	*n*	Slope ± SE	Cry1F (ng/cm²) LC_{50} (95% CI)	Cry1F (ng/cm²) EC_{50} (95% CI)	X^2
Winger-Sus (ON)	432	3.31 ± 1.02	6.48 (1.66-9.39)a	4.43 (2.62-6.01)a	6.48
Delaware-Sus (ON)	648	2.84 ± 0.29	6.65 (5.54-7.74)a	3.78 (2.33-5.93)a	12.51
Non-UXI (NS)	432	NE	>200 b	>200 b	NE
UXI-1 (NS)	432	NE	>200 b	>200 b	10.03
UXI-2 (NS)	648	NE	>200 b	>200 b	24.53*
UXI-3 (NS)	432	NE	>200 b	>200 b	17.14
UXI-4 (NS)	648	NE	>200 b	>200 b	23.31*

*p<0.10

NE = not estimable due lack of mortality response within the concentration range tested.

Concentrations tested: 0, 12.5, 25.0, 50.0, 100.0, 200.0 ng cm^{-2} for all collections except Delaware, ON where concentrations were: 0, 1.9, 3.8, 7.6, 15.0, 30.0 ng cm^{-2}.

Smith et. al. 2019 Scientific Reports

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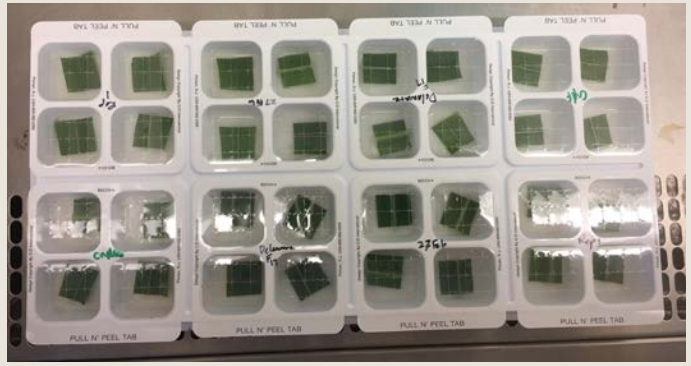
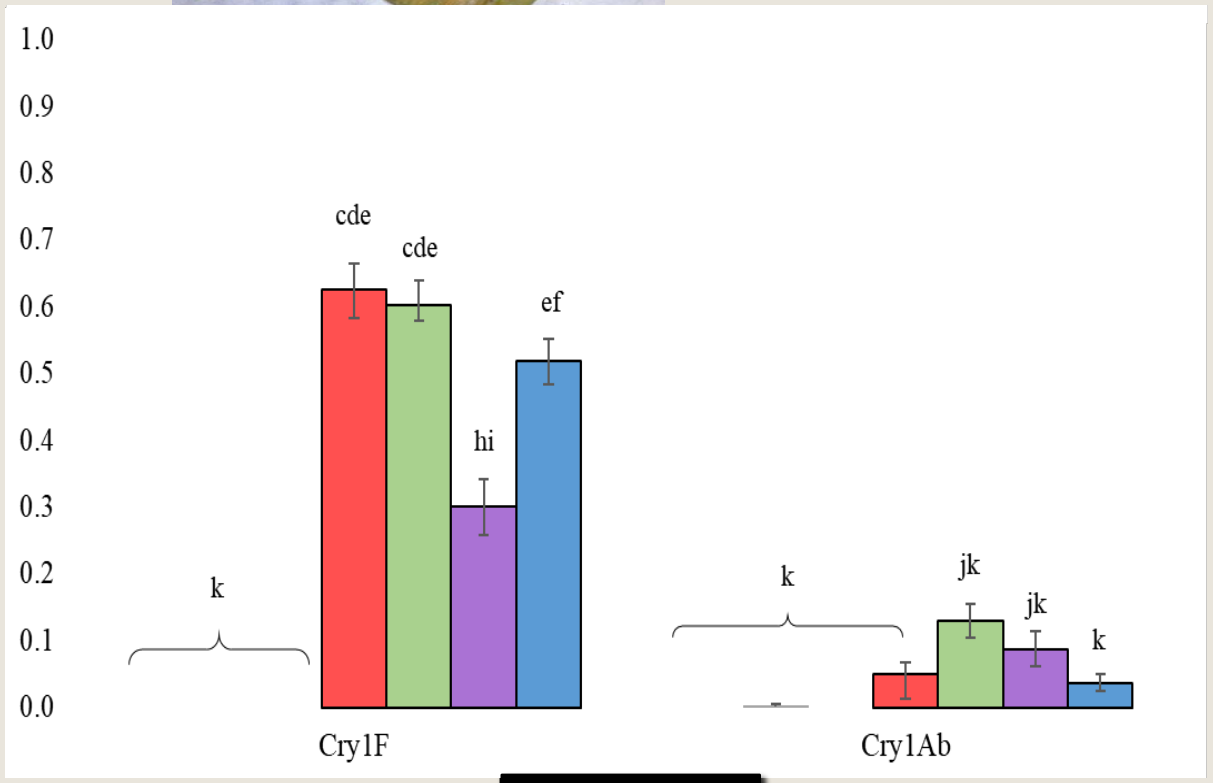
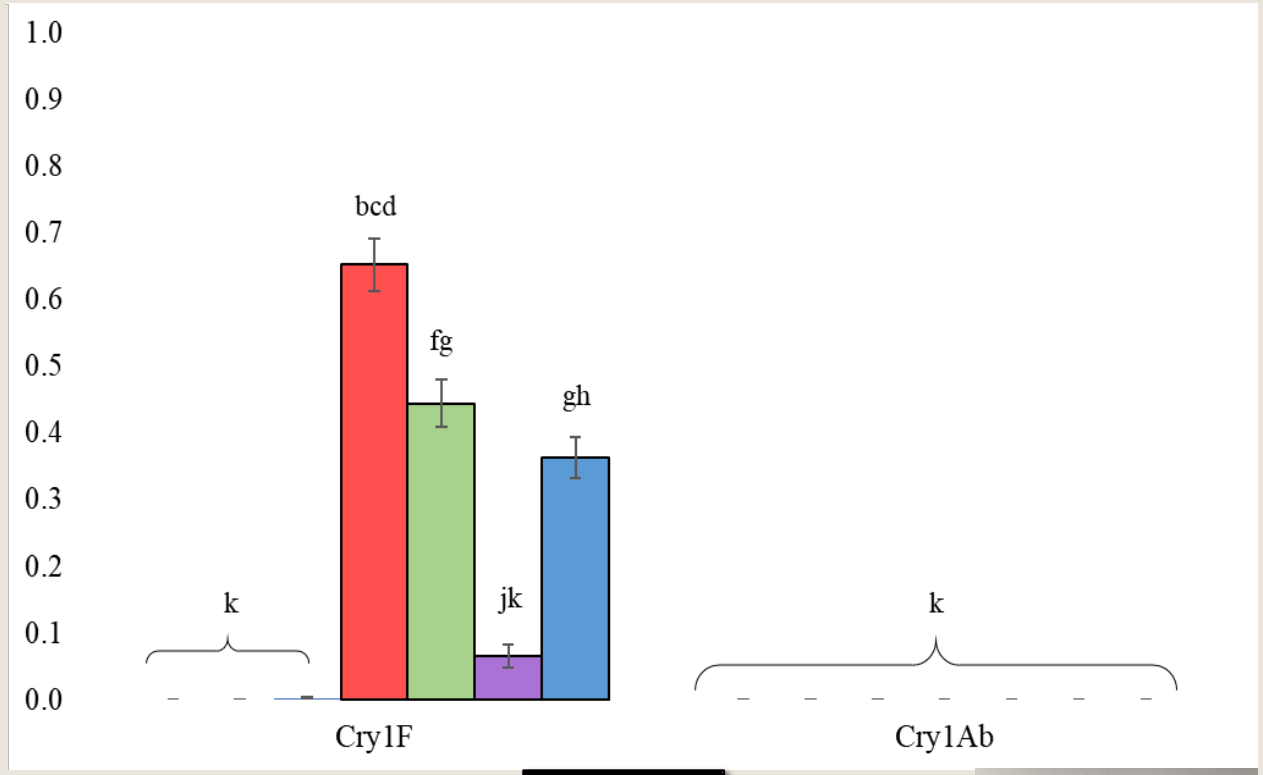
Leaf tissue bioassay results



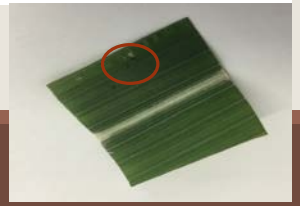
Proportional survival ± SE



4-5 DAI



7 DAI



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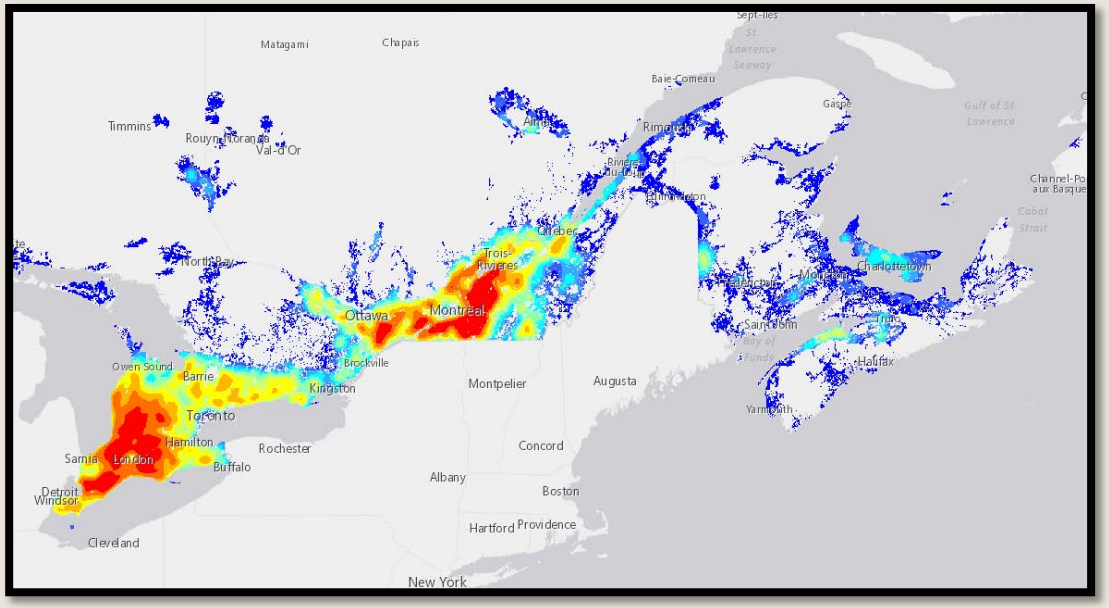
Why did Cry1F resistance evolve in Nova Scotia?

- "Island Effect"?
- Single toxin corn hybrids being sold in small, short-season markets
- Violation of the High-Dose **Refuge** Strategy?
  - Very little refuge compliance monitoring
- Under the radar…
  - Resistance monitoring historically focused on major corn growing regions
  - ECB resistance monitoring to Cry1F was halted in 2017 in Canada
  - Failure to react to early warning signs
- A combination of things…



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Recommendations for Mitigation

1. Stop sales and planting of corn hybrids that express a single Bt toxin targeting ECB in Canada.
   - Corteva replaced popular Cry1F hybrid with **Cry1Ab x Cry1F** pyramid hybrid in Maritimes Region in 2019
   - Single toxin Bt hybrids for ECB sold in Manitoba in 2019
   - CFIA requested phase-out plans for single toxin products from trait providers

2. In UXI fields, corn stalks should be chopped and buried using tillage in the fall to reduce the frequency of resistance alleles in ECB populations.
3. Determine susceptibility of ECB in this region to Cry1F, Cry1Ab, Cry1A.105, and Cry2Ab2.
4. Increase Bt resistance monitoring of ECB in the Maritimes, Manitoba, and surrounding regions.
5. Study of ECB phenology, voltinism, pheromone races, host range in the Maritimes and surrounding regions.

Management of Western Bean Cutworm and Deoxynivalenol in Canada

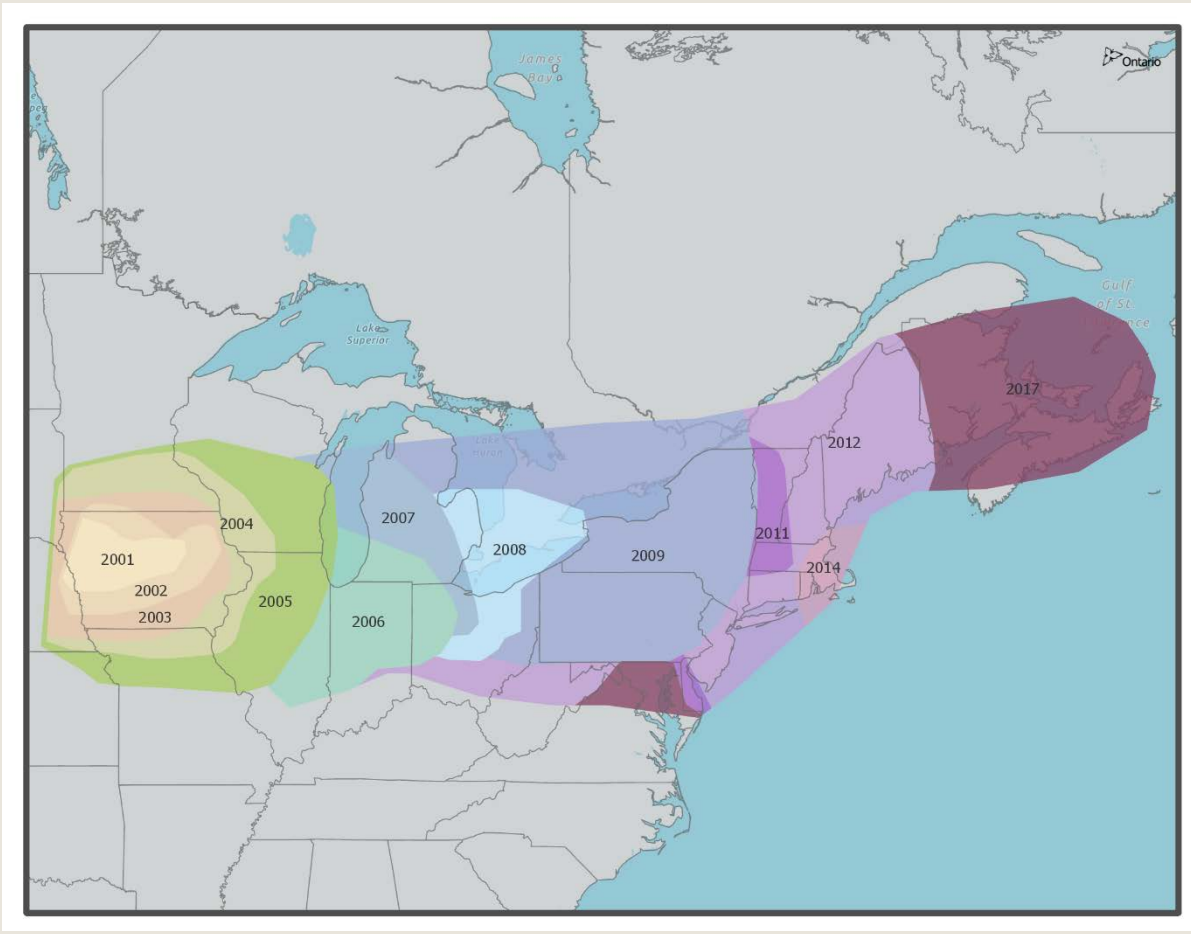
JOCELYN SMITH[1], DAVID HOOKER[1], TRACEY BAUTE[2], AND ART SCHAAFSMA[1]

[1]UNIVERSITY OF GUELPH RIDGETOWN CAMPUS, RIDGETOWN, ON

[2] ONTARIO MINISTRY OF AGRICULTURE, FOOD AND RURAL AFFAIRS

Western Bean Cutworm Range Expansion

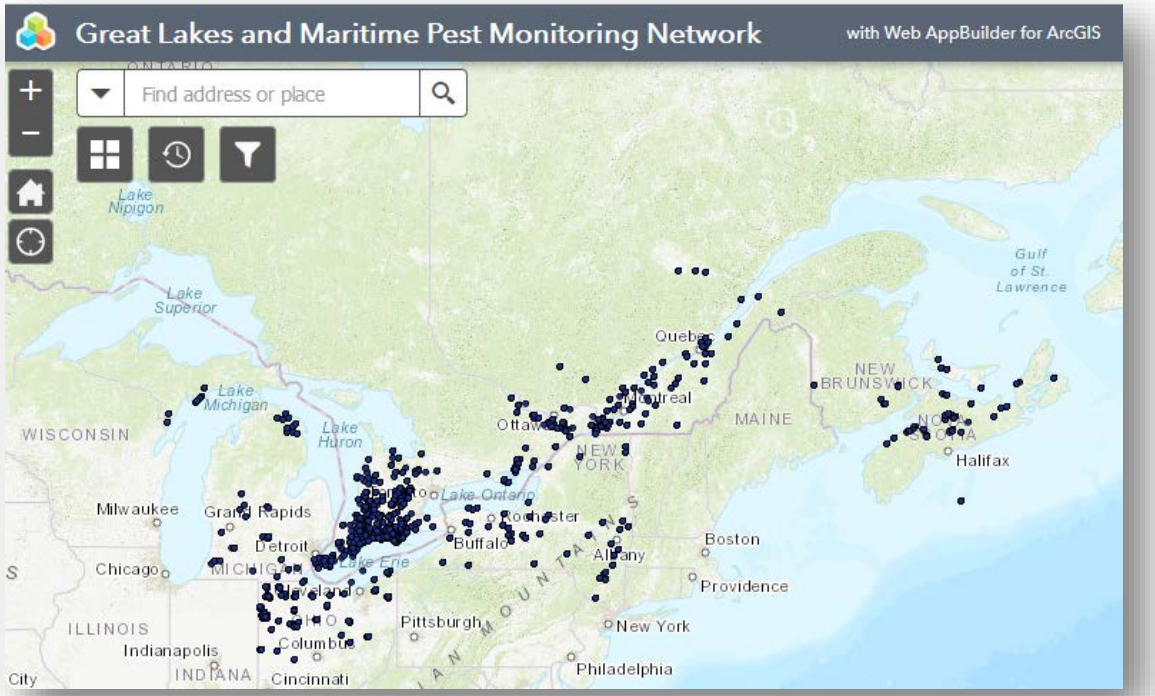
Historical range



Since 2000

Smith et al. 2019 JIPM

Great Lakes and Maritimes Pest Monitoring Network



ADB and EMB Collaboration (Jen Birchmore, GIS)

- Over 850 traps in 2019.
- Real-time mapping and dashboard to show weekly trap results.
- Pests on the network include:
  - Black cutworm
  - Corn earworm
  - European corn borer
  - Fall armyworm
  - True armyworm
  - Western bean cutworm
- Currently includes corn (all types), dry and snap beans, and other crops with these pests.

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Michigan State University
IPM
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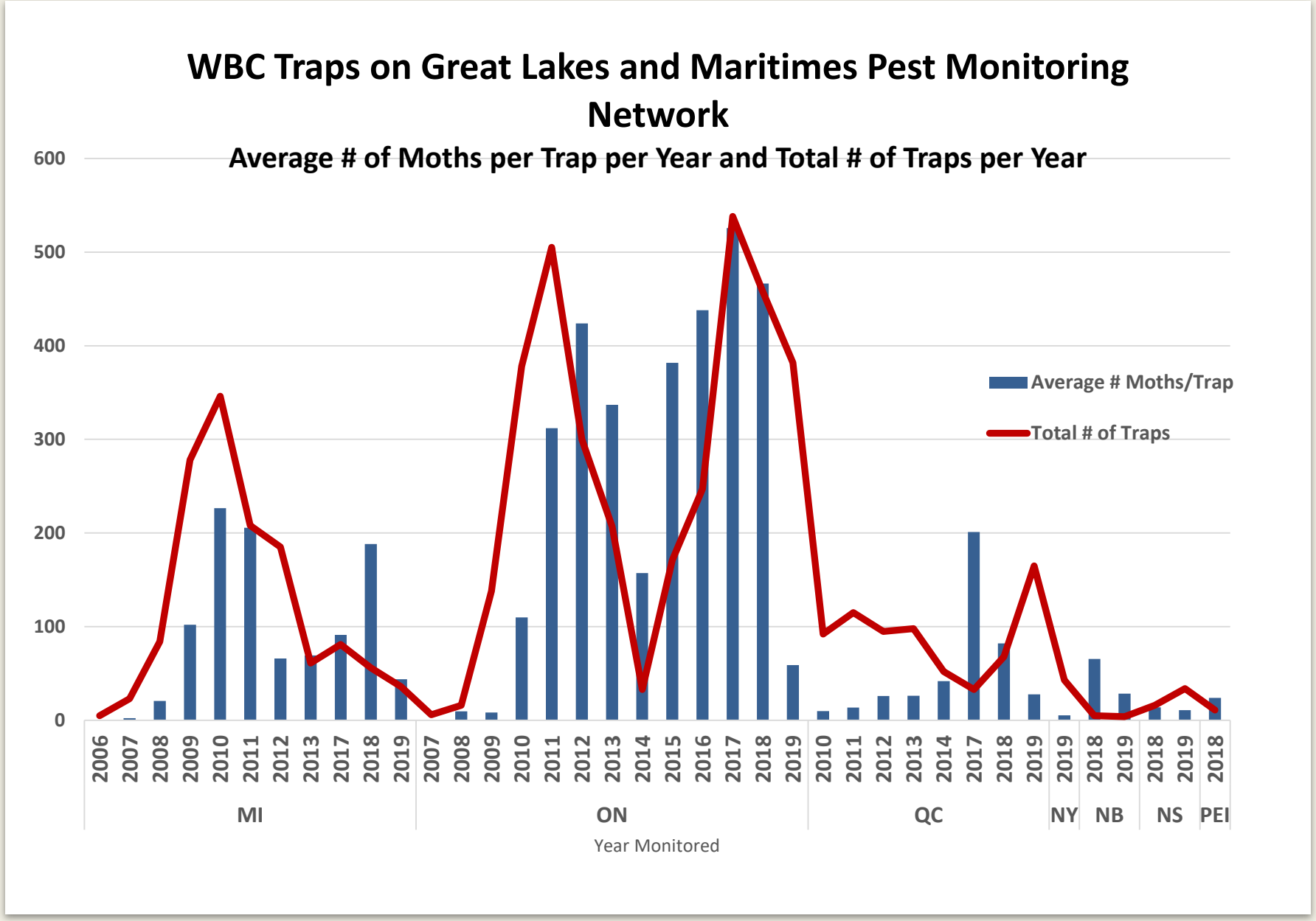
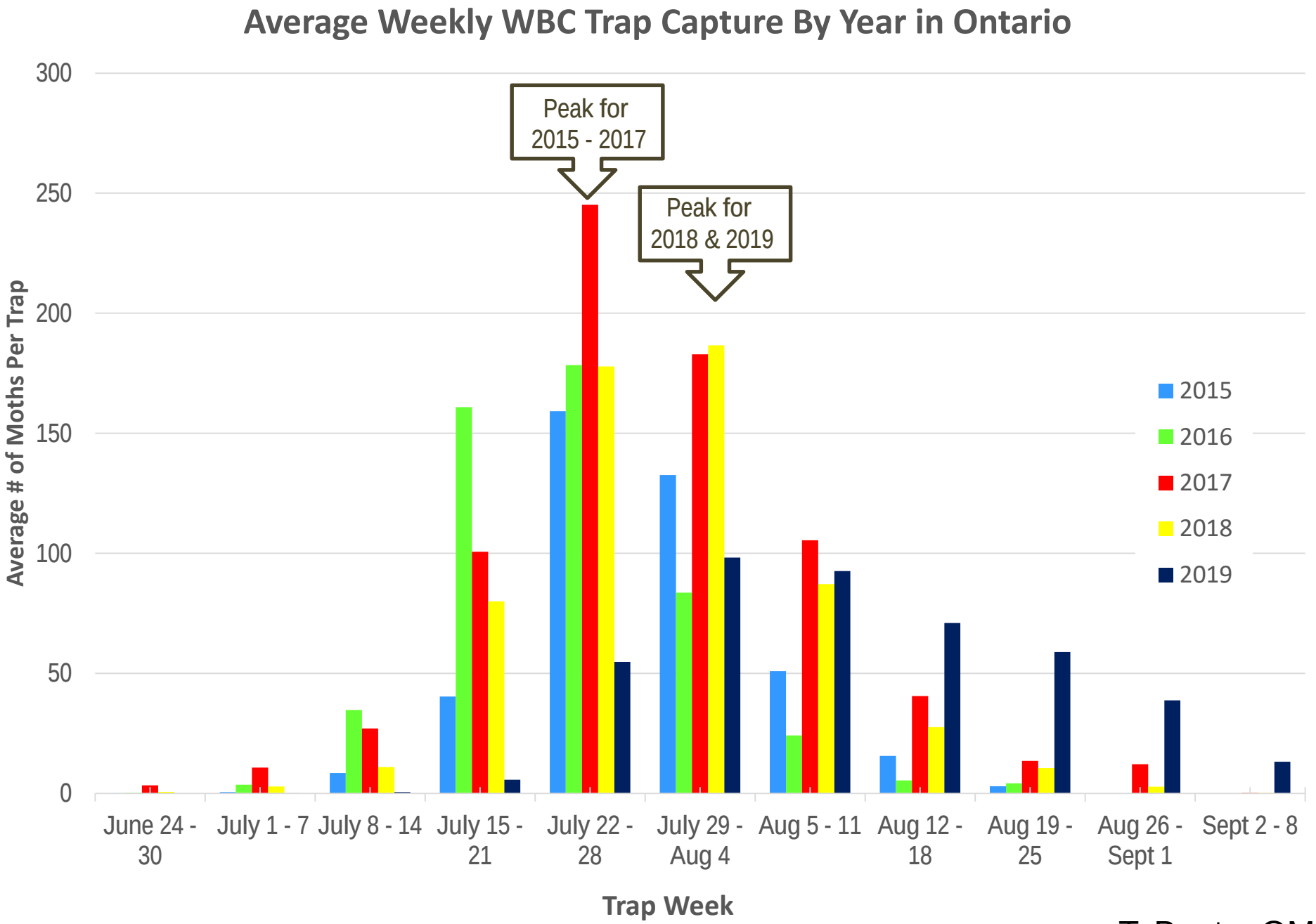
Prince Edward Island Canada
Newfoundland Labrador



T. Baute, OMAFRA 2019



T. Baute, OMAFRA 2019

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WBC Injury

- Yield loss of 3.6-15 bu/ac with one larva per plant
- Grain quality loss
- Secondary pests
- Mycotoxins

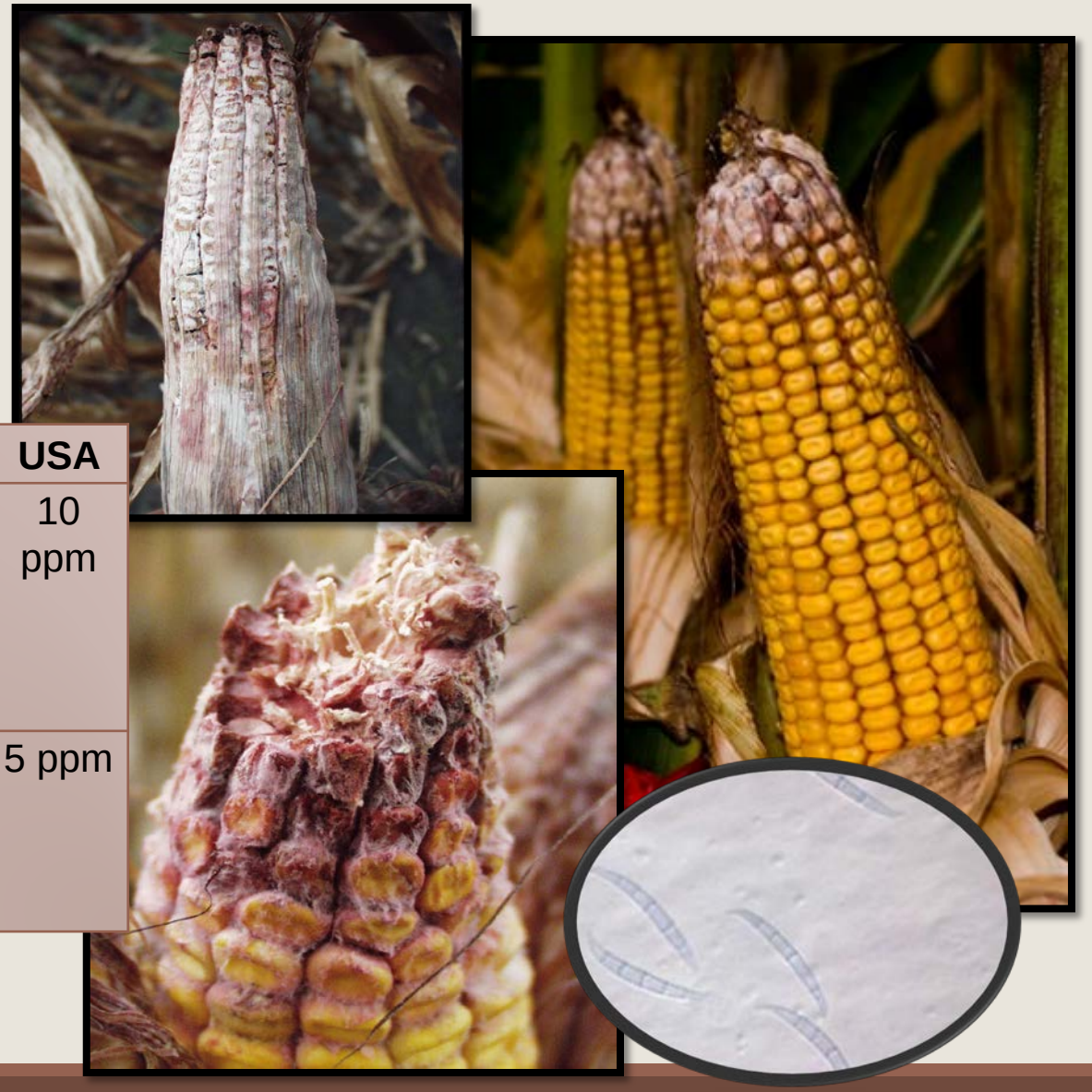
C. DiFonzo, MSU

Gibberella Ear Rot

Asexual state: *Fusarium graminearum*
Sexual state: *Gibberella zeae*

Mycotoxins: Deoxynivalenol (DON), Zearalenone

Commodity	Canada	Commodity	USA
Diets for cattle & poultry	5 ppm	Grains and grain by-products destined for ruminating beef and feedlot cattle older than 4 months and chickens (not exceeding 50% of the cattle or chicken total diet)	10 ppm
Diets for swine, young calves, & lactating dairy animals	1 ppm	Grains and grain by-products (not exceeding 40% of the diet)	5 ppm



www.inspection.gc.ca/animals/feeds/regulatory-guidance/rg-8/eng/1347383943203/1347384015909?chap=1#s1c1 http://extensionpublications.unl.edu/assets/html/g2181/build/g2181.htm

Fusarium graminearum and DON in Ontario

DON	2011	2012	2013	2014	2015	2016	2017	2018	2019
<0.5 ppm	47%	84%	83%	66%	75%	48%	69%	33%	84%
0.5-<2.0 ppm	28%	12%	15%	26%	20%	26%	17%	27%	12%
2.0-5.0 ppm	**17%**	4%	1%	6%	5%	**18%**	8%	**15%**	4%
>5.0 ppm	**7%**	0%	0%	2%	0%	**8%**	6%	**25%**	0%

B. Rosser and A. Tenuta, OMAFRA 2019

- **Dependent on:** Weather, hybrid susceptibility, insect injury = primarily WBC in ON
- Difficult to forecast
- Incidence of WBC injury is more important than severity

To target both WBC and Fusarium, you must compromise on timing:

Target full silk emergence and tank mix insecticide and fungicide

Infection by wounding – broad window

European corn borer

J. Obermeyer, Purdue

Sap beetles

J. Obermeyer, Purdue

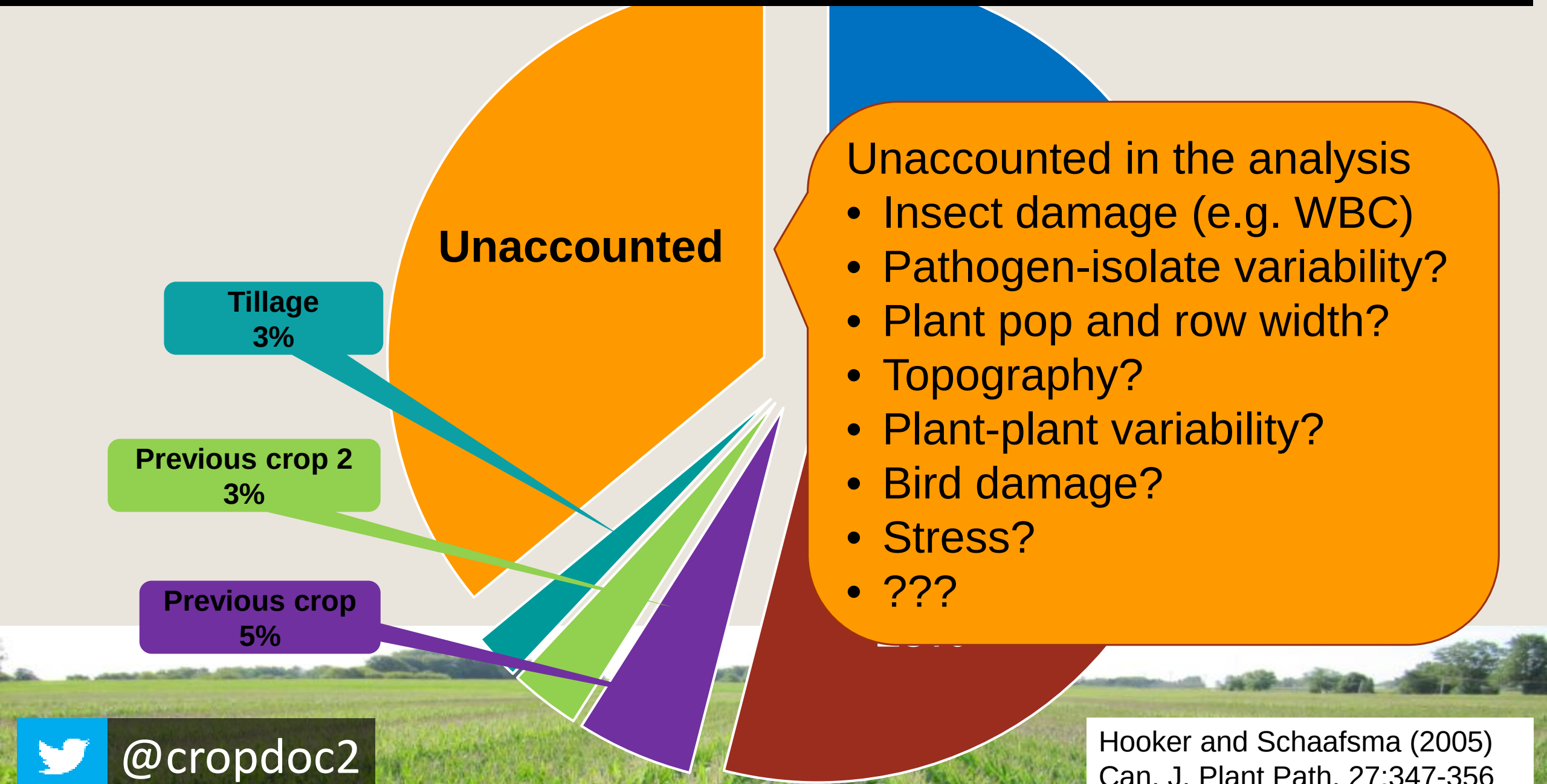
Western bean cutworm

Fall armyworm, corn earworm & fumonisins

P. Porter, TAMU

Stink bugs, corn rootworm adults, and birds

What is responsible for DON variability from year-year, field-field, etc?



Unaccounted in the analysis

- Insect damage (e.g. WBC)
- Pathogen-isolate variability?
- Plant pop and row width?
- Topography?
- Plant-plant variability?
- Bird damage?
- Stress?
- ???

@cropdoc2

Hooker and Schaafsma (2005)
Can. J. Plant Path. 27:347-356

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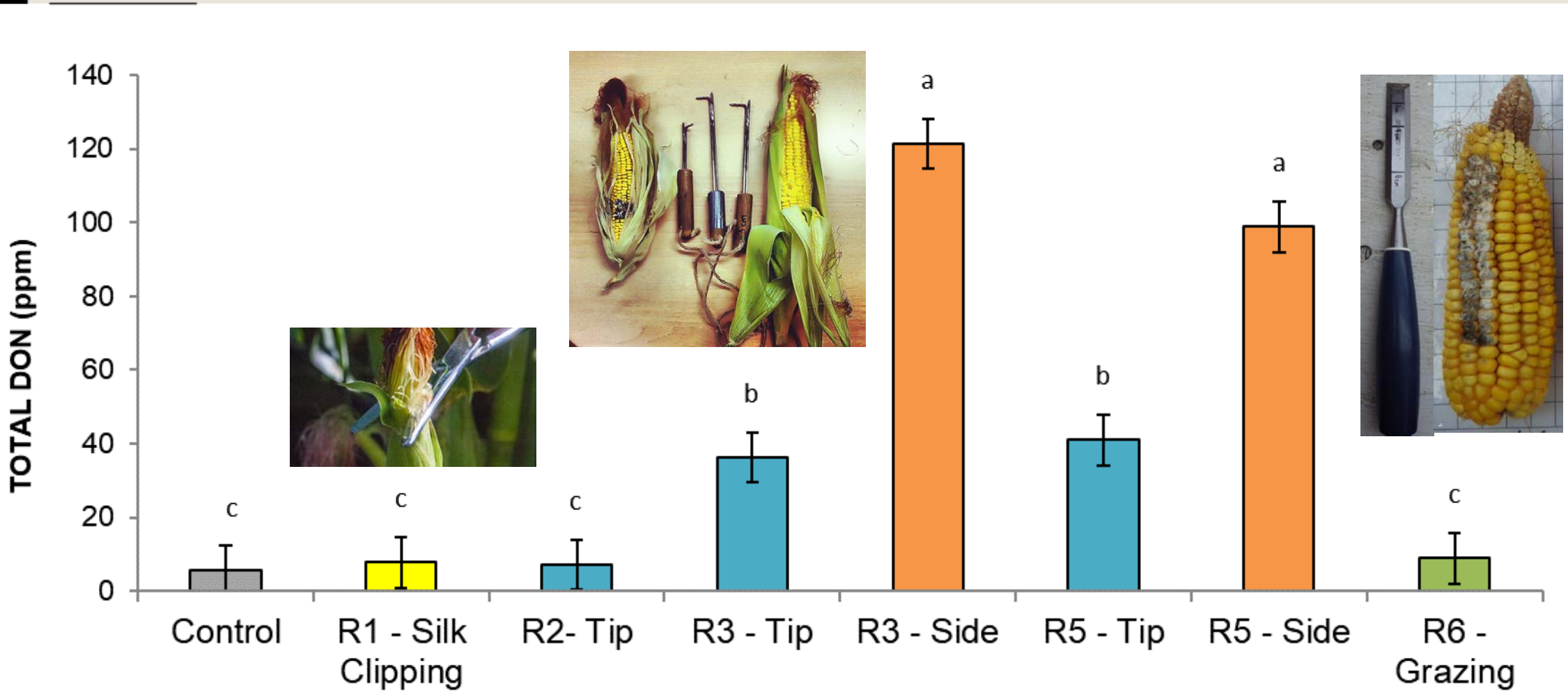
Effect of injury at different corn stages on DON



Limay-Rios, Smith, and Schaafsma, 2012-13

Managing DON and WBC

- Select multiple hybrids: select those with some tolerance to GER/DON
  - Reduce Weather risk: select hybrids with different silking dates across fields
  - Silk infection by *F. graminearum* happens regardless of WBC

- **SCOUT for WBC egg masses every 5 days**
  - **BEGIN when moths are active (3rd week of July), CONTINUE for 3 weeks, CUMULATIVE THRESHOLD = 5% (?)**
  - **High water volume (20 GPA), over the top**

- Fungicide (+ **Insecticide for WBC if warranted**): Triazole (Proline or Caramba) **at full silking**
- Manage to reduce plant-plant variability (uniform emergence)
- Adjust combine for max cleanout/clean grain
- Harvest infected grain early and dry immediately after harvest

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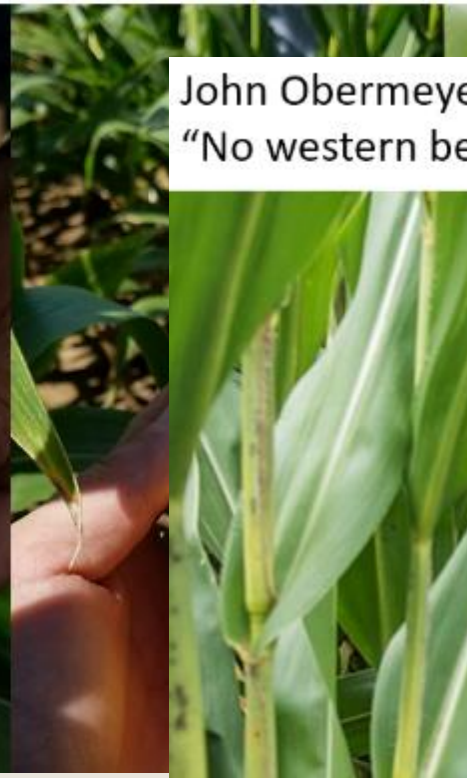
WBC Resistance to Cry1F

Year	Trmt	Plants infested (% ± se)		Kernel damage (% ± se)		Yield (T/ha ± se)
		Egg masses	Larvae (R3)	Incidence	Severity	
2011	Non-Bt	1.2 (0.52)	11.1 (4.01)	88.9 (3.16)b	3.1 (0.31)b	10.1 (1.15)
	SSX	1.0 (0.47)	10.2 (3.80	54.5 (5.45)a	1.4 (0.19)a	10.6 (1.15)
2012	Non-Bt	2.9 (1.08)	75.0 (2.85)	85.5 (7.95)	5.3 (0.63)	10.2 (1.93)
	SSX	5.6 (1.60)	67.7 (3.03)	84.5 (8.18)	6.2 (0.68)	9.5 (1.93)
2013	Non-Bt	3.4 (0.57)	71.9 (6.50)	100.0	5.3 (0.69)	6.6 (1.08)
	SSX	4.2 (0.63)	52.9 (7.25)	100.0	7.9 (0.53)	7.3 (1.08)
2014	Non-Bt	16.0 (1.82)	35.6 (8.91)b	47.9 (7.55)	2.4 (0.45)	6.3 (0.47)
	SSX	19.9 (2.13)	6.1 (3.69)a	50.0 (7.56)	2.5 (0.46)	6.6 (0.47)
	SSX RA	23.1 (2.35)	12.3 (5.30)a	56.3 (7.50)	2.7 (0.50)	6.1 (0.47)

Smith et al. 2017 JEE 110(5): 2217-2228

2016, southcentral MI
WBC infested Cry1F fields



John Obermeyer, IPM Specialist, Purdue University
"No western bean cutworm control in this Cry1F-expressing corn"

Dr. Andy Michel, Ohio State: "Just plain ugly"

C. Difonzo, MSU, 2017

Vip3A and WBC

- Likely high dose for 1st instars
- Likely not high dose for 3rd and 5th instars

Collection	Instar	n	Slope ± SE	LC_{50} (95% CI)	LC_{99} (95% CI)	X^2	TR_{50}	TR_{99}
Middlesex F_4	1st	504	2.17 (0.291)	25.0 (20.7-29.3)b	180.5 (130.5-291.3)b	9.78	.	.
	3rd	480	2.47 (0.330)	3433 (2251-4539)a	29977 (21910-48861)a	7.78	137	166
	5th	336	2.11 (0.255)	4058 (2559-5496)a	42915 (28794-83197)a	20.27	162	238
Norfolk F_2	1st	432	2.76 (0.359)	46.3 (36.3-55.8)b	322.1 (226.8-566.5)b	13.62	.	.
	3rd	432	2.38 (0.301)	3583 (2957-4216)a	24597 (17889-39378)a	12.11	77	76
	5th	288	2.23 (0.322)	2678 (1617-3812)a	29579 (18969-60206)a	12.25	58	92

Farhan et al. 2017. JEE 111(9): 65-71 Farhan et al. 2019. JEE 112(5): 2335-2344

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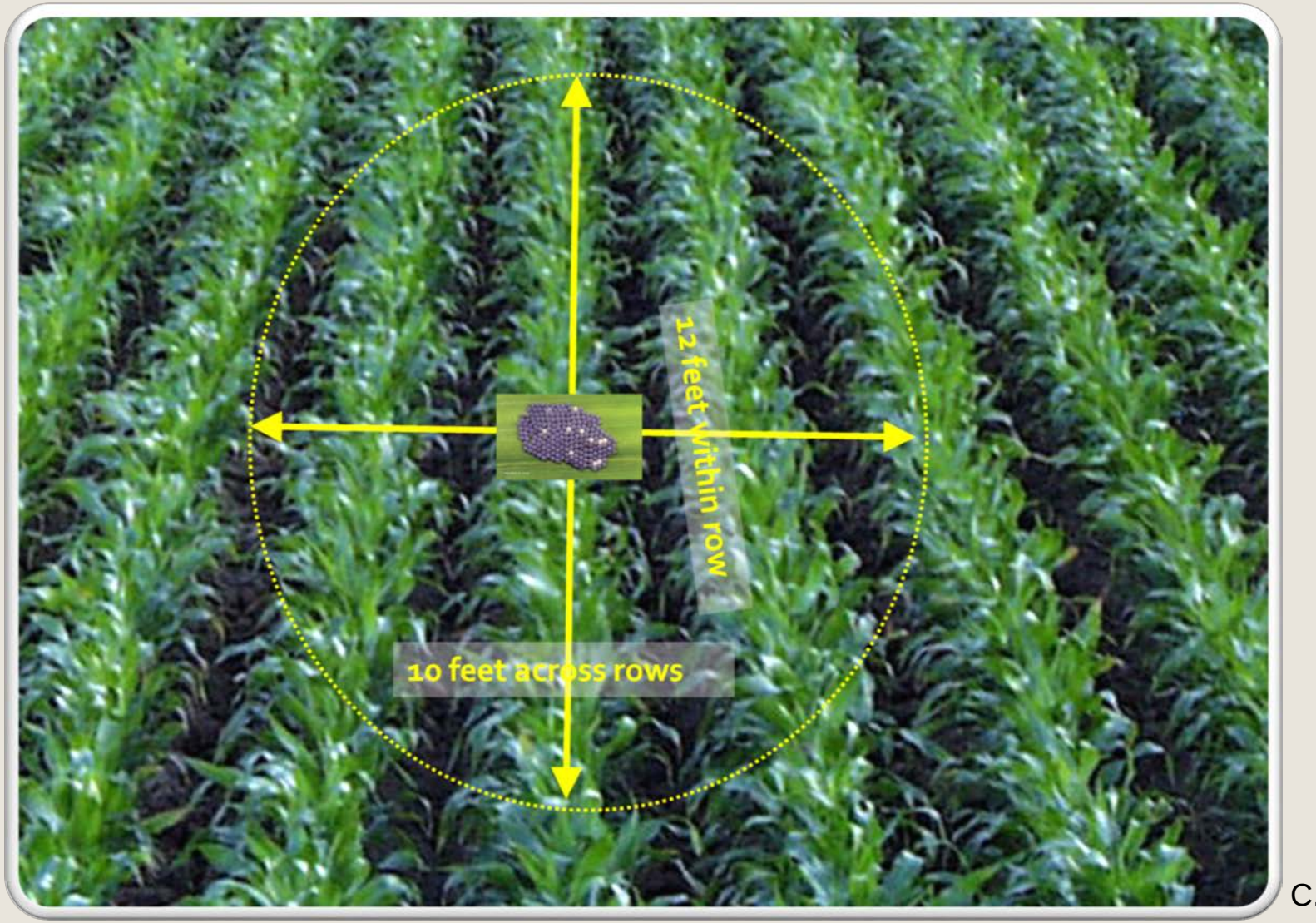
Inter-plant movement up to 3.5 m in any direction from natal plant (Pannuti et al. 2016)



C. DiFonzo, MSU

Manage WBC and Prevent Resistance

▪ROTATE WBC CONTROL OPTIONS YEARLY

•Insecticides and Vip3a corn

- Pyrethroids (Group 3)
  - Matador (lamba-cyhalothrin)
  - Decis (dimethoate)
- Diamides (Group 28)
  - Coragen (chlorantraniliprole)
- Spinosyns (Group 5)
  - Delegate (Spinetoram)
- Pre-mix of Groups 3 & 28
  - Voliam Xpress (lamba-cyhalothrin + chlorantraniliprole)

▪Monitor for unexpected damage by WBC in late August

Bt toxins for control of Lepidoptera

TARGET PEST	EFFECTIVE	INEFFECTIVE	FUTURE TOXINS
EUROPEAN CORN BORER	Cry1Ab Cry1F Cry1A.105 x Cry2Ab2	Vip3A	Unknown… 10 yrs +
WESTERN BEAN CUTWORM	Vip3A	Cry1Ab Cry1F Cry1A.105 x Cry2Ab2	Unknown… 10 yrs +
CORN EARWORM	Vip3A	Cry1Ab Cry1F Cry1A.105 x Cry2Ab2*	Unknown… 10 yrs +

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Growing Forward
A federal-provincial-territorial initiative

Grain Farmers of Ontario