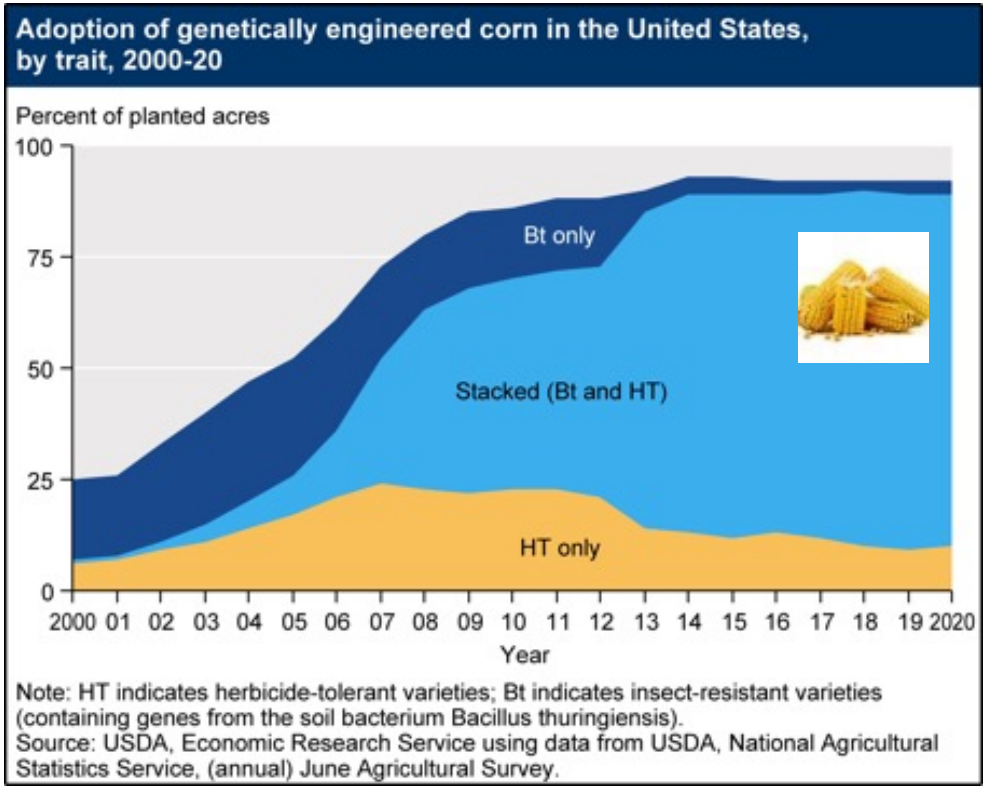
New corn traits for 2022:
What do they mean for resistance management?

Christian Krupke
PURDUE
UNIVERSITY

Most corn is Bt corn, targeting all key pests

- Approximately 85% of corn expresses Bt toxins
- Very few single-trait varieties (i.e. usually several stacked traits)
- Virtually **all** corn seeds are treated with at least one neonicotinoid seed treatment (NST)



Living in a Bt corn world: Pros

- Reduced overall use of some older, more toxic (to vertebrates) insecticide classes
- High selectivity
- Worker exposure to toxic chemicals reduced

Living in a Bt corn world: Cons

- Limited options, limited variability = constant selection pressure, resistance risks are high, especially for low dose toxins

Fall Armyworm*

*Dr. Kelley Tilmon, OSU “Insects Are Full of Surprises: Field Crop Gotchas in 2021”
Wednesday, Dec. 15 at 8AM and 1PM

The Handy Bt Trait Table for U.S. Corn Production, updated February 2021

Trait packages in alphabetical order (acronym that may be used)	**Bt protein(s) (or other trait) in package**	Marketed for control of:										Resistance confirmed to the combination of Bts in package (check local situation)	Herbicide trait			Non-Bt Refuge % (cornbelt)
		BCW	CEW	ECB	FAW	SB	SCB	SWB	TAW	WBC	CR		GR	LL	E	
AcreMax (AM)	Cry1Ab Cry1F	x	x	x	x	x	x	x				CEW FAW WBC	x	x		5% in bag
AcreMax CRW (AMRW)	Cry34/35Ab1										x	NCR WCR	x	x		10% in bag
AcreMax1 (AM1)	Cry1F Cry34/35Ab1	x		x	x	x	x	x			x	ECB FAW SWB WBC NCR WCR	x	x		10% in bag 20% ECB
AcreMax Leptra (AML)	Cry1Ab Cry1F Vip3A	x	x	x	x	x	x	x	x	x			x	x		5% in bag
AcreMax TRIsect (AMT)	Cry1Ab Cry1F mCry3A	x	x	x	x	x	x	x			x	CEW FAW WBC WCR	x	x		10% in bag
AcreMax Xtra (AMX)	Cry1Ab Cry1F Cry34/35Ab1	x	x	x	x	x	x	x			x	CEW FAW WBC NCR WCR	x	x		10% in bag
AcreMax Xtreme (AMXT)	Cry1Ab Cry1F mCry3A Cry34/35Ab1	x	x	x	x	x	x	x			x	CEW FAW WBC WCR	x	x		5% in bag
Agrisure 3010 (BR)	Cry1Ab		x	x			x	x				CEW	x	x		20%
Agrisure 3000GT & 3011A	Cry1Ab mCry3A		x	x			x	x			x	CEW WCR	x	x		20%
Agrisure Viptera 3110 (VR)	Cry1Ab Vip3A	x	x	x	x	x	x	x	x	x			x	x		20%
Agrisure Viptera 3111 (A4)	Cry1Ab Vip3A mCry3A	x	x	x	x	x	x	x	x	x	x	WCR	x	x		20%
Agrisure 3120 E-Z Refuge (BZ)	Cry1Ab Cry1F	x	x	x	x	x	x	x				CEW FAW WBC	x	See bag tag. EZ0 = no EZ		5% in bag
Agrisure 3122 E-Z Refuge	Cry1Ab Cry1F mCry3A Cry34/35Ab1	x	x	x	x	x	x	x			x	CEW FAW WBC WCR	x			5% in bag
Agrisure Viptera 3220 E-Z (VZ)	Cry1Ab Cry1F Vip3A	x	x	x	x	x	x	x	x	x			x			5% in bag
Agrisure Viptera 3330 E-Z	Cry1Ab Vip3A Cry1A.105/Cry2Ab2	x	x	x	x	x	x	x	x	x			x			5% in bag
Agrisure Duracade 5122 E-Z (D1)	Cry1Ab Cry1F mCry3A eCry3.1Ab	x	x	x	x	x	x	x			x	CEW FAW WBC WCR	x			5% in bag

The Handy Bt Trait Table

for U.S. Corn Production

Updated February 2020

The newest version of the table is posted at https://www.texasinsects.org/bt-corn-trait-table.html

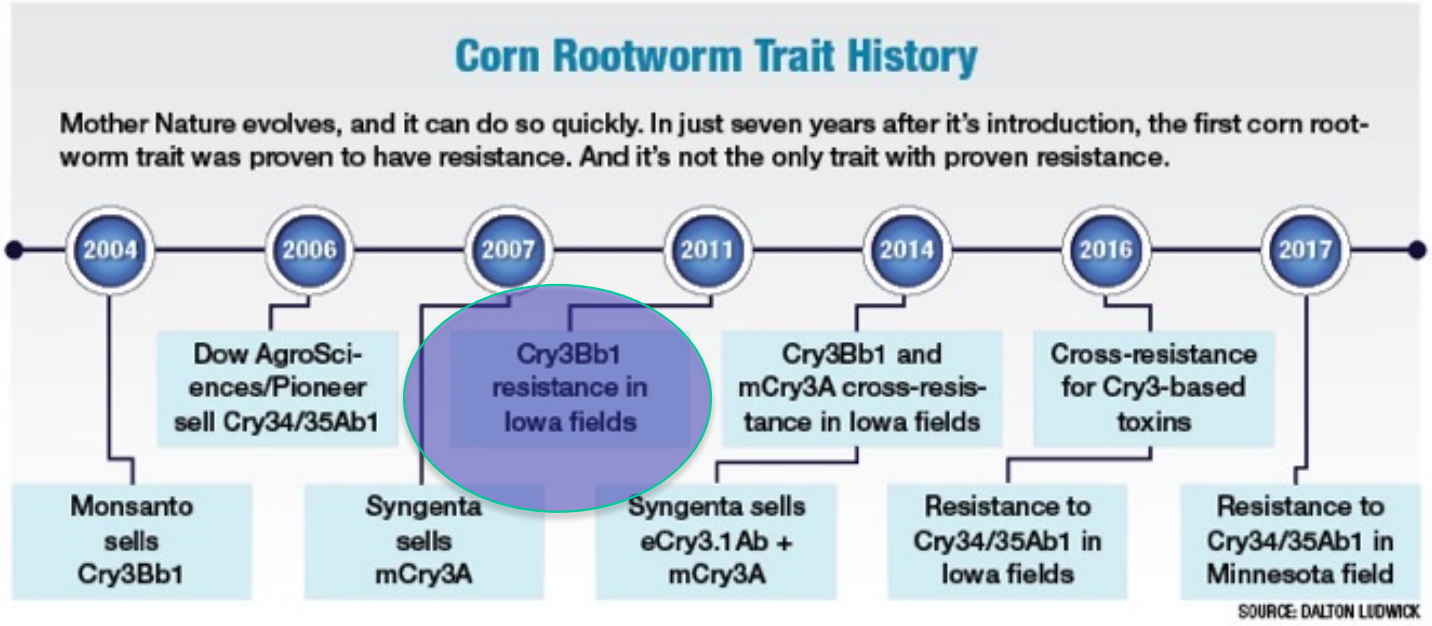
Editor: Chris DiFonzo, Michigan State University, difonzo@msu.edu Web host: Pat Porter, Texas A&M University

- Resistance to traits is common in US corn production
- Vip3a trait stands alone vs. corn ear feeders (caterpillars) in many regions
- No reliable rootworm control with traits in parts of IA, MN, NE etc.
- BUT… still satisfactory in most of IL, and eastward
- Rotation of crops, and technologies, is key

The Handy Bt Trait Table for U.S. Corn Production, updated February 2020

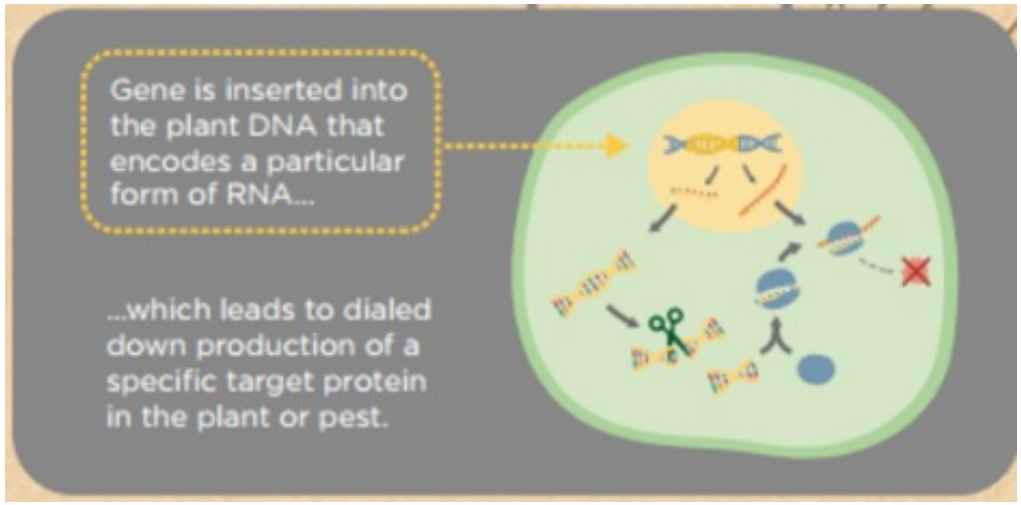
Trait packages in alphabetical order (acronym that may be used)	Bt protein(s) in the trait package	Marketed for control of: BCW	CEW	ECB	FAW	SCB	SWB	TAW	WBC	CR	Resistance confirmed to the combination of Bts in package (check local situation)	Herbicide Trait GR	LL	E	Non-Bt Refuge % (cornbelt)
AcreMax (AM)	Cry1Ab Cry1F	x	x	x	x	x	x				CEW FAW WBC	x	x		5% in bag
AcreMax CRW (AMRW)	Cry34/35Ab1									x	NCR WCR	x	x		10% in bag
AcreMax1 (AM1)	Cry1F Cry34/35Ab1	x		x	x	x	x			x	ECB FAW SWB WBC NCR WCR	x	x		10% in bag 20% ECB
AcreMax Leptra (AML)	Cry1Ab Cry1F Vip3A	x	x	x	x	x	x	x	x			x	x		5% in bag
AcreMax TRIsect (AMT)	Cry1Ab Cry1F mCry3A	x	x	x	x	x	x			x	CEW FAW WBC WCR	x	x		10% in bag
AcreMax Xtra (AMX)	Cry1Ab Cry1F Cry34/35Ab1	x	x	x	x	x	x			x	CEW FAW WBC NCR WCR	x	x		10% in bag
AcreMax Xtreme (AMXT)	Cry1Ab Cry1F mCry3A Cry34/35Ab1	x	x	x	x	x	x			x	CEW FAW WBC WCR	x	x		5% in bag
Agrisure 3010 (BR)	Cry1Ab		x	x		x	x				CEW	x	x		20%
Agrisure 3000GT & 3011A	Cry1Ab mCry3A		x	x		x	x			x	CEW WCR	x	x		20%
Agrisure Viptera 3110 (VR)	Cry1Ab Vip3A	x	x	x	x	x	x	x	x			x	x		20%
Agrisure Viptera 3111 (A4)	Cry1Ab Vip3A mCry3A	x	x	x	x	x	x	x	x	x	WCR	x	x		20%
Agrisure 3120 E-Z Refuge (BZ)	Cry1Ab Cry1F	x	x	x	x	x	x				CEW FAW WBC	x			5% in bag
Agrisure 3122 E-Z Refuge	Cry1Ab Cry1F mCry3A Cry34/35Ab1	x	x	x	x	x	x			x	CEW FAW WBC WCR	x			5% in bag
Agrisure Viptera 3220 E-Z (VZ)	Cry1Ab Cry1F Vip3A	x	x	x	x	x	x	x	x			x			5% in bag
Agrisure Viptera 3330 E-Z	Cry1Ab Vip3A Cry1A.105/Cry2Ab2	x	x	x	x	x	x	x	x			x			5% in bag
Agrisure Duracade 5122 E-Z (D1)	Cry1Ab Cry1F mCry3A eCry3.1Ab	x	x	x	x	x	x			x	CEW FAW WBC WCR	x			5% in bag
Agrisure Duracade 5222 E-Z (D2)	Cry1Ab Cry1F Vip3A mCry3A eCry3.1Ab	x	x	x	x	x	x	x	x	x	WCR	x			5% in bag
Herculex I (HX)	Cry1F	x		x	x	x	x				ECB FAW SWB WBC	x	x		20%
Herculex RW (HXRW)	Cry34/35Ab1									x	NCR WCR	x	x		20%
Herculex XTRA (HXX)	Cry1F Cry34/35Ab1	x		x	x	x	x			x	ECB FAW SWB WBC NCR WCR	x	x		20%
Intrasect (YHR)	Cry1Ab Cry1F	x	x	x	x	x	x				CEW FAW WBC	x	x		5%
Intrasect TRIsect (CYHR)	Cry1Ab Cry1F mCry3A	x	x	x	x	x	x			x	CEW FAW WBC WCR	x	x		20%
Intrasect Xtra (YXR)	Cry1Ab Cry1F Cry34/35Ab1	x	x	x	x	x	x			x	CEW FAW WBC NCR WCR	x	x		20%
Intrasect Xtreme (CYXR)	Cry1Ab Cry1F mCry3A Cry34/35Ab1	x	x	x	x	x	x			x	CEW FAW WBC WCR	x	x		5%
Leptra (VYHR)	Cry1Ab Cry1F Vip3A	x	x	x	x	x	x	x	x			x	x		5%
Powercore ® (PW)	Cry1A.105/Cry2Ab2	x	x	x	x	x	x				CEW WBC	x	x		ª 5%
PW Refuge Advanced ᵇ (PWRA)	Cry1F														ᵇ 5% in bag
Powercore Enlist (PWE)	Same as Powercore	x	x	x	x	x	x				Same as Powercore	x	x	x	5% in bag
QROME (Q)	Cry1Ab Cry1F mCry3A Cry34/35Ab1	x	x	x	x	x	x			x	CEW FAW WBC WCR	x	x		5% in bag
SmartStax ® (SX,STX or SS)	Cry1A.105/Cry2Ab2	x	x	x	x	x	x			x	CEW WBC	x	x		ª 5%
STX Refuge Advanced ᵇ (SXRA)	Cry1F Cry3Bb1										NCR WCR				
STX RIB Complete ᵇ (STXRIB)	Cry34/35Ab1														ᵇ 5% in bag
SmartStax Enlist (SXE)	Same as SmartStax	x	x	x	x	x	x			x	Same as SmartStax	x	x	x	5% in bag
Trecepta ® (TRE)	Cry1A.105/Cry2Ab2	x	x	x	x	x	x	x	x			x			ª 5%
Trecepta RIB Complete ᵇ (TRERIB)	Vip3A														ᵇ 5% in bag
TRIsect (CHR)	Cry1F mCry3A	x		x	x	x	x			x	ECB FAW SWB WBC WCR	x	x		20%
VT DoublePRO ® (VT2P)	Cry1A.105/Cry2Ab2		x	x	x	x	x				CEW	x			ª 5%
VT2P RIB Complete ᵇ (VT2PRIB)															ᵇ 5% in bag
VT TriplePRO ® (VT3P)	Cry1A.105/Cry2Ab2		x	x	x	x	x			x	CEW	x			ª 20%
VT3P RIB Complete ᵈ (VT3PRIB)	Cry3Bb1										NCR WCR				ᵇ 10% in bag
Yieldgard Corn Borer (YGCB)	Cry1Ab		x	x		x	x				CEW	x			20%
Yieldgard Rootworm (YGRW)	Cry3Bb1									x	NCR WCR	x			20%
Yieldgard VT Triple (VT3)	Cry1Ab Cry3Bb1		x	x		x	x			x	CEW NCR WCR	x			20%

Western corn rootworm (WCR) resistance to Bt traits since introduction




AG WEB
News Markets Weather Opinion Topics Events Video
CROP PRODUCTION
Former "Billion Dollar Bug" is Mounting a Come Back
June 2018
AG WEB
News Markets Weather Opinion Topics Events Video
CORN
SmartStax Pro Approved, Available to Plant in 2022
January 2021

SmartStax [a] (SX,STX or SS) STX Refuge Advanced [b] (SXRA) STX RIB Complete [b] (STXRIB)	Cry1A.105/Cry2Ab2 Cry1F Cry3Bb1 Cry34/35Ab1	x	x	x	x	x	x	x			x	CEW WBC NCR WCR	x	x		[a]5% [b]5% in bag
SmartStax Enlist (SXE)	Same as SmartStax	x	x	x	x	x	x	x			x	Same as SmartStax	x	x	x	5% in bag
SmartStax Pro *2022 commercialization date	Same as SmartStax + DvSnf7 dsRNA	x	x	x	x	x	x	x			x	CEW WBC	x	x		5% in bag
Trecepta [a] (TRE) Trecepta RIB Complete [b] (TRERIB)	Cry1A.105/Cry2Ab2 Vip3A	x	x	x	x	x	x	x	x	x			x			[a]5% [b]5% in bag



https://croplife.org/wp-content/uploads/2017/02/RNAi.png

RNAi: Helpful, but not "game-changing" for WCR management

- Initial trials show very low rootworm survival (similar to early days of Cry3Bb1) in the field when <u>combined</u> with existing Bt traits (will not be available on it's own)

- BUT - still not a "high dose" toxin… no reason to expect a different outcome than what we have seen with current Bt offerings

- <u>Bottom line</u>: Don't count on refuges to avoid resistance. ROTATION of crops and management approaches will be key

SmartStax Pro *2022 commercialization date	Same as SmartStax + DvSnf7 dsRNA	x	x	x	x	x	x	x			x	CEW WBC	x	x		5% in bag

Bt corn, WCR, and refuges

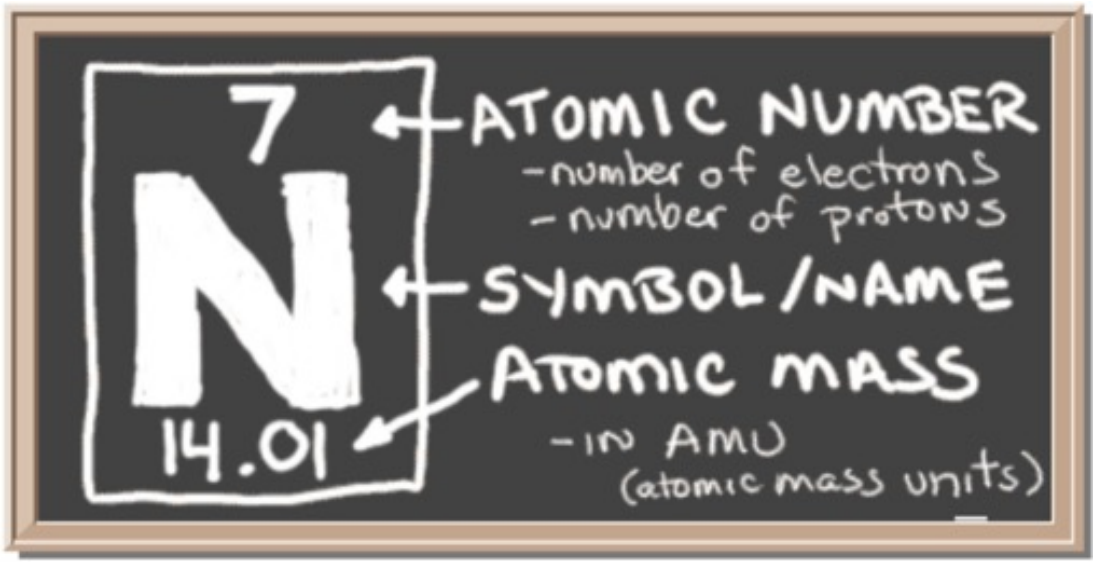
Previous research has shown: WCR from Bt and refuge plants have 1) different emergence timings, and 2) vary in size.

Hypothesis – There is limited mating between resistant and susceptible beetles in refuges.

Problem – Who mates with who, and when? Where did these adult beetles feed as larvae? A permanent mark was needed to characterize beetles…

Periodic Table Review!

^{14}N	^{15}N
14.00307	15.0001
99.63%	0.37%
Stable	Stable



BUT… Nitrogen can sometimes have 8 protons in the nucleus (atomic mass = ^{15}N) but still behaves as ^{14}N

Using stable isotopes as markers

^{15}N is found in environment, but very uncommon (^{14}N is dominant)

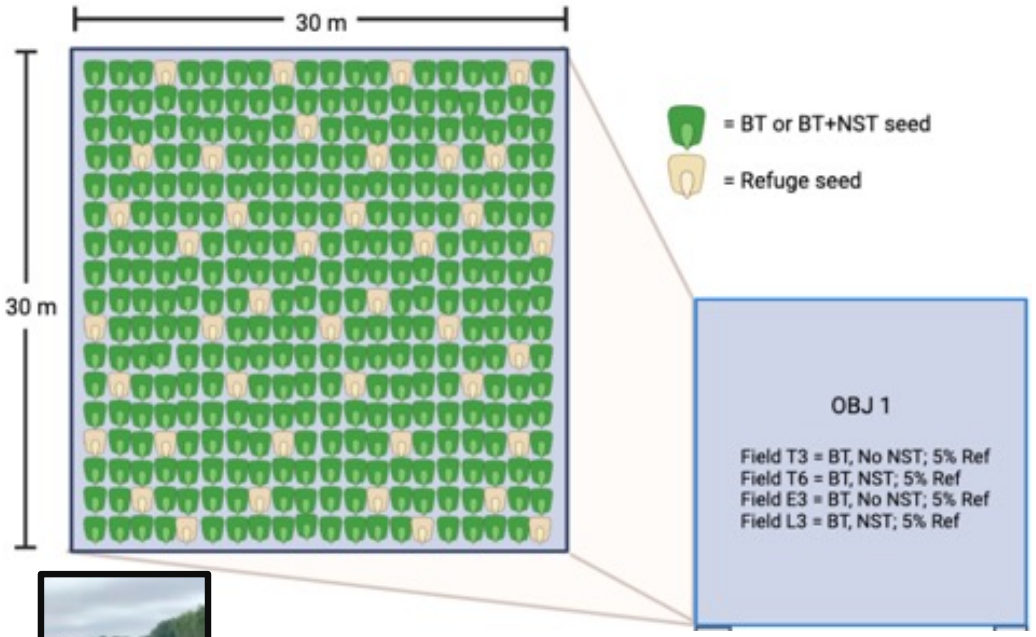
Enriching any substrate with "store-bought" ^{15}N can provide a harmless, stable and permanent marker

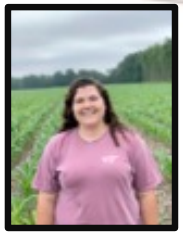
- **<u>Example</u>: ^{15}N spiked diet used to determine transfer of nitrogen from male to female to eggs (Murphy & Krupke 2011).**

Tracking WCR mating in Bt/refuge environments

Methods

- Compared two treatments:
  - Neonicotinoid treated hybrid seeds, 5% untreated Refuge (Bt+)
  - Untreated Bt seeds, 5% untreated Refuge (Bt-)
- Replicated at two field locations for two growing seasons (2019, 2020) at TPAC and PPAC

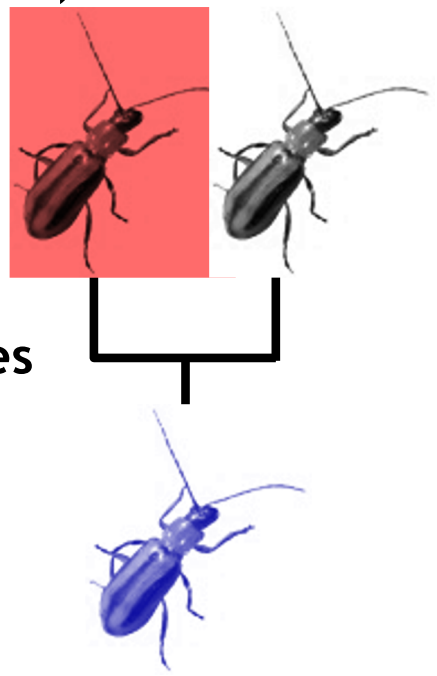




Kathleen Miller
MS 2021

Corn Rootworm
Insect Resistance Management (IRM)

- 5% Refuge is planted to provide non-Bt environment for larvae to feed and survive
  - Produces population of susceptible beetles
  - Refuge beetles theoretically mate with Bt-fed beetles to produce Bt-susceptible heterozygous offspring to delay resistance evolution
- Unknown: does the refuge corn (5%) provide enough beetles to mate with Bt-fed beetles?

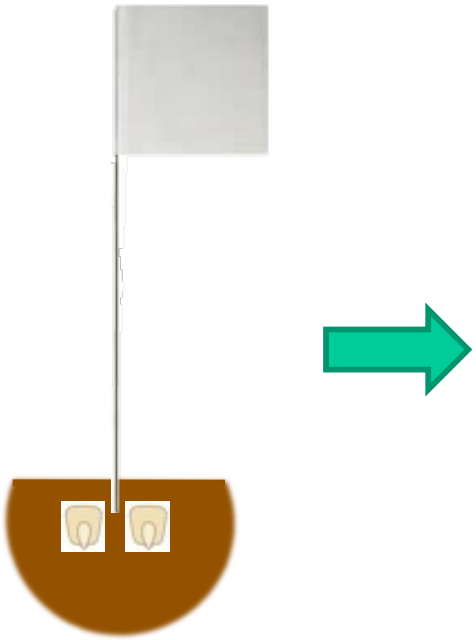


Tracking mating in Bt/refuge environments

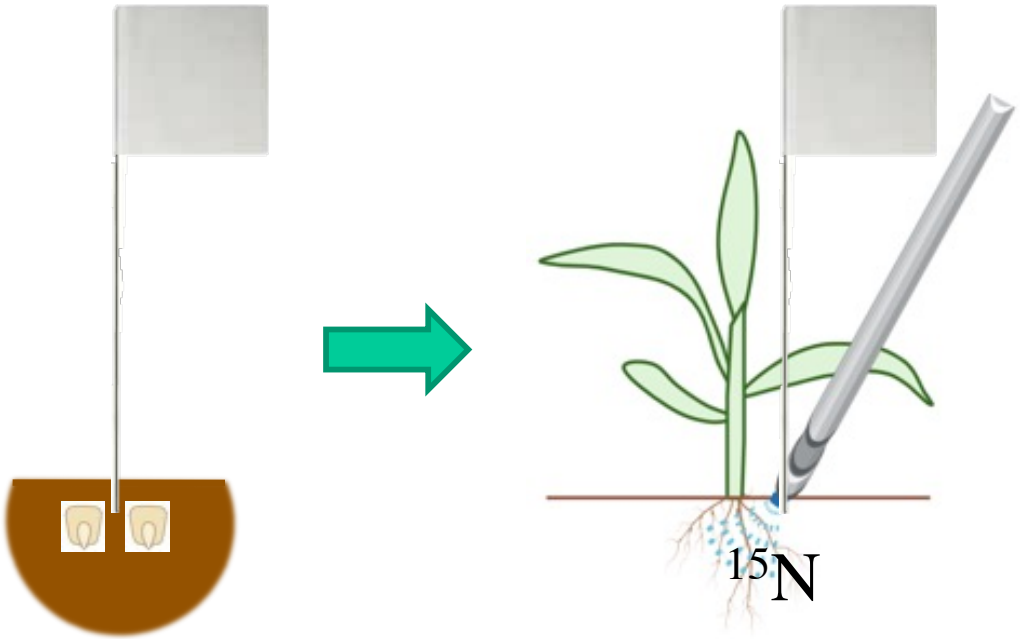
Methods

- Refuge handplanted and flagged
  - Refuge plants labeled with ^{15}N soil drench in using pressurized backpack sprayer
    - ^{15}N marked refuge-fed insects

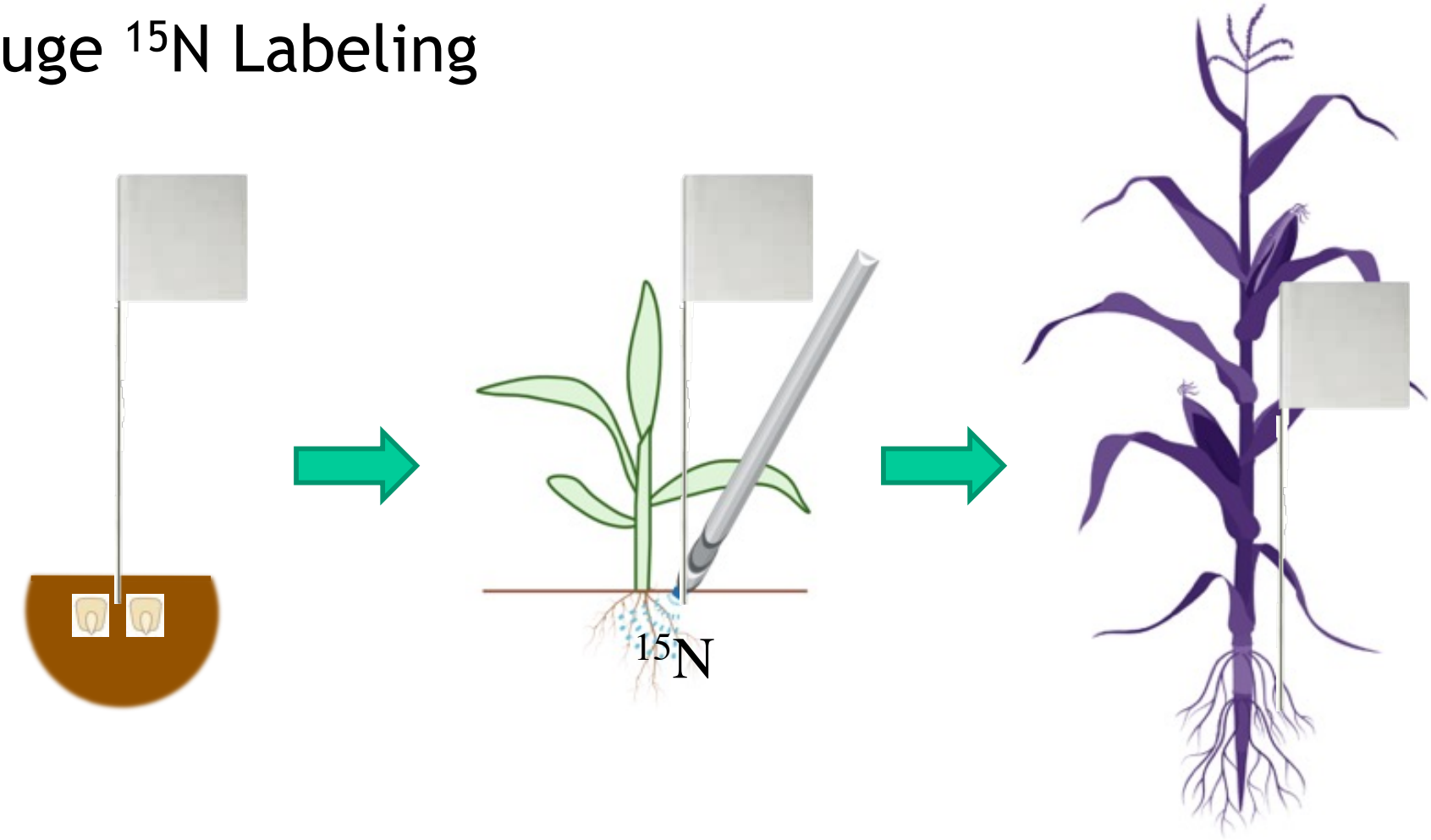
Refuge ^{15}N Labeling

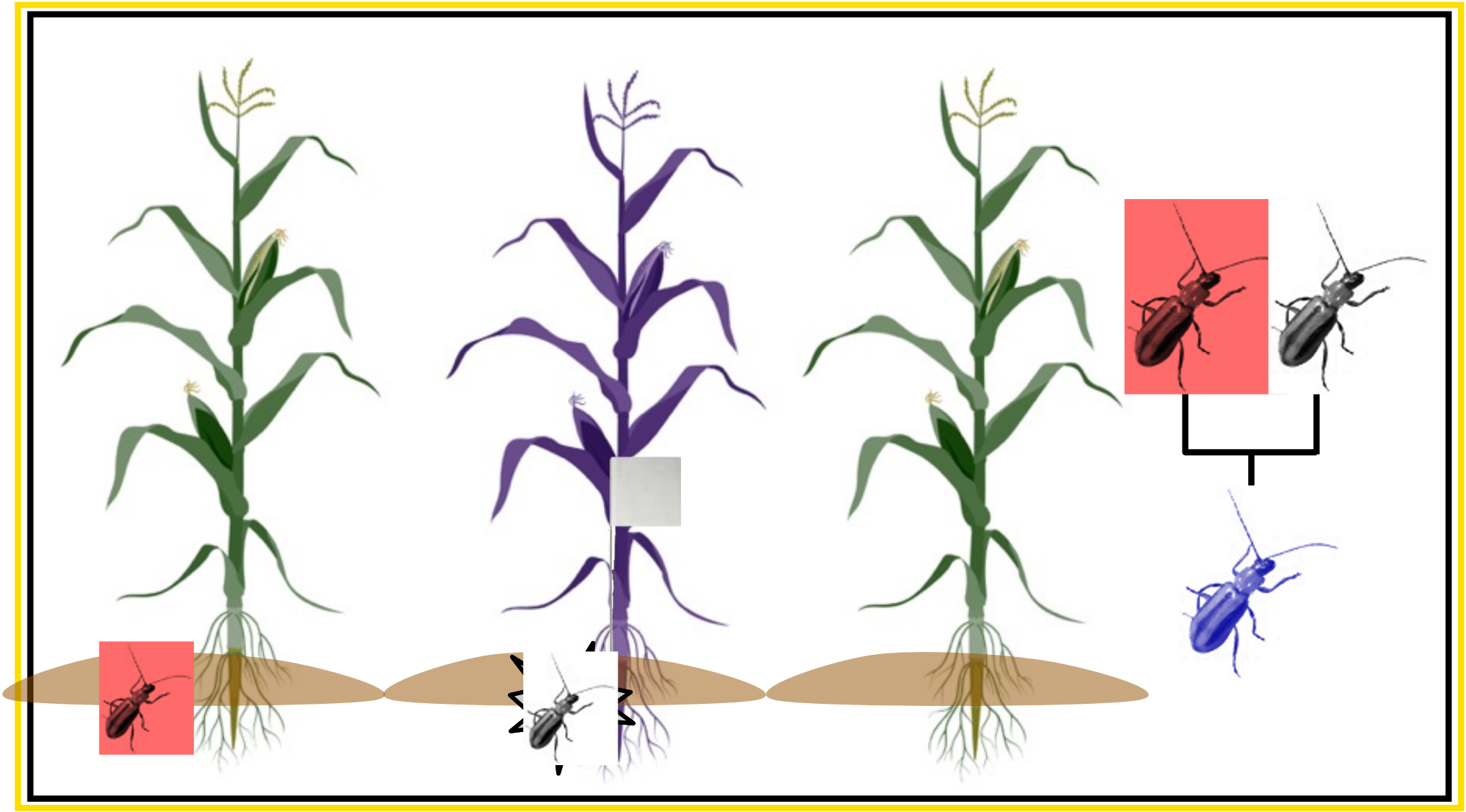


Refuge ^{15}N Labeling



Refuge ^{15}N Labeling

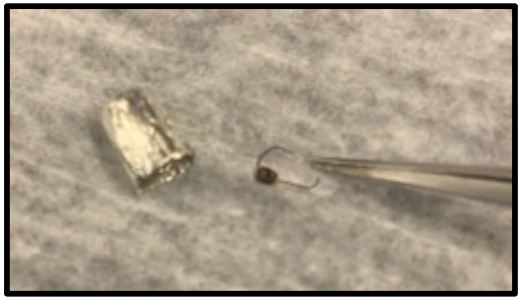




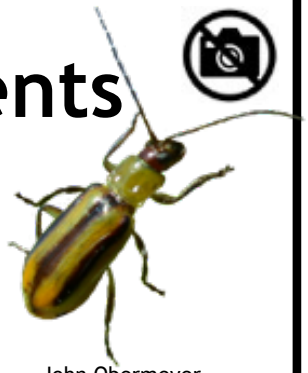
Tracking mating in Bt/refuge environments

Methods

- Beetle collection
  - 8 random rows at each field were sampled 2-3 times/week
  - Adults were collected into a 30 mL amber glass vial with a funnel attachment. Mating pairs were collected and stored together.
- Head capsule width and dry weight were recorded, and larval host identified using stable isotope testing



Tracking mating in Bt/refuge environments



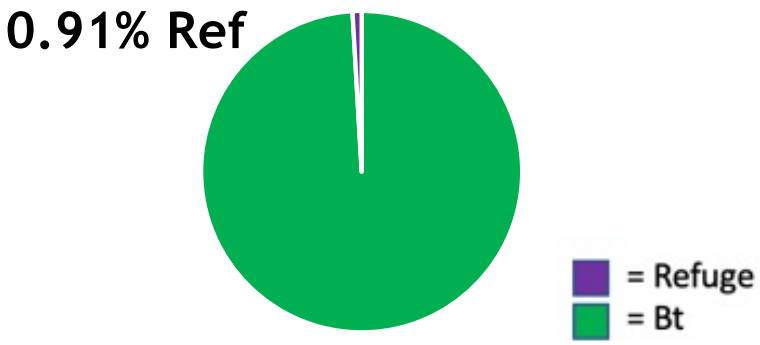
John Obermeyer

- Goal of 5% untreated refuge:
  - Produce sufficient population of refuge beetles to mate with Bt-fed beetles and delay resistance evolution

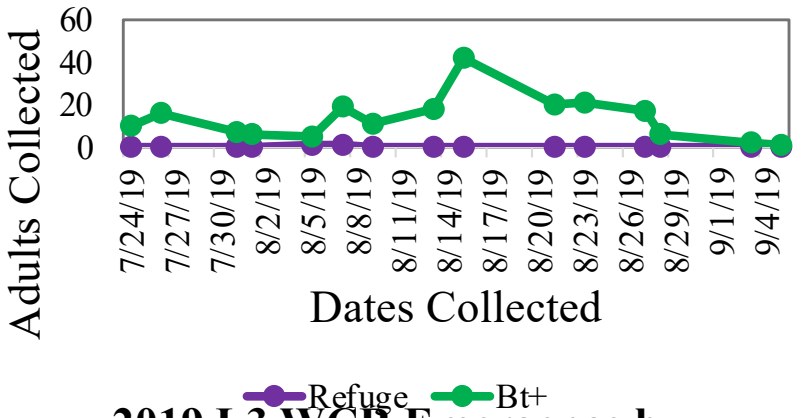
<u>Results</u>

- Adult beetle population
  - 2019: 1028 beetles
  - 2020: 2901 beetles
  - Representative sample of 493 beetles in 2019 and 594 in 2020
- Proportion of refuge beetles:
  - 2019 Bt+ fields collected 0.91% refuge beetles
  - 2019 Bt- fields collected 2.93% refuge beetles
  - 2020 Bt+ fields collected 2.86% refuge beetles
  - 2020 Bt- fields collected 4.01% refuge beetles

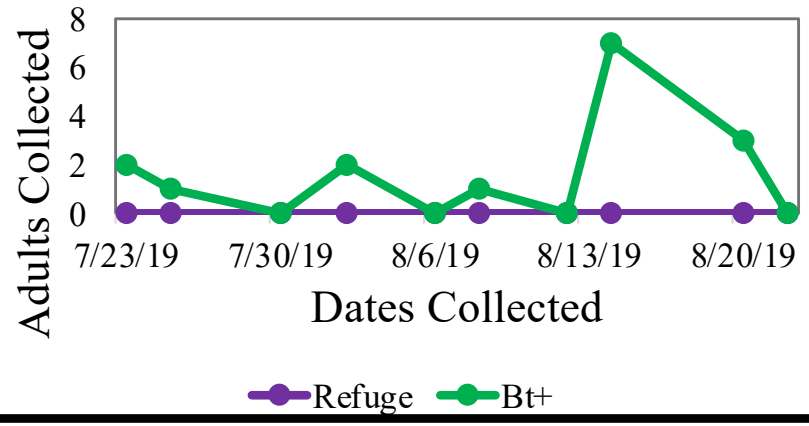
Proportion of Beetles Collected from Bt+ Plots in 2019



2019 T6 WCR Emergence by Natal Host Plant

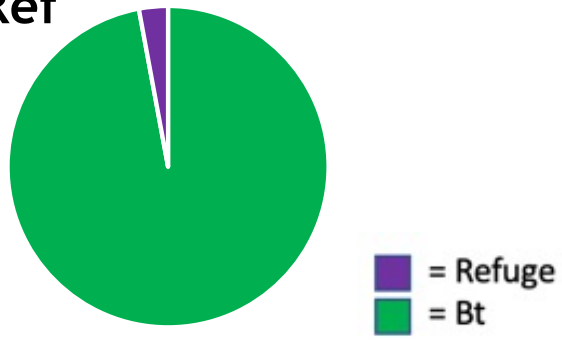


2019 L3 WCR Emergence by Natal Host Plant

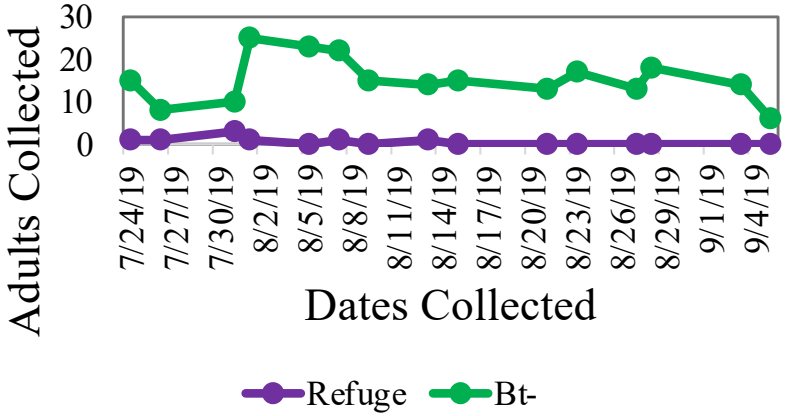


Proportion of Beetles Collected from Bt- Plots in 2019

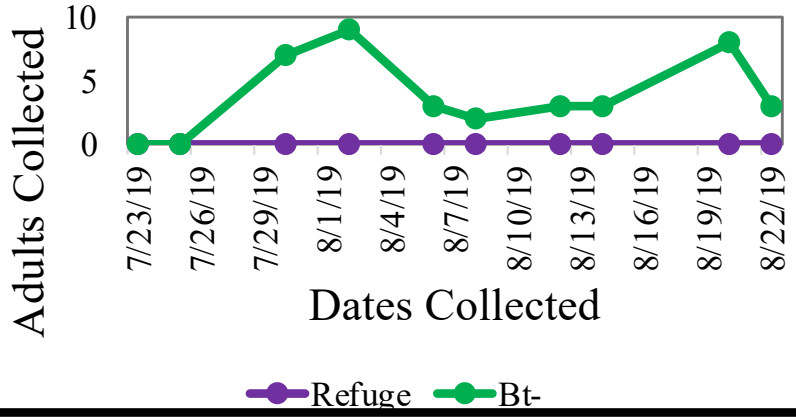
2.93% Ref



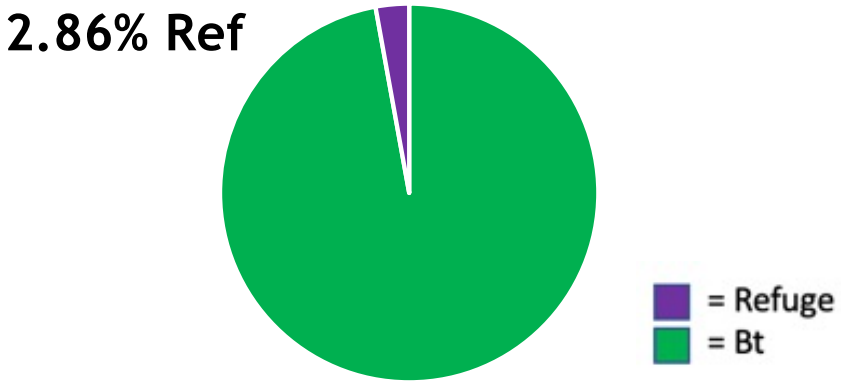
2019 T3 WCR Emergence by Natal Host Plant



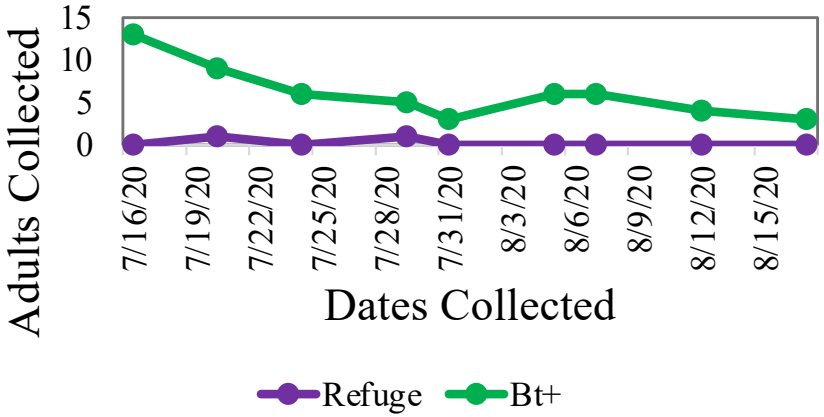
2019 E3 WCR Emergence by Natal Host Plant



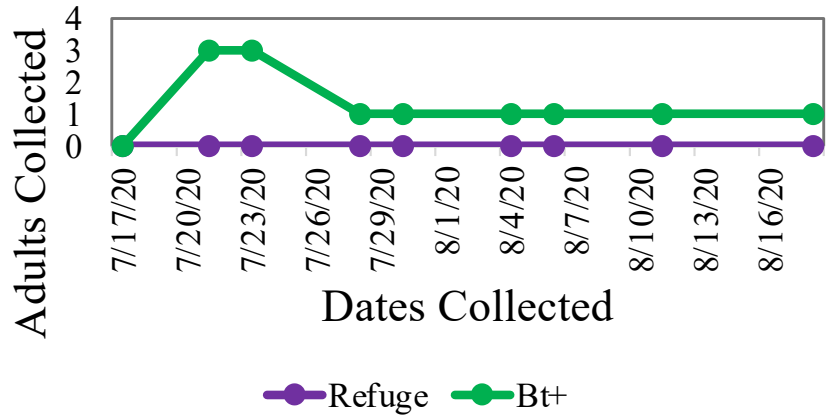
Proportion of Beetles Collected from Bt+ Plots in 2020



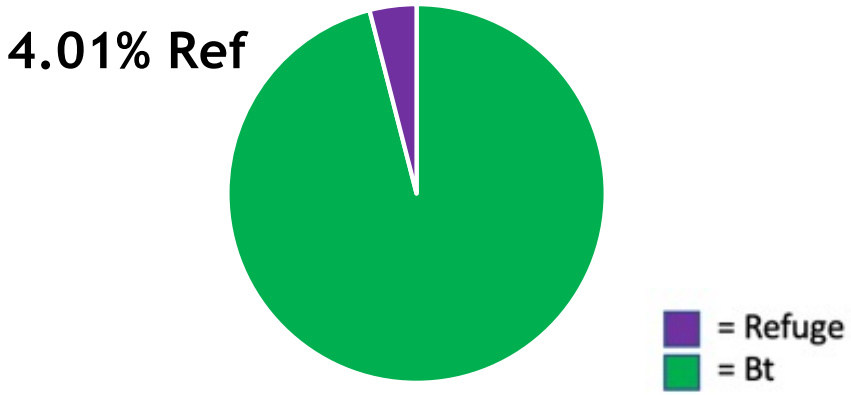
2020 T6 WCR Emergence by Natal Host Plant



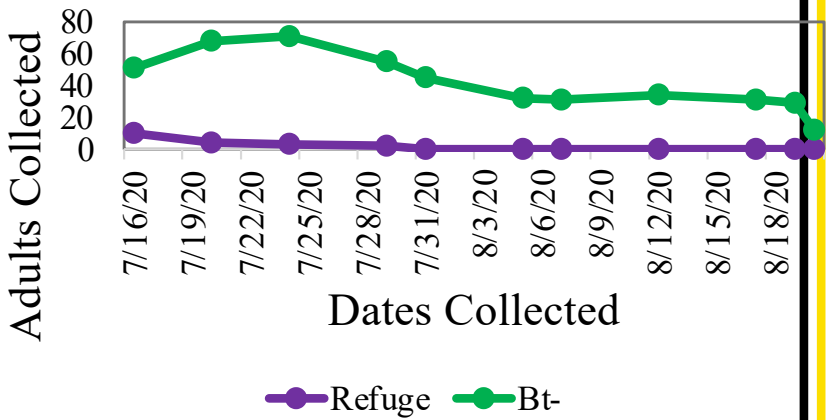
2020 L3 WCR Emergence by Natal Host Plant



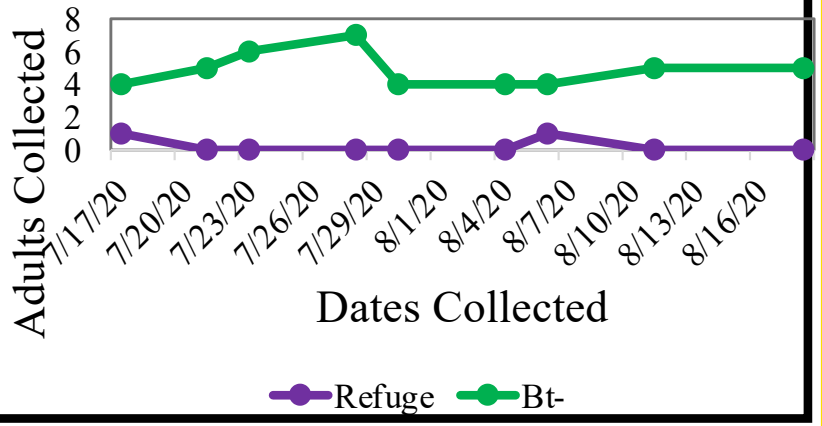
Proportion of Beetles Collected from Bt- Plots in 2020



2020 T3 WCR Emergence by Natal Host Plant



2020 E3 WCR Emergence by Natal Host Plant



Tracking mating in Bt/refuge environments

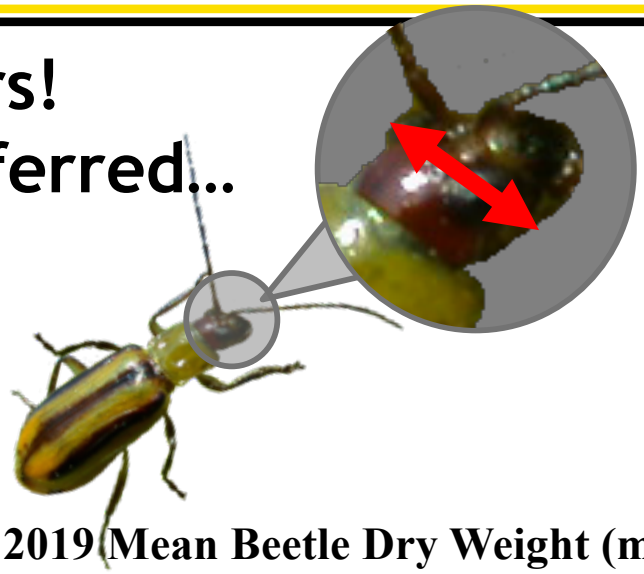
- 12 of 33 (36%) total refuge beetles collected were males
  - 2019: 4 refuge males collected, 343 Bt-emerged females collected
  - 2020: 8 refuge males collected, 335 Bt-emerged females collected

- Males mate avg 2.24 times within 10 days after first mating (Kang & Krupke, 2009)
  - 2019: ~13 (12.96) females mated by refuge males
  - 2020: ~26 (25.92) females mated by refuge males

- 330 (or 96%) in 2019 and 309 (or 92%) in 2020 of remaining Bt-emerged females to potentially mate with Bt-emerged males in these plots…

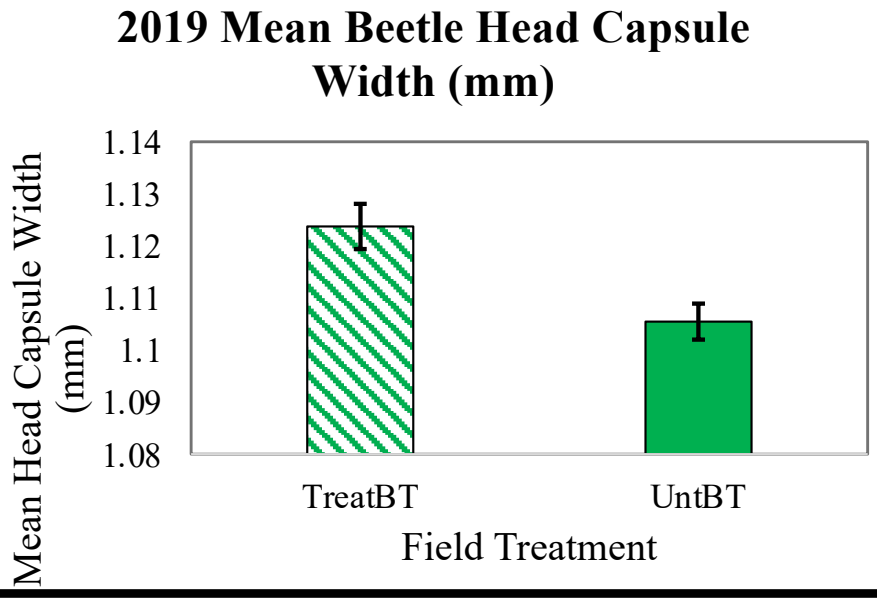
John Obermeyer

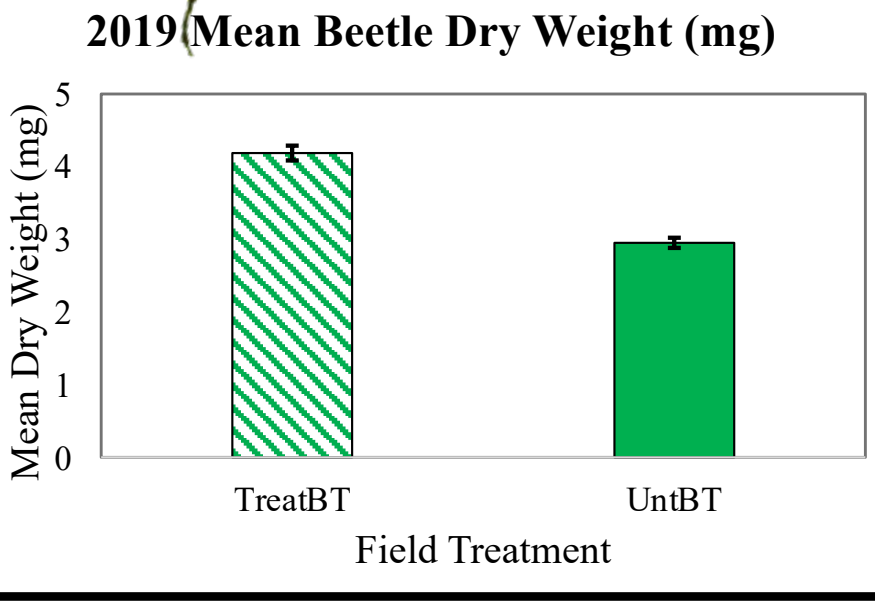
Size matters!
Large mates preferred…



Results

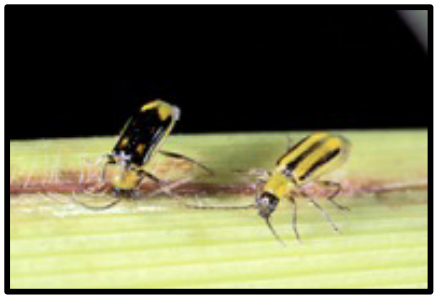
- 2019 Head capsule and dry weight
  - Significant difference in mean head capsule width and dry weight





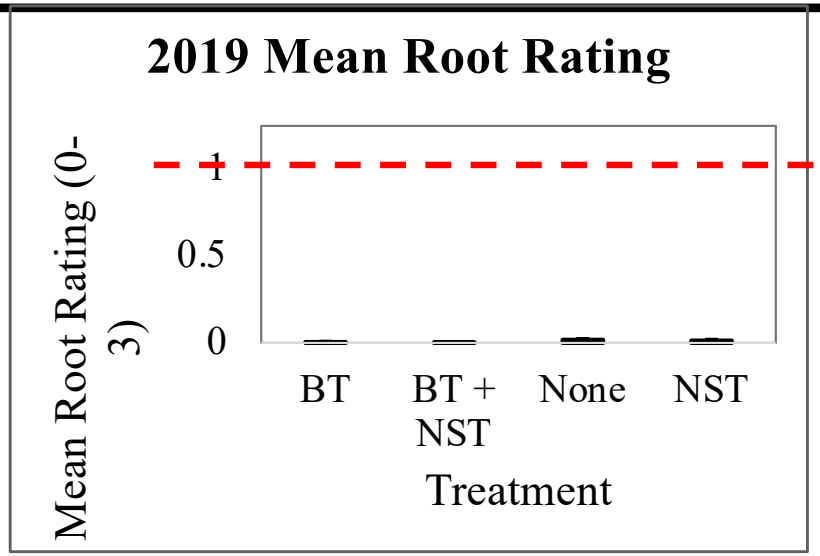
Conclusions

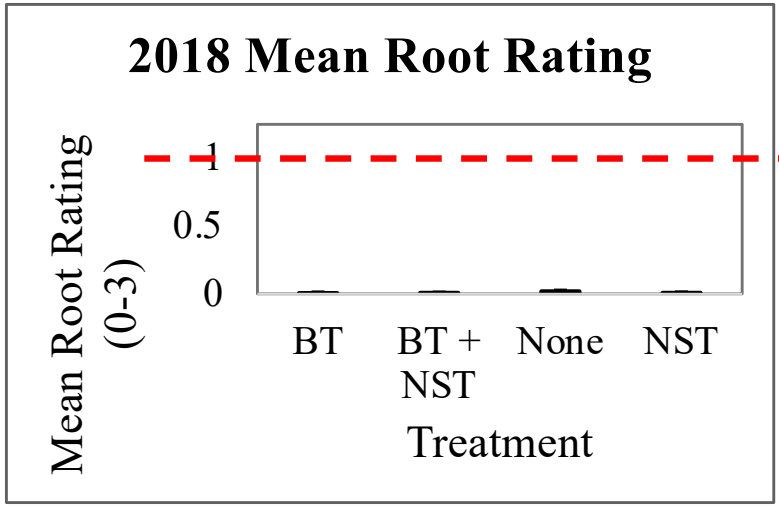
- Very low numbers of refuge beetles produced by 5% seed blend
  - Beetles developing from refuge are not doing much to delay resistance development
  - Even with an untreated (no neonicotinoid seed treatment) refuge, a sufficient population of refuge beetles was not produced
- Larger RIB refuges would facilitate greater degree of mixed matings, but not likely to happen

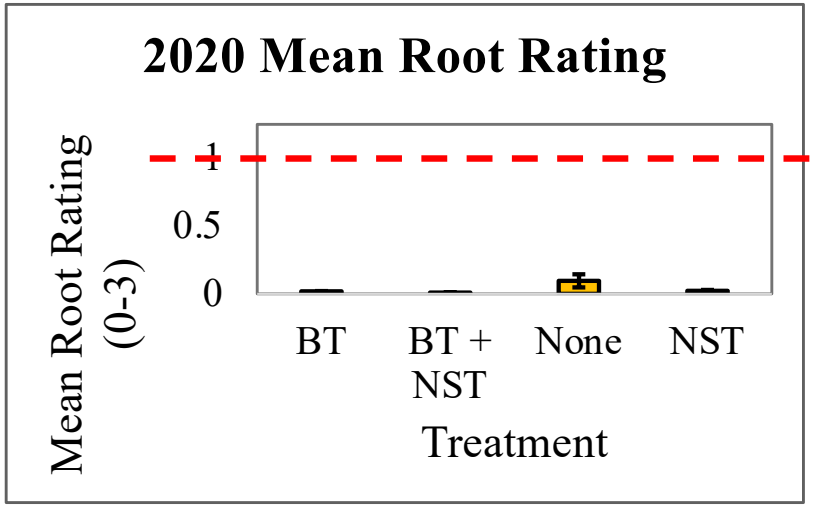


John Obermeyer

Good news - RW pressure levels

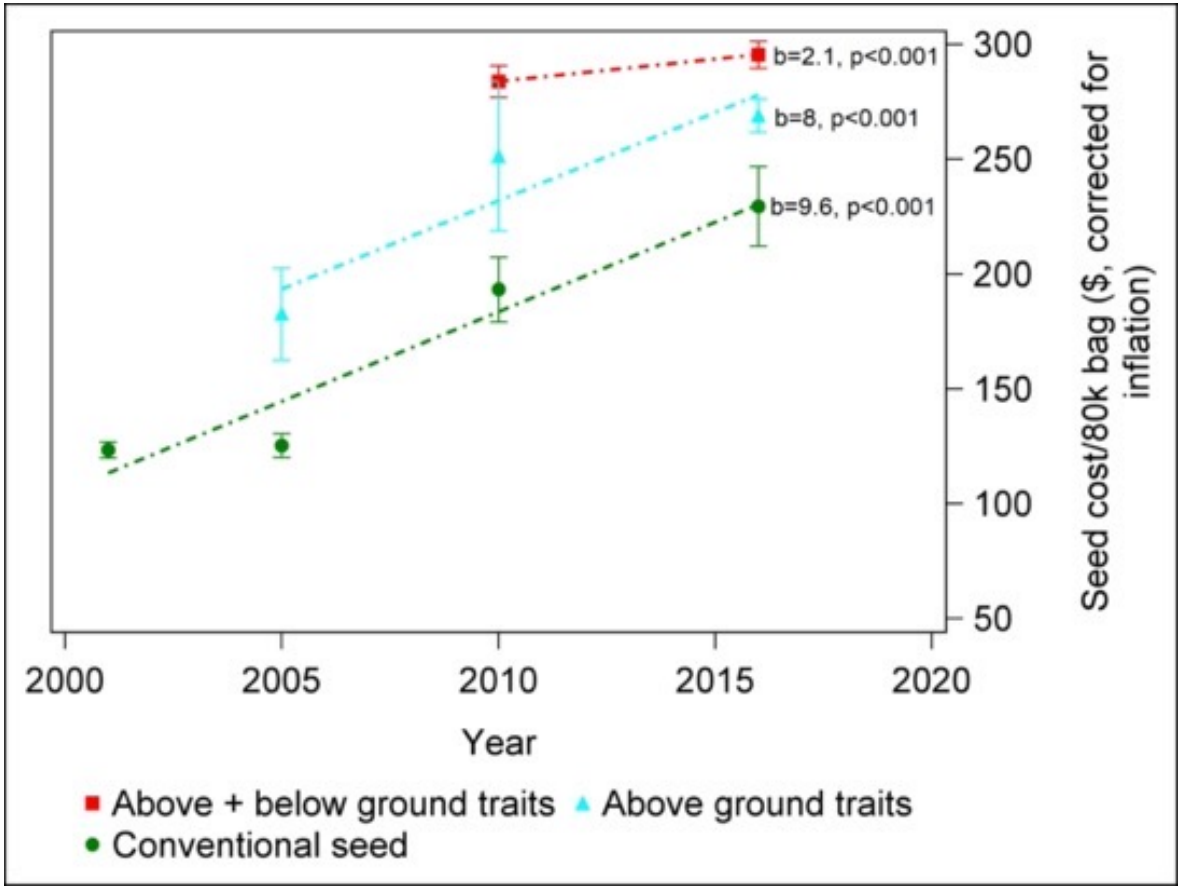




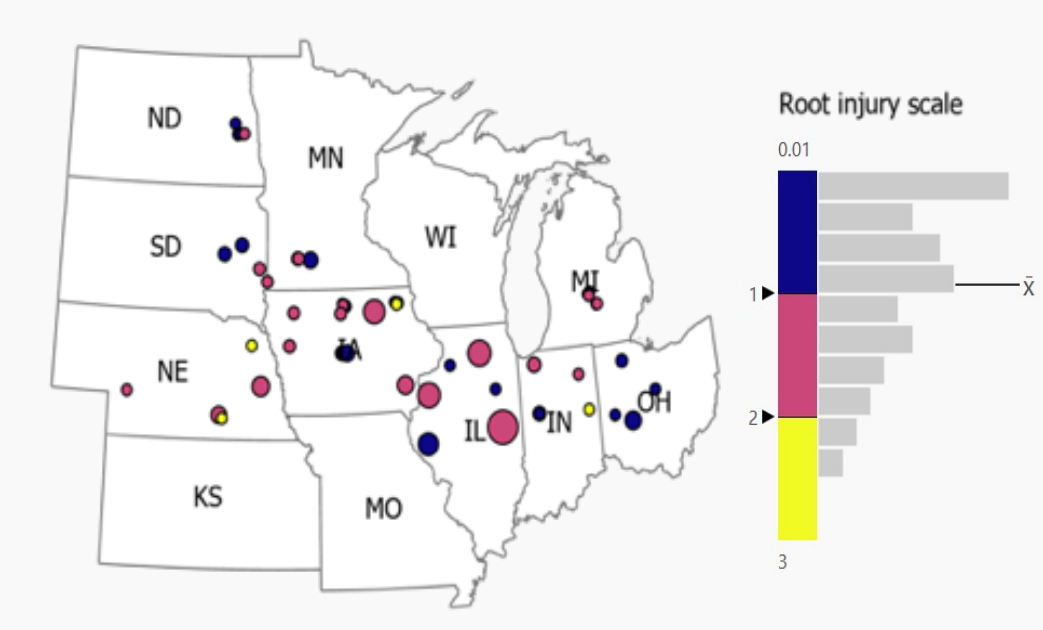


Are Bt traits still the best default option?

- Combined pricing data for traits vs. untraited corn from nine "Corn Belt" states (IA, IL, IN, MI, MN, ND, NE, OH, SD)
- Pricing data, corrected for inflation
- Take-home message: traits cost more than they used to… but is it worth it?



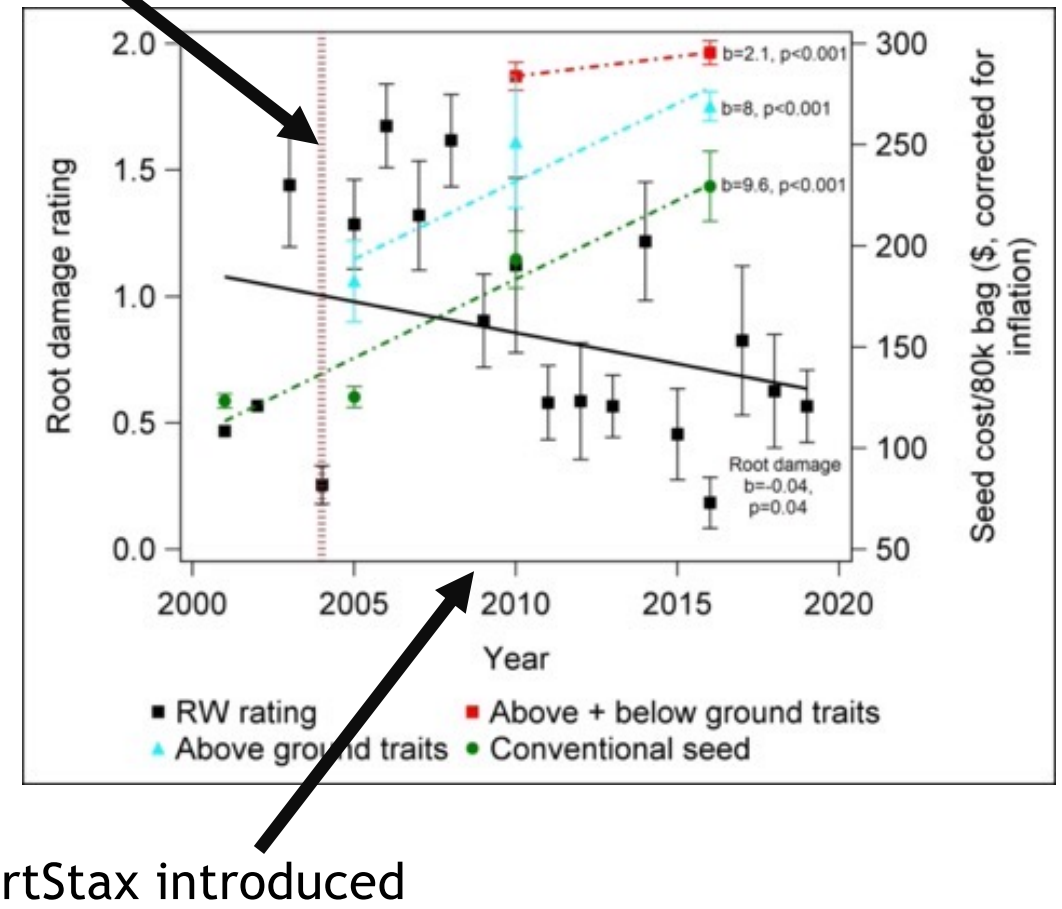
Multi-state survey of corn trap crops



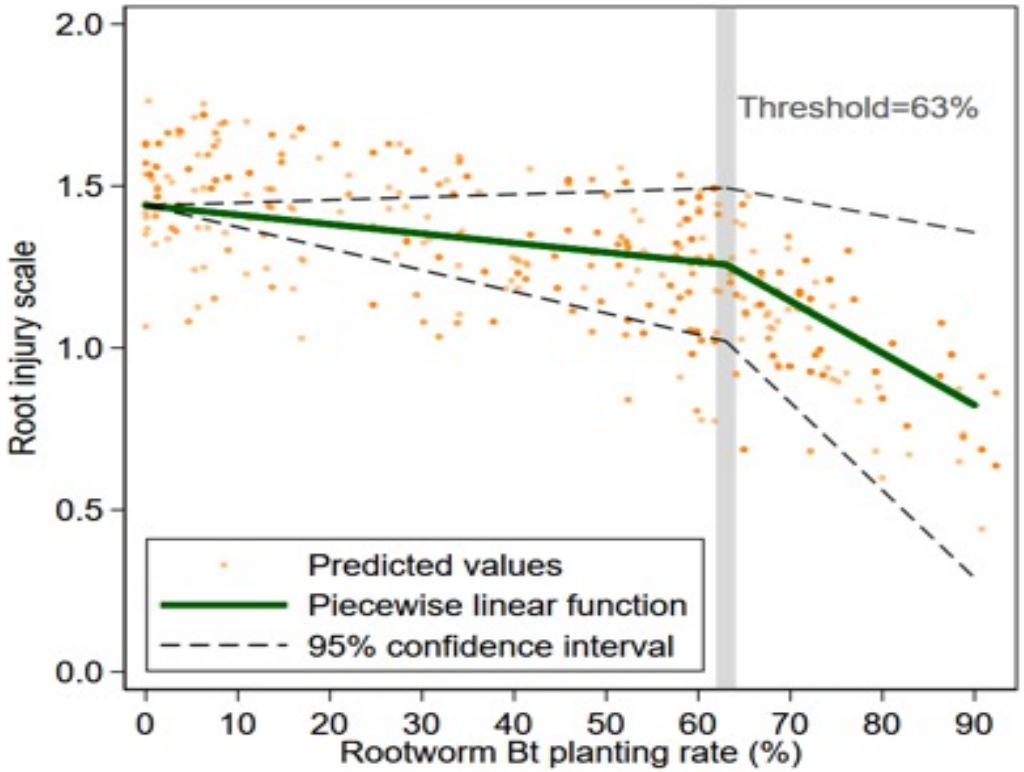
9 states, 697 observations (2003-2020)

Trait costs vs. Rootworm damage

- When root damage pressure is included, we see a negative slope across the region
- Why? Probably because of trait use, insecticide use, weather etc.
- Take-home message: for most producers, the risks from rootworm are at historic lows



Benefits from planting RW corn begin at around 60-65% adoption



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Here are the steps Take Action encourages to preserve usefulness:

- Plant the required refuge. Take into account the product and geography you're in—corn-growing states' refuge is 5% (in-bag) or 20% (structured refuge), and cotton-growing states are 20% (in-bag) and 50% (structured refuge).
- Use insect resistance management strategies: rotate crops, use pyramided traits, rotate traits and rotate and use multiple modes of action for insecticide seed treatments, soil-applied insecticides and foliar-applied insecticides.
- Actively scout to see if control methods are working, if there are escapes or possible resistance. Take additional action to control pests when necessary.

https://ncga.com/stay-informed/media/in-the-news/article/2021/06/its-time-to-take-action-during-pest-week

NATIONAL CORN GROWERS ASSOCIATION

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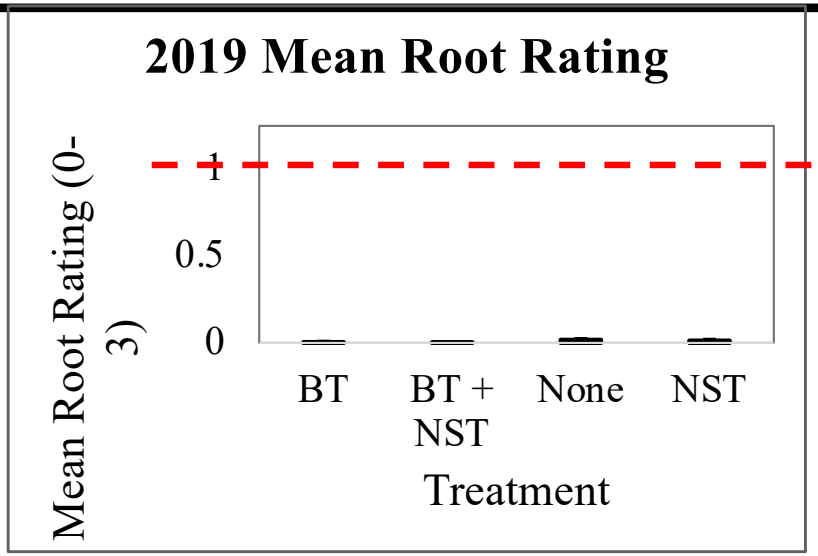
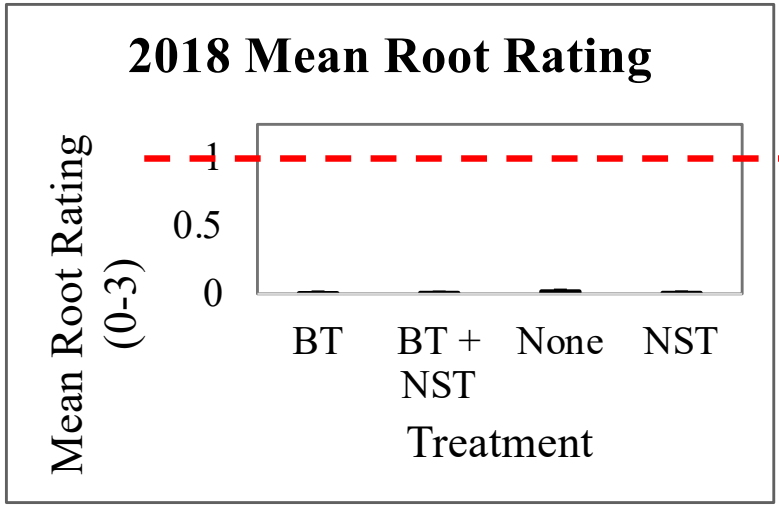
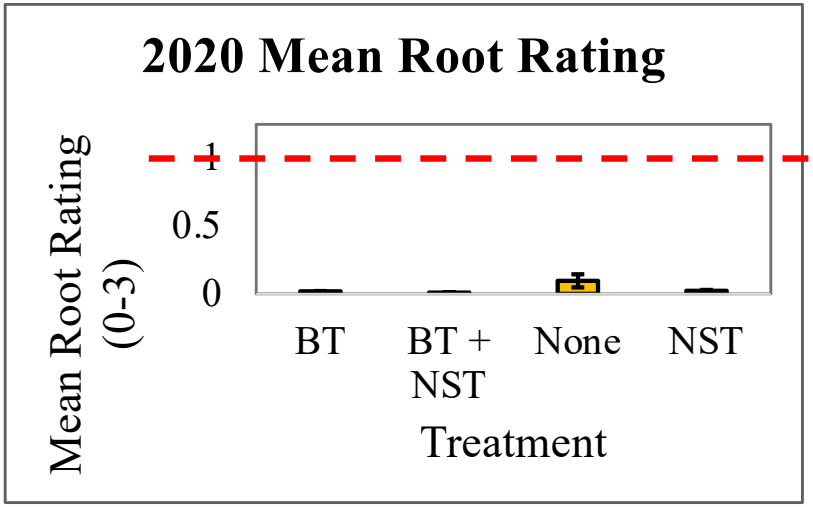
https://ncga.com/stay-informed/media/in-the-news/article/2021/06/its-time-to-take-action-during-pest-week

There may be another option…

RW pressure levels, again







-3 year study, continuous corn at 3 IN locations
-low pest pressures/damage, some RW pressure in year 3, but not yield differences

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BRITISH ECOLOGICAL SOCIETY

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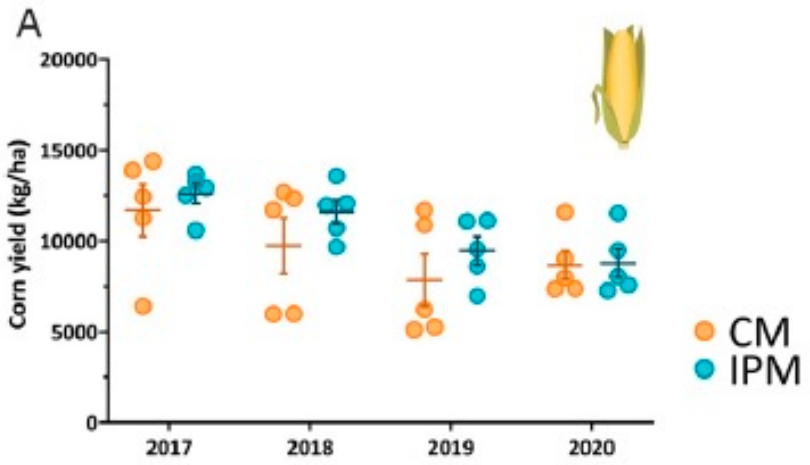
Planting of neonicotinoid-treated maize poses risks for honey bees and other non-target organisms over a wide area without consistent crop yield benefit

C. H. Krupke, J. D. Holland, E. Y. Long, B. D. Eitzer

First published:22 May 2017 | https://doi.org/10.1111/1365-2664.12924 | Citations: 30



IPM reduces insecticide applications by 95% while maintaining or enhancing crop yields through wild pollinator conservation

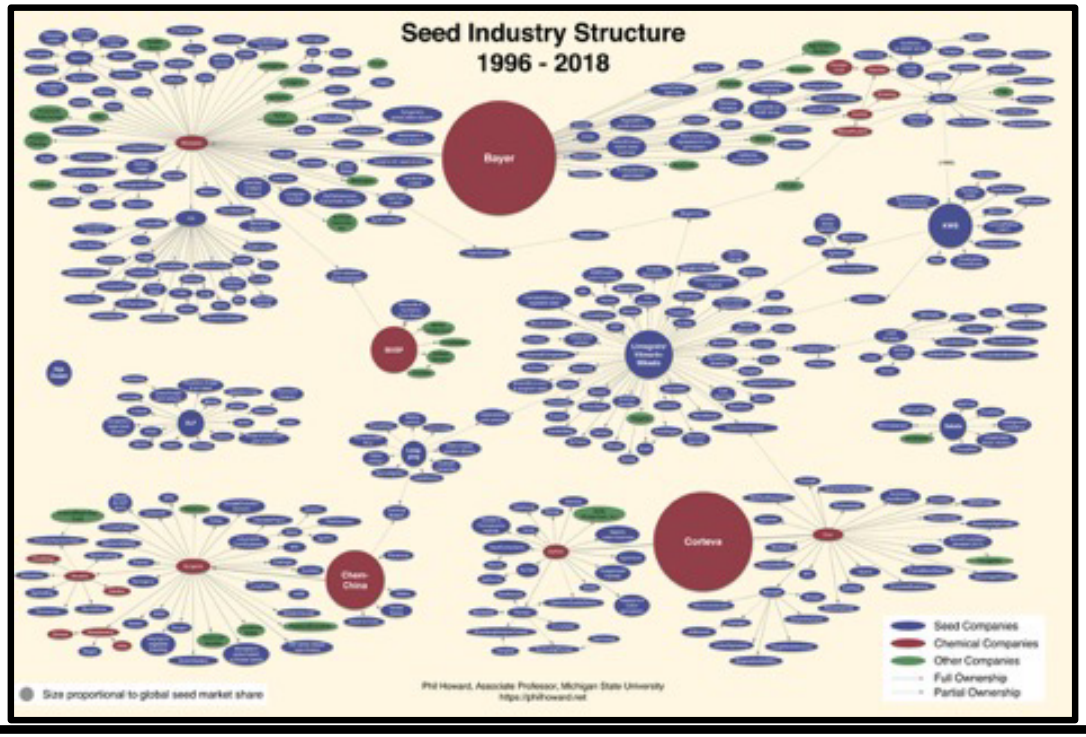
Jacob R. Pecenka[a,1], Laura L. Ingwell[a], Rick E. Foster[a], Christian H. Krupke[a], and Ian Kaplan[a]

[a]Department of Entomology, Purdue University, West Lafayette, IN 47907

-4 year study (2017-20), 5 Indiana locations
-low pest pressures/damage, no yield differences
-rootworm damage at one location only, beginning in year 4

Challenge:
Fewer options for seed and ag-chem choices

- Limited options/choices for US farmers = “one size fits all” pest management



Final thoughts

- RNAi will be helpful for high RW pressure, but expect similar results to previous Bt offerings
- Do not rely on 5% seed mix refuge to delay resistance – it is doing little or nothing
- Most Indiana growers do not need to invest in additional RW protection

The End