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2024 Applied Research Results
Field Crop Disease and Insect Management

Evaluations of insect and disease control tactics for corn, soybean, and wheat

Statewide surveys of corn and soybean pests

A digital copy of this guide can be obtained at go.illinois.edu/PestManagementResearchReport

College of Agricultural, Consumer, and Environmental Sciences

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Funding
Federal Agencies
USDA-NIFA (Hatch project numbers ILLU-802-979 and ILLU-875-969; Crop Protection and Pest Management Program grant no. 2021-70006-35476; National Plant Diagnostic Network)

Commodity Groups
Illinois Soybean Association

North Central Soybean Research Program

United Soybean Board

Private Companies
AMVAC Corporation, Los Angeles, CA

BASF Corporation, Research Triangle Park, NC

Bayer CropScience, St. Louis, MO

FMC Corporation, Philadelphia, PA

Pro Farm Group, Inc., Davis, CA

Syngenta Crop Protection, Greensboro, NC

Valent USA, Walnut Creek, CA

Acknowledgements
Jason Ballard, Talon Becker, Dennis Bowman, Adam Braun, Yony Callohuari Quispe, Sagnika Das, Karena Escobedo, Andy Fisher, Max Garmon Will Foulke, Emily Hansen, William Hong, Dane Hunter, Marty Johnson, Darin Joos, Jaqueline Kellerman, Tim Lecher, Luke Merritt, Grayce Montano, Willard Mott, Juan Paredes, Isabel Placencia, Bruno Pugliese, Joe Schmid, Lane Simpson, Greg Steckel, Alan Tammen, Melissa Wahlen, Shengnan Wang, Ethan Whitaker

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Helpful links

Multi-state corn rootworm management information, including annual report of regional monitoring network: www.rootwormipm.org

University of Illinois Plant Clinic:
go.illinois.edu/plantclinic

Illinois Agronomy Handbook:
go.illinois.edu/agronomyhandbook

Regional moth trap network:
corn.ipmpipe.org/insects

Illinois Extension field crop production resources:
go.illinois.edu/cropcentral

Previous editions of this report:
go.illinois.edu/pestmanagementresearchreport

Statewide Insect Survey Annual Summary - 2024

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Illinois Natural History Survey

One of the most longstanding pest surveys, the Illinois statewide insect survey has occurred in thirteen of the last fourteen years (2011, 2013-2024). The goal of this survey is to estimate densities of common insect pests in corn and soybean cropping systems throughout the nine crop reporting districts in Illinois.

Survey methods have remained consistent throughout the years. Sampling occurs at the same time each year. Within each crop reporting district, 4-5 counties are surveyed, with 5 corn and 5 soybean fields sampled in each county. Within the soybean fields surveyed, 100 sweeps were performed on both the exterior of the field (outer 2 rows) and interior (at least 12 rows beyond the field edge) using a 38-cm diameter sweep net. The insects collected in sweep samples were identified and counted to provide an estimate of the number of insects per 100 sweeps (Tables 1 and 2).

Similar to recent years, insect populations in 2024 varied greatly by species and locations across the state. It was not unusual to observe variation between fields in a county and counties within a crop reporting district. As a reminder, fields are randomly selected in this survey and pest management strategies are unknown. Other factors such as climate and recent weather events may also impact insect populations.

Once again populations of bean leaf beetles, grape colaspis, and grasshoppers were low throughout the state. The same was true for green cloverworm, soybean loopers and stink bugs. While information is presented at the district level, Sangamon county recorded higher than district averages of grape colaspis, cloverworm/loopers, and stink bugs.

Statewide averages of Japanese beetle populations have been trending downward, but are areas with higher than average numbers (Table 3). Counties in the northwest, northeast and west southwest crop reporting districts reported some of the highest Japanese beetle densities. Carroll, Ogle, Lee, Dekalb, LaSalle, and Sangamon topped the list of counties with Japanese beetle populations. Other counties that had noticeable Japanese beetle populations when compared to their district averages were Ford, Warren, and Peoria.

Dectes Stem Borer (Table 4) continues to be more noticeable in the southern third of Illinois, though populations were lower than previous years. Clinton, White, and continue to have higher numbers of Dectes stem borer in sweeps compared to surrounding counties and the rest of the state. Observations of Dectes were also made in Adams and Peoria counties, but it is evident that Dectes stem borer is well established in southern Illinois.

Rootworm abundance is also an important part of this survey. Western corn rootworm numbers in soybean have trended lower over the years, but recently, there have been areas of the state with noticeably higher populations. That is also true for northern corn rootworm in soybeans. Once again this is seen more readily in county averages. Dekalb county had the highest number of western corn rootworm per hundred sweeps, with Carroll, Lee, Warren, and Adams county also having higher than district average populations. Dekalb also had the highest populations of northern corn rootworms in fields along with Caroll, Warren, McDonough, Ford and McLean having higher than district average population.

In addition to sweep samples in soybeans, cornfields were also sampled for rootworm by counting the number of beetles on 20 consecutive plants beyond the end rows of a given field. A beetle per plant average was then calculated for each field. Frequent requests to include northern corn rootworm counts in this calculation have been received in the past several years. In 2024, counts reflect in Table 5 indicate the average number of western and northern corn rootworms observed in corn. Overall, western corn rootworm beetle populations continue to remain low in several areas of the state, but higher numbers of both western and northerns corn rootworms were observed in the northwest and west crop reporting districts. Carroll and McDonough counties reported higher numbers of corn rootworm beetles per plant count (1.63 and 1.47, respectively).

Funding for survey activities was provided by the USDA National Institute of Food and Agriculture. This survey would not be possible without the hard work and contributions of many people, including Cooperative Agriculture Pest Survey Program interns.

Table 1. Average number of insects per 100 sweeps in the exterior of the field (2024).

District	Bean Leaf Beetle	Grape Colaspis	Japanese Beetle	Northern CRW	Southern CRW	Western CRW	Grasshopper	Cloverworm/ Loopers	Stink Bugs	Dectes Stem Borer
Northwest	0	0.2	30.8	3.6	0	0.8	2.6	0	0.1	0
Northeast	0.27	0	31.33	6.13	0.4	3.2	3.6	1.07	0.27	0
West	0.1	1.3	8.63	7.5	0	1.3	1.8	0.44	0.2	0.3
Central	0.1	0.8	10.55	1.1	0.5	0.2	1.3	0.5	1.3	0.03
East	0.1	0.6	8.4	2.3	0.4	0	0.9	0.2	0	0
West Southwest	0.1	3.3	22.5	0	0	0	1.6	1.2	2.3	0
East Southeast	0.2	1.3	5.2	0	0.2	0	4.3	0.3	0.7	0.2
Southwest	0.22	1.82	2.27	0	0	0	1.63	1.1	0.13	0.53
Southeast	0	1.87	1.47	0	0.4	0	0.93	0.4	0.13	0.53
STATE AVE	0.12	1.24	13.46	2.29	0.21	0.61	2.07	0.58	0.57	0.18

Table 2. Average number of insects per 100 sweeps in the interior of the field (2024).

District	Bean Leaf Beetle	Grape Colaspis	Japanese Beetle	Northern CRW	Southern CRW	Western CRW	Grasshopper	Cloverworm/ Loopers	Stink Bugs	Dectes Stem Borer
Northwest	0.2	0	18.4	1.3	0.2	0.8	2.1	0.2	0.2	0
Northeast	1.3	0	11.03	2.5	0.2	0.9	2.4	0.6	0.3	0
West	0.6	0.57	3.17	1.1	0.1	0.7	0.4	0.2	0	0.1
Central	0.1	0.2	9.8	0.3	0.3	0	0.7	0.6	0.5	0
East	0	1.1	6.3	0.5	0.8	0.1	1.1	0.4	0.3	0
West Southwest	0	2.5	10.9	0	0.2	0.3	1.1	0.4	0.3	0
East Southeast	0	0.9	4.3	0.1	0.2	0	2	0.65	0.4	0.2
Southwest	0.22	0.62	3.16	0.13	0.22	0.27	0.83	3.67	0	0
Southeast	0	1.07	0.93	0	0.27	0	1.07	0.4	0.27	1.07
STATE AVE	0.27	0.77	7.55	0.66	0.28	0.34	1.33	0.89	0.25	0.16

Table 3. Average number of Japanese beetles per 100 sweeps, 2011-2024.

District	2017	2018	2019	2020	2021	2022	2023	2024
Northwest	54	175.1	52.64	67.1	119.8	48.4	8.48	30.8
Northeast	31.8	36.46	23.28	7.33	20.2	39.3	11.3	31.33
West	133.6	151.7	26.3	21.87	37.36	107.6	13.64	8.63
Central	10	30.6	17.52	15.9	6	7.5	14.96	10.55
East	2.7	25.4	51.3	9.4	7.2	10.5	19.1	8.4
West Southwest	20.8	85.34	20.24	11.9	12.6	25.2	23.68	22.5
East Southeast	4.4	27.53	10.6	15.7	4.8	9.76	43.04	5.2
Southwest	1.8	11.95	3.9	2.67	3.83	2.13	13.5	2.27
Southeast	0.4	12.96	3.34	13.73	3.27	4.6	2.1	1.47
STATE AVE	28.23	47.45	19.56	12.3	23.9	29.44	16.64	13.46

Table 4. Average number of Dectes Stem Borer in soybeans per 100 sweeps for each crop reporting district (2020-2024).

District	2019	2020	2021	2022	2023	2024
Northwest	0	0	0	0	0	0
Northeast	0	0	0	0	0	0
West	0	0.67	0	0	0	0.3
Central	0	0	0.16	0	0.15	0.03
East	0	0	0	0	0	0
West Southwest	0.16	0.2	0.2	0	0.08	0
East Southeast	0.1	0	0.4	0.08	0.08	0.2
Southwest	1.6	0.4	3.52	6.4	2.1	0.53
Southeast	2.54	0.4	2.5	2.3	4.4	0.53
STATE AVE	0.55	0.21	0.75	1.01	0.76	0.18

Table 5. Mean number of corn rootworm beetles per plant in corn by crop reporting district and year (2011-2024).

District	2011	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024*
Northwest	0.26	0.33	0.05	0.02	0.02	0.1	0.04	0.08	0.13	0.55	0.28	0.32	0.49
Northeast	0.15	0.2	0.02	0	0.02	1.95	0.35	0	0	0.16	0.03	0.07	0.05
West	0.01	0.1	0.1	0.01	0	0.75	0	0	0	0.03	0.02	0.16	0.38
Central	0.35	0.37	0.37	0.02	0.05	0.3	0.12	0.12	0.03	0.08	0.03	0.01	0
East	0.31	0.81	0.81	0.01	0.01	0.4	0.02	0.12	0.05	0.05	0.03	0.02	0
West Southwest	0.01	0.2	0.2	0	0.01	0.7	0.35	0.52	0.01	0.03	0.01	0.18	0.01
East Southeast	0.02	0.01	0.01	0	0	0	0.03	0.05	0.01	0	0.03	0.02	0
Southwest	0	0	0	0.01	0.01	0.15	0	0	0	0	0	0.05	0
Southeast	0	0.03	0.03	0	0	0.2	0.03	0	0	0.01	0	0.01	0
State Average	0.12	0.23	0.18	0.01	0.01	0.51	0.1	0.01	0.03	0.1	0.05	0.09	0.1

*Counts in 2024 reflect combined counts of western corn rootworm and northern corn rootworm averages.

Regional Monitoring of Insects using the USA Midwest Suction Trap Network

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The USA Midwest Suction Trap Network (https://suctiontrapnetwork.org) has been in operation since 2005 and continues working thanks to the unconditional collaboration of universities' personnel and private farmers. It was established to monitor the distribution and migratory patterns of soybean aphids, *Aphis glycines* Matsumura. Throughout the past years, we have recorded many additional aphid species using these traps including invasive species (Lagos-Kutz et al. 2018ab, 2020). In addition to aphids, we have also collected a variety of other insects, including crop pests and vectors of plant diseases (Crossley et al. 2022; Thekke-Veetil et al. 2020, 2024; Lagos-Kutz et al. 2024). This report is a summary of 2024 seasonal population dynamics of some of the most abundant insects of economic importance [soybean thrips *Neohyadatothrips variabilis* Beach (Fig. 1A) vector of soybean vein necrosis virus SVNV, soybean aphids (Fig. 1B), green peach or peach-potato aphids *Myzus persicae* (Sulzer) (Fig. 1C), corn leaf aphids *Rhopalosiphum maidis* (Fitch) (Fig. 1D) and unique information about the adventive corn leafhopper *Dalbulus maidis* (DeLong & Wolcott)] caught in the suction traps between 17 May and 18 October 2024. All of the data on aphids and other insects caught in the STN from past years until 2024 can be seen at https://suctiontrapnetwork.org/data/. The data included in this report were collected from suction traps located in Illinois (University of Illinois at Urbana-Champaign): Champaign (J. McGraham), Monmouth (G. Steckel), Morris (R. Higgins) and Orr (M. Luke); Indiana (Purdue University-Research stations): DPAC (J. Boyer), NEPAC (C. Lake and C. Emley), PPAC (S. Boyer), SEPAC (D. Bauerle) and TPAC (Peter Illingworth); Iowa (Iowa State University): Ames (E. Hodgson), Kanawha (M. Schnabel), Nashua (K. Pecinovsky) and Sutherland (A. Weaver); Kansas (Kansas State University): Manhattan (B. McCornack); Kentucky (University of Kentucky): Princeton (R. Villanueva); Michigan: Hickory Corners (C. Bahlai and S. VanderWulp, Kellogg Biological Station, Michigan State University) and Kalkaska (D. Iott, private farmer); Minnesota (University of Minnesota): T. Vollmer; Missouri (University of Missouri): Columbia (D. Finke); Nebraska (University of Nebraska): Concord (N. Luhr) and Keith (J. Garbisch and J. DeLong); Wisconsin (University of Wisconsin-Madison): Arlington (S. Chapman), Eau Claire (S. Spranger), Hancock (A. Walker), Lancaster (D. Wiedenbeck), Langlade (K. Gallenberg), Rhinelander (M. Hall) and Seymour (D. Lawkowski).

We have been monitoring soybean thrips and *Frankliniella tritici* (Fitch) (Eastern flower thrips) since 2020 because both have been cited as vectors of soybean vein necrosis virus (SVNV) (Keough et al. 2016). Our preliminary studies on detecting SVNV from both species caught in the suction traps between 2022 and 2023 showed that Eastern flower thrips do not carry the virus under normal environmental conditions. Soybean thrips, in contrast, often tested positive for SVNV using a PCR-based analytical test. For this reason, in 2024 we only monitored soybean thrips. The spring peaks of soybean thrips were recorded on samples from Missouri and Indiana (SEPAC). Peak densities in mid-summer were observed in samples from Kentucky and Kansas. However, the largest summer peaks were between 30 August and 6 September from samples from Illinois, Indiana, Iowa, Kansas and Nebraska. The last fall peak was on 27 September; surprisingly, along with the states mentioned before, a peak was detected in Lamberton, Minnesota. The average counts of soybean thrips from Michigan and Wisconsin were minimal throughout the season. The presence of soybean thrips might not cause a decrease in yield of soybean fields because soybeans were mature and less susceptible to SVNV when they increased populations in late season. However,SVNV can reduce soybean seed quality, especially oil and protein (Irizarry 2016, Bloomingdale et al. 2017).

While soybean aphid counts (Fig. 1B) were often in the thousands between 2005 and 2009 between mid-July and August (Lagos-Kutz et al. 2020), populations of this insect have decreased over time. Speculative explanations for this insect's population decline include increased predation and parasitism by natural enemies, infection with fungal diseases, host plant resistance with RAG (Resistant to Aphis glycines) genes, and insecticide use (Dean and Hodgson 2024). We are still monitoring for this Asian invasive species, which in past years negatively impacted the cost of soybean production. In 2024, the summer peak is very distinct between 9 and 23 August in Iowa, Michigan, Minnesota, Nebraska, and Wisconsin. We did not find soybean aphids in suction traps located in Kentucky and Missouri, and very few in other states such as Illinois and Indiana.

The green peach aphid (Fig. 1C) is an important agricultural pest worldwide. It is highly polyphagous and causes major economic losses due to its ability to transmit over 100 viruses, including the non-persistent Potato virus Y (PVY) (Clark et al. 2022). Our data shows that the state with the highest peak is Wisconsin, which was on 23 August and it is one of the main states that produces certified seed potatoes (https://seedpotato.russell.wisc.edu/). Additional information about the use of the aphids data for pest management can be found in Groves et al. (2025). There were no records from suction traps located in Indiana and Kentucky, and single records in Illinois and Minnesota.

Corn leaf aphids (Fig. 1D) were present at higher populations this summer compared to past years. This aphid migrates from south to north and is usually found in the suction traps between July and September (Crossley et al. 2022).One possible explanation for reduced populations in recent years is that intensive chemical spraying has occurred in some areas to control sugarcane aphid, *Melanaphis* spp on sorghum (another host for corn leaf aphid) since 2012-2013. In 2024, the summer peaks in Illinois, Indiana, Kansas and Missouri between 26 July and 16 August were unexpected. Villanueva (2024) reported the outbreak of corn leaf aphids in Kentucky and other neighboring states. They mentioned that corn leaf aphids feed on small grains including corn and sorghum and are vectors of barley yellow dwarf virus.

We detected a male of corn leafhopper (Fig. 2A) for the first time in our suction traps on 9 August from a trap located in Kentucky. Additional records followed until October from most of suction traps that belong to STN. Data shows that the state with the highest counts was Kansas (Fig. 2B and Fig. 3). The monitoring of this adventive species, which has been observed sporadically in the Midwest in past years (C. Dietrich, personal communication), needs to be continued determine its status as a pest of corn in the region. Its typical distribution ranges from the Southern states of USA to most of the South American countries, where it can be a severe pest (Triplehorn and Nault 1985; Carloni et al. 2013). This insect is a threat to corn *Zea mays* L. because of its ability to transmit corn stunt disease caused by the bacteria *Spiroplasma kunkelii* (Nault 1980, 1990). In the USA, the states with the most records of this insect and detections of corn stunt diseases are California and Oklahoma, and for the first time we are reporting corn leafhoppers caught in suction traps set across the USA Midwest (Lagos Kutz et al. 2025). We are planning through molecular approaches to screen these specimens for corn stunt disease, as well as looking back from suction traps stored from previous years. This information will provide insight into the distribution of these diseases and their vector and will lead to more exploration of what other factors affect their incidence in the fields.

We will continue monitoring to obtain more migratory information about these insects and more and correlate their abundance with weather parameters and landscape.

Acknowledgement

We thank the North Central Soybean Research Program, United Soybean Board and United States Department of Agriculture-Agricultural Research Service for financial support of the suction trap network. Special thanks to the collaborators in the Midwest for checking and maintaining traps, and University of Illinois at Urbana-Champaign's undergraduate assistant Isabel Plasencia.

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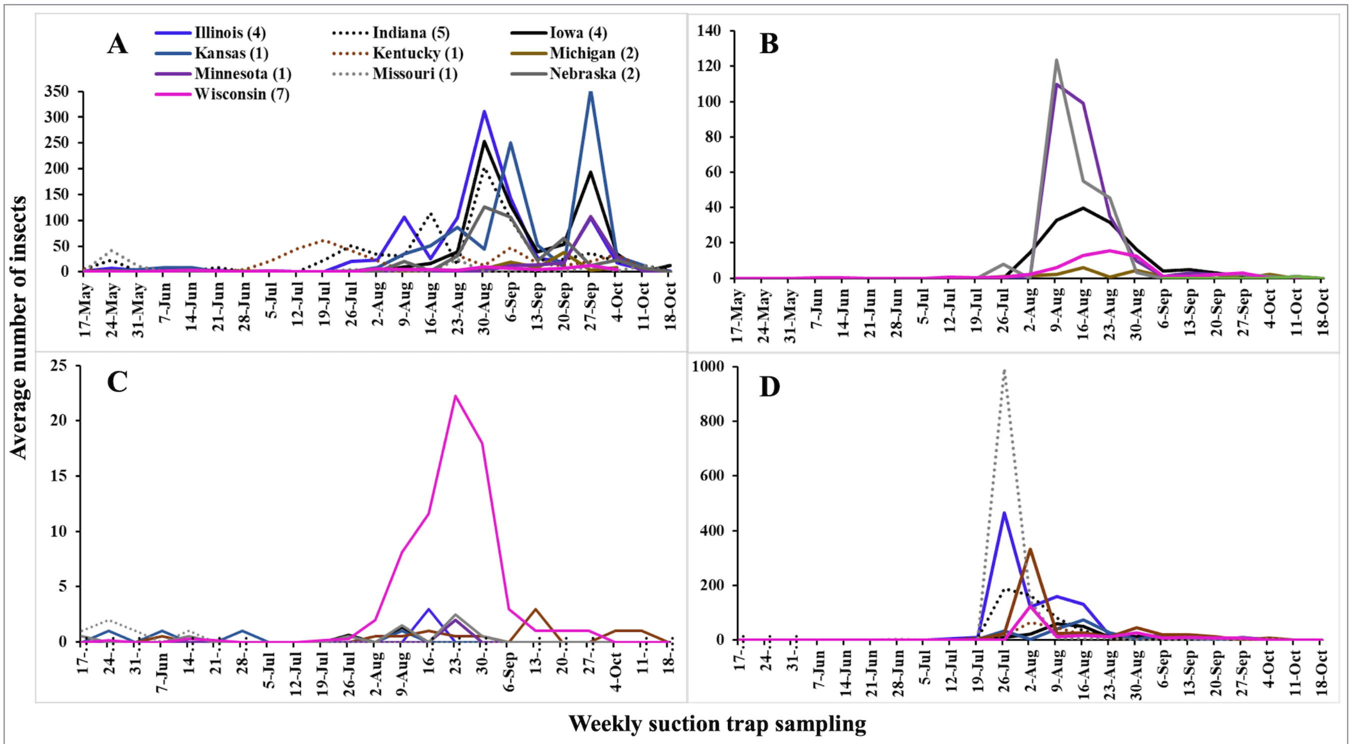

Figure 1. Seasonal population dynamics of insects collected between 17 May and 30 August 2024 in the Midwest Suction Trap Network. **A**) *Neohyadatothrips variabilis*. **B**) *Aphis glycines*. **C**) *Myzus persicae*. **D**) *Rhopalosiphum maidis*. The Y axis corresponds to the average number of insects and X axis to the weekly sampling. Numbers in parenthesis represent the number of suction traps located per state.

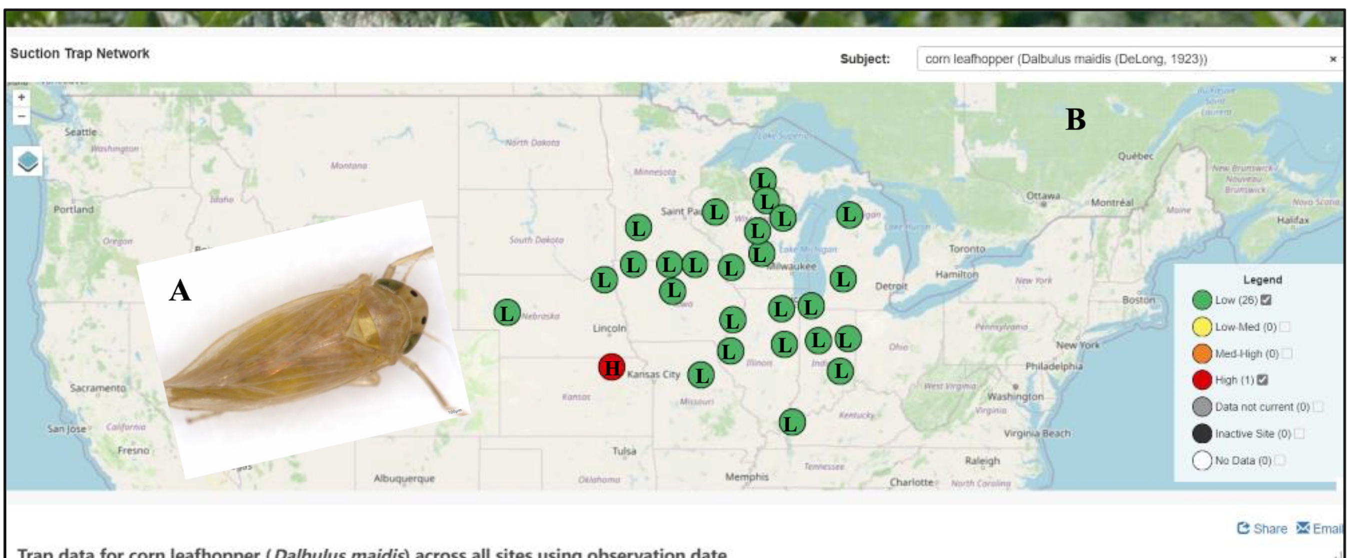

Figure 2. Map produced by Early Detection and Distribution Map System (EDDMapS) (https://www.eddmaps.org/) with corn leafhopper data entered to AG Pest Monitoring (https://agpestmonitor.org/report/sitemonitoring/), a database used also to update the USA Midwest Suction Trap Network (https://suctiontrapnetwork.org/data/). (**A**)Adult corn leafhopper *Dalbulus maidis*, which is about 1/8 inch long and distinct for the 2 black spots on forehead (Photograph: Isabel Plasencia) (**B**) Corn leafhopper suction trap data in the US Midwest. Kansas has the highest (H) density of corn leafhopper compared to low (L) densities from other Midwestern states.

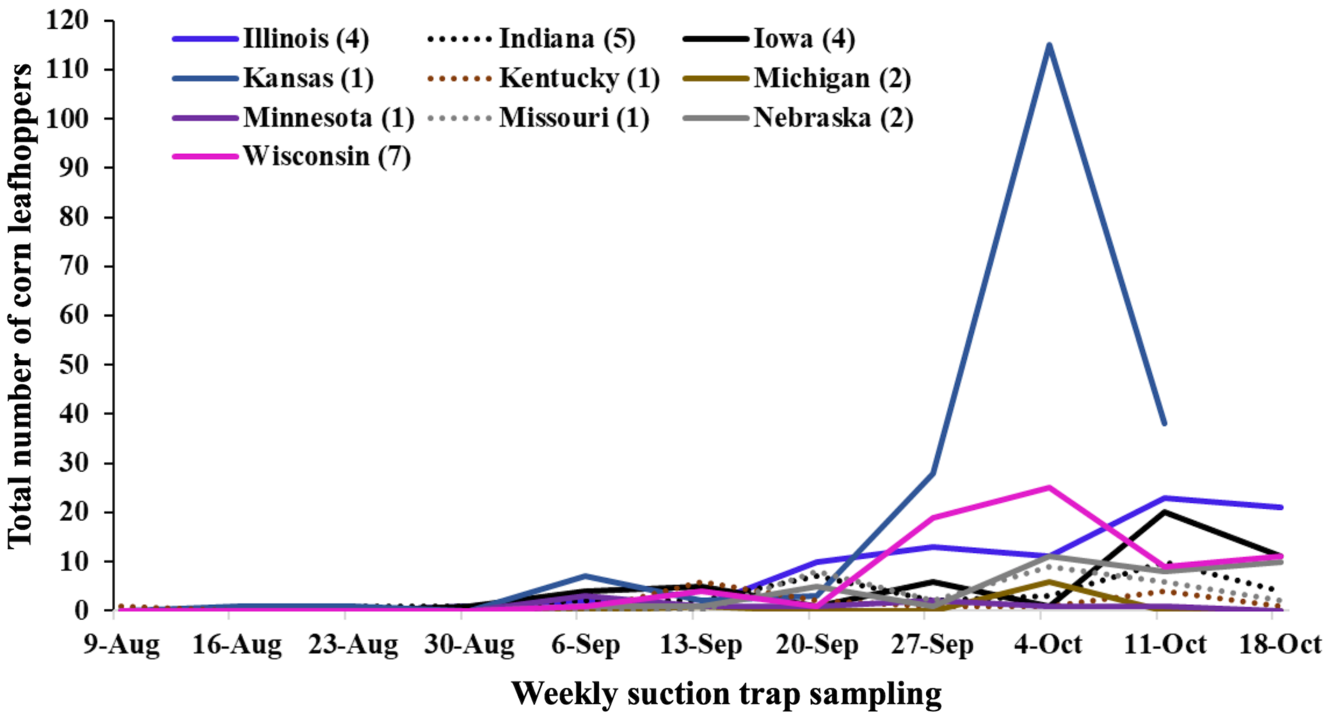

Figure 3. Population dynamics of corn leafhopper, *Dalbulus maidis*. caught in suction traps between 9 August (single specimen of corn leafhopper caught in Princeton, Kentucky) to 18 October 2024 in the USA Midwest Suction Trap Network. Numbers in parenthesis represent the number of suction traps located per state.

2024 University of Illinois Plant Clinic Agronomic Sample Summary

Diane Plewa, Esneider Mahecha, Alison Colgrove

The University of Illinois Plant Clinic received 3,348 samples in 2024. These samples include field crop, nursery, and ornamental plant samples, along with Amaranth weeds submitted for herbicide resistance screening, seed lots submitted to test for the presence of Palmer amaranth, soil samples submitted for vermiform nematode identification and SCN egg counts and typing, and seed screening to test for SCN resistance. Plant Clinic staff use a combination of traditional laboratory methods including incubation, culturing, microscopy, along with other techniques such as bioassays and serological and molecular assays for diagnosis and identification.

In 2024, a total of 2,780 field crop samples were received, approximately 83% of all Plant Clinic submissions. These included 1,763 soil samples for nematode identification and enumeration and 956 plant samples for pest and pathogen diagnosis. Additionally, Amaranth weed samples were submitted for herbicide resistance testing, and seed lots were analyzed for the presence of Palmer amaranth.

Among the 956 plant samples received, the distribution was as follows: 368 corn, 362 soybean, 208 industrial hemp, and 18 wheat. Samples were submitted from 63 counties in Illinois and 9 other states, highlighting the Plant Clinic's wide-reaching impact in plant diagnostics and management.

The plant samples included field crop samples submitted by farmers, crop consultants, and researchers, as well as samples processed for phytosanitary certification. While most of the corn, soybean, and wheat samples were from within Illinois, many of the hemp samples were submitted from the surrounding Midwest states as part of a regional research project.

The most frequently diagnosed corn diseases in 2024 were Common Rust (44% confirmed), Northern Corn Leaf Blight (39%), Common Smut (21%), Gray Leaf Spot (20%), and Tar Spot (20%). All of these are considered common corn diseases in the Midwest. We saw less Gray Leaf Spot compared to last year (32% confirmed in 2023) and an increase in Tar Spot. Tar Spot appeared much earlier in 2024, especially in irrigated fields or areas with high humidity. However, the early incidence of the disease does not appear to have resulted in significant yield loss in most cases. 73 samples of Tar Spot were confirmed (compared to 25 last year) from Bureau, Cass, Champaign, Christian, Crawford, Cumberland, Douglas, Effingham, Ford, Henry, Jasper, Livingston, Logan, Macon, Macoupin, McHenry, McLean, Menard, Ogle, Randolph, Sangamon, Tazewell, Vermilion, Warren, and Whiteside counties. Southern Rust was present, but in very low amounts (13 samples confirmed).

Of the corn vermiform soil samples submitted, Spiral nematodes were the most frequently detected (96% of samples submitted), followed by Lesion (81%), Lance (45%), Stunt (32%), and Dagger (23%).

For soybean samples, the most common diseases diagnosed were Downy Mildew (62% of submitted samples), Soybean Vein Necrosis Virus (55%), Bacterial Blight (28%), Sudden Death Syndrome (19%), and Phytophthora Crown and Root Rot (17%). As with corn, these are common diseases frequently seen in Illinois. Downy Mildew and SVNV increased significantly (from 38% and 39% of samples, respectively, in 2023), while SDS and Phytophthora remained at similar levels. The incidence of Downy Mildew and Soybean Vein Necrosis was high in 2024, but their reported impact on soybean yield remains classified as low or minor. Red Crown Rot, a fairly new disease described in Illinois, was confirmed on 11 samples from Champaign, Christian, Coles, Jersey, Knox, Madison, Marion, Menard, and White counties. Soybean Rust was not diagnosed on any of the soybean samples submitted to the Plant Clinic.

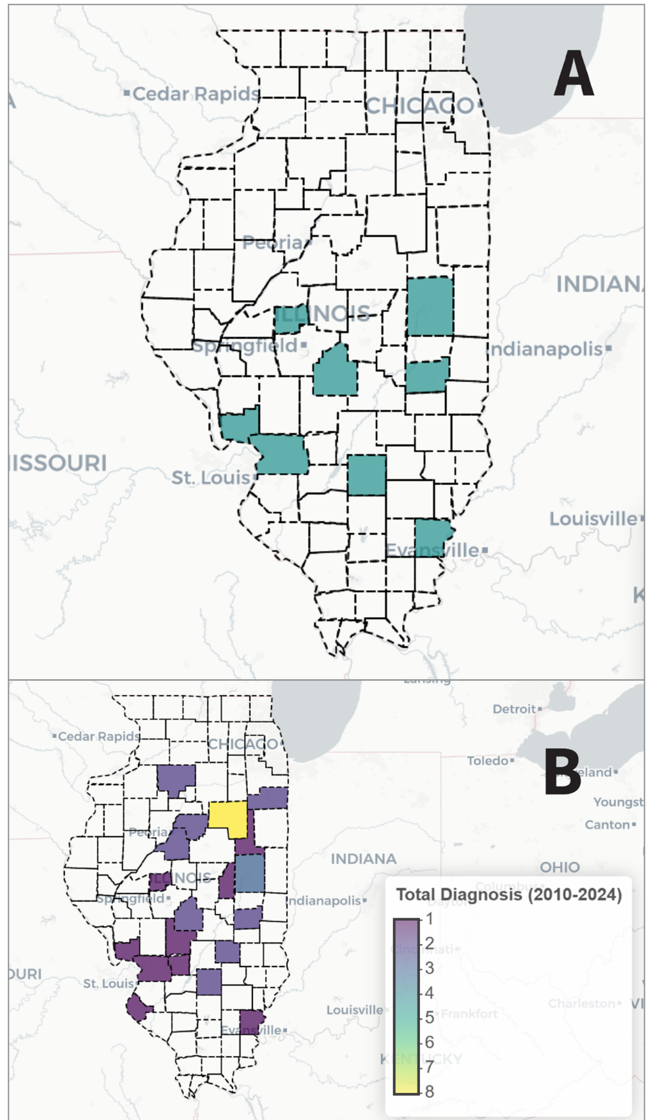

Figure 1A) Frequency of Red Crown Rot diagnoses in 2024.
Figure 1B) Total diagnoses of Red Crown Rot, 2010-2024.

We continue to see moderate to high numbers of SCN eggs found in fields across the state sufficient to cause yield loss. Yield loss is usually most severe on lighter, sandy soils, but drastic losses have been observed even in the heavy clay-loam soils typical of much of the soybean acreage in Illinois. SCN Type 2 is the most common in Illinois, though Type 1 is increasing in prevalence, continuing the trend seen in previous years.

The industrial hemp (*Cannabis sativa*) samples submitted are part of a research grant investigating seed and fiber hemp production in the Midwest. Samples submitted ranged from seedlings to fully mature plants, along with soil samples for nematode testing. These samples were collected from research stations, growers' farms, and commercial companies spanning Indiana, Michigan, Wisconsin, and Illinois. Septoria Leaf Spot (17% of submitted samples), Fusarium bud blight (10%), and Downy Mildew (9%) were the most common diseases found on hemp samples. Among the soil samples, lesion and spiral nematodes were consistently detected. Both of these are common pathogens in Midwest corn cultivation. This investigation into prevalent diseases in Midwest hemp crops marks an initial step in determining the frequency of these pathogens and their potential impact on seed and fiber yields.

This year, samples submitted for agronomic nematode analysis consisted of soil samples for soybean cyst nematode (SCN) egg counts, vermiform nematode analysis, and HG Type and SCN Type testing. One new project is a partnership with the Illinois Soybean Association (ISA) to provide Illinois soybean producers with SCN Egg Count analysis on their soil samples at no charge to them. Producers can contact freeSCNtesting@illinois.edu to receive a kit with sampling instructions and information to receive free shipping for sending the samples to the Plant Clinic. Over 1500 samples have already been received since the project began in October 2023. Currently the project is funded through August 31, 2025. SCN egg counts (measured as the number of eggs per 100 cubic centimeters of soil) provide a snapshot of the status of SCN in a field and can help inform the producer's management plan. A low count indicates that the management plan is successfully incorporating best practices for SCN management, which should include rotation with a non-host (including corn or wheat), use of SCN resistant soybean varieties, as well as monitoring their SCN egg count. Because SCN is known to be prevalent in Illinois soybean fields and to cause significant yield losses especially at high levels, it is important for Illinois soybean farmers to test their fields to determine if they have a problem with SCN in their soybean fields and if their management plan should be re-evaluated.

Besides providing important assistance to Illinois farmers, this project provides the Illinois Soybean Association, the Plant Clinic, soybean researchers, and seed companies with a valuable survey of the status of SCN in Illinois. For more information about the University of Illinois Plant Clinic, please see our website at go.illinois.edu/plantclinic.

Efficacy of fungicide programs against tar spot of corn in northwestern Illinois, 2024

Corn (Zea mays)
Phyllachora maydis

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A trial was established at the Northwestern Illinois Agricultural R&D Center in Warren County, IL. The experiment was a randomized complete block design with four replications. Plots were 30 ft wide and 60 ft long, consisted of 12 rows, and the two center rows were used for evaluation. The previous crop was soybean. Standard practices for non-irrigated grain corn production in Illinois were followed. Corn hybrid 'DK107-33RIB' was planted in 30-in row spacing at a rate of 34,000 seeds/A on 19 May. Foliar applications were made at the R1 growth stage on 19 Jul, with a second application 3 weeks after treatment (WAT) for treatments requiring two applications. Fungicides were applied using an Agras T10 drone sprayer at 3 gal/A. Disease ratings were assessed on 08 Aug (R3), 22 Aug (R4), and 04 Sep (R5). Tar spot severity was visually assessed as a percentage (0-100%) of symptomatic leaf area at the ear leaf on 10 plants per plot and averaged for the statistical analysis. Tar spot incidence was recorded in earlier stages to document disease development. The two center rows of each plot were harvested on 09 Oct, and yields were adjusted to 15.5% moisture. All disease and yield data were analyzed in RStudio. Incidence data were analyzed using a generalized linear model, while severity data were analyzed with linear models. Means were calculated using the package 'emmeans' and compared with Tukey's test (α=0.05).

In 2024, weather conditions were favorable for the development of tar spot disease; however, it manifested late in the season, with significant severity observed only on 04 Sep (Table 1). Overall, tar spot was present in the trial and reached moderate severity by the end of the season. On 22 Aug, Headline followed by Veltyma was the only treatment that significantly reduced tar spot incidence compared to the non-treated control, while other treatments did not differ statistically. Disease severity remained very low during this period (data not shown). By 04 Sep, the disease was present on most leaves, and no statistical differences were observed among treatments for disease incidence. However, regarding disease severity, Headline followed by Veltyma exhibited the lowest values. Headline also showed significantly lower severity values compared to the non-treated control when followed by Aproach Prima and Miravis Neo. Other treatments provided intermediate control but were not statistically different from the control. Tar spot developed late in the season and no significant differences in yield were observed between treatments.

Table 1. Effect of fungicide programs on tar spot in northwestern Illinois, 2024.

Treatment, rate [z]	Incidence [y] (22 Aug.)	Incidence (4 Sep.)	Severity (4 Sep.)	Yield [w] (bu/acre)
Non-treated Control	90.0 a	100.0 a	2.5 a	238
Veltyma 3.34 S 7 fl oz	83.7 ab	100.0 a	1.8 ab	237
Aproach Prima 2.34 SC, 6.8 fl oz	82.1 ab	100.0 a	2.2 a	248
Miravis Neo 2.5 SE 13.7 fl oz	73.6 ab	100.0 a	1.4 ab	233
Delaro Complete 458 SC 8.0 fl oz	64.6 ab	98.4 a	0.8 abcd	232
Headline Amp 10 fl oz	62.8 ab	98.4 a	1.1 abc	247
Veltyma 3.34 S 7 fl oz FB Headline Amp 10 fl oz	85.3 ab	95.0 a	1.1 abc	247
Aproach Prima 2.34 SC 6.8 fl oz FB Headline Amp 10 fl oz	73.6 ab	96.6 a	1.2 ab	245
Miravis Neo 2.5 SE 13.7 fl oz FB Headline Amp 10 fl oz	86.9 ab	100.0 a	1.1 abc	248
Delaro Complete 458 SC 8.0 fl oz FB Headline Amp 10 fl oz	83.7 ab	91.6 a	0.7 abcd	240
Headline Amp 10 fl oz FB Veltyma 3.34 S 7 fl oz	59.1 b	83.4 a	0.3 d	239
Headline Amp 10 fl oz FB Aproach Prima 2.34 SC 6.8 fl oz	75.3 ab	81.6 a	0.6 bcd	250
Headline Amp 10 fl oz FB Miravis Neo 2.5 SE 13.7 fl oz	78.7 ab	83.4 a	0.3 cd	241
Headline Amp 10 fl oz FB Delaro Complete 458 SC 8.0 fl oz	75.3 ab	100.0 a	1.3 ab	245
Headline Amp 10 fl oz FB Headline Amp 10 fl oz	85.3 ab	96.6 a	1.3 ab	244
p-value [w]	<0.001	0.1	<0.001	0.61

[z] *FB* = followed by. Foliar applications were made at R1 on 19 Jul. Treatments involving two applications received second application 3 WAT.

[y] Tar spot severity was visually assessed as the percentage (0-100%) of leaf area covered by stroma on 10 plants in each plot. The incidence was recorded as the percentage of ear leaves with symptoms of tar spot.

[x] Yields were adjusted to 15.5% moisture and harvested on 09 Oct.

[w] Treatment mean values with the same letter are not significantly different based on Tukey's test (α=0.05).

Standard Evaluation of Soil Insecticides and Bt Traits for Corn Rootworm Control, Urbana 2024

Location: University of Illinois Agricultural and Biological Engineering Farm, Urbana, IL (40.0696, -88.2124)

Study directors: Nicholas Seiter and Ashley Decker

Objective

To assess the performance of Bt trait packages with and without a soil insecticide for control of corn rootworm (particularly western corn rootworm, *Diabrotica virgifera virgifera*) larval damage.

Materials and Methods

Field experiments were established in a randomized complete block design with 4 replicate blocks and 8 treatments. The experimental units were plots of corn (Table 1) that were 4 rows wide and 30 ft. long with 5 ft. of unplanted alley separating plots vertically. Treatments (Table 2) were two corn hybrids with each of four different corn rootworm trait packages (VT Double Pro, SmartStax, SmartStax PRO, VT4 PRO), either without insecticide or treated with Force Evo (8 oz/a). Plant stands were assessed on 23 May (growth stage V1), and 29 May 2024 (growth stage V3). Larval corn rootworm damage was rated on 17 July 2024 (R1) by digging 5 root masses per plot from rows 1 and 4, removing all soil using an electric high-pressure water sprayer, and rating damage using the 0-3 Node-injury scale. Percent lodging was estimated for each plot on 3 October 2024 (R6). Yields were assessed for each plot on 10 October 2024 by harvesting rows 2 and 3 using a small-plot combine (Massey Ferguson 8XP, Kincaid Equipment, Haven, KS) with a built-in weight and moisture monitor (HarvestMaster, Logan, UT).

Data Analysis

Percent consistency of root ratings for each plot was set equal to the percentage of roots that were given a node-injury rating of less than 0.25. Weights per plot were corrected to a standard weight at 15.5% moisture, then converted to bushels per acre using the standard bushel weight of 56 pounds. Consistency and lodging are reported as percentages but were analyzed as proportions. Plant stand (lognormal), root injury rating (gamma), proportion consistency (normal), proportion gooseneck lodging (normal), proportion stalk lodging (normal) and yield (lognormal) were analyzed separately using a generalized linear mixed model (PROC GLIMMIX, SAS version 9.4, SAS Institute, Cary, NC; probability distribution indicated in parentheses for each response variable) where treatment was considered a fixed effect and replicate block was considered a random effect.

Summary

While root injury ratings were low overall, for both VT Double Pro and SmartStax a soil insecticide resulted in lower node-injury scores than plots without an insecticide. Differences in yield among hybrids did not appear to be related to the small amount of corn rootworm injury we observed, as there was not a general pattern for increased yield where root injury was decreased.

Funding

Project funding and seed were provided by Bayer Crop Science.

Acknowledgements

We thank Tim Lecher (Farm Manager) for assisting with planting and plot maintenance, academic hourly Grayce Montano, graduate students Yony Callohuari Quispe, and Will Foulke, and undergraduate students Melissa Wahlen, Jason Ballard, Shengnan Wang, Joe Schmid, and Karina Escobedo for assisting with plot maintenance and data collection. In addition, we thank Dr. Joseph Spencer (Illinois Natural History Survey) and his undergraduate research assistants for their help with root damage assessments.

Table 1. Plot information.

Input	Value
Previous crop	Trap crop: late-planted, non-Bt field corn inter-seeded with pumpkins
Soil type	Drummer silt loam/ Elburn silt loam
Tillage	Conventional
Row spacing	30 inches
Seeding Rate	35,000 seeds per acre
Planting date	May 12 2024
Emergence date	May 20 2024
Herbicide	Pre-emerge: 32% UAN (52 gal/ac), Harness Xtra[a] (2 qt/ac)
	Post-emerge: Acuron[b] (3 qt/ac)
Plot size	4 rows (10 ft) wide by 30 ft long, 5 ft unplanted alleys

[a] Bayer CropScience, St. Louis, MO; [b] Syngenta Crop Protection, Greensboro, NC

Table 2. Corn rootworm treatments

Trt	Treatment	Variety	Trait Package	Insecticide	Seed Treatment
1	VT DoublePro	DKC62-70 [a]	None	None	Clothianadin (0.50 mg ai/ seed) Acceleron [FALEH2VQ]
2	VT Double Pro + Force Evo [b] (8 oz/a)	DKC62-70	None	Tefluthrin, 2.1 lbs active ingredient per gallon, emulsifiable concentrate (EC)	Clothianadin (0.50 mg ai/ seed) Acceleron [FALEH2VQ]
3	SmartStax	DKC64-34 [a]	Cry3Bb1 + Cry34/35Ab1	None	Clothianadin (0.50 mg ai/ seed) Acceleron [FALEH2VQ]
4	SmartStax + Force Evo (8 oz/a)	DKC64-34	Cry3Bb1 + Cry34/35Ab1	Tefluthrin, 2.1 lbs active ingredient per gallon, EC	Clothianadin (0.50 mg ai/ seed) Acceleron [FALEH2VQ]
5	SmartStax Pro	DKC111-33 [a]	Cry3Bb1 + Cry34/35Ab1 + DvSnf7 dsRNA	None	Clothianadin (0.50 mg ai/ seed) Acceleron [FALEKH2VQ]
6	SmartStax Pro + Force Evo (8 oz/a)	DKC111-33	Cry3Bb1 + Cry34/35Ab1 + DvSnf7 dsRNA	Tefluthrin, 2.1 lbs active ingredient per gallon, EC	Clothianadin (0.50 mg ai/ seed) Acceleron [FALEKH2VQ]
7	VT4 Pro	DKC114-99 [a]	Cry3Bb1 + DvSnf7 dsRNA	None	Clothianadin (1.25 mg ai/ seed) Acceleron [FALEKH2VQ]
8	VT4 Pro + Force Evo (8 oz/a)	DKC114-99	Cry3Bb1 + DvSnf7 dsRNA	Tefluthrin, 2.1 lbs active ingredient per gallon, EC	Clothianadin (1.25 mg ai/ seed) Acceleron [FALEKH2VQ]

[a] Dekalb, Bayer CropScience, St. Louis, MO; [b] Syngenta Crop Protection, Greensboro, NC

Table 3. Generalized linear mixed model statistics. Probability distribution is given in parentheses after each dependent variable.

Dependent Variable	Date	df (numerator, denominator)	*F*	*P*
Plant stand (lognormal)	23 May	7, 21	0.63	0.723
Plant stand (lognormal)	29 May	7, 21	0.24	0.970
Root injury rating (gamma) [a]	17 July	7, 21	4.44	0.004
Proportion consistency (normal) [a]	17 July	7, 21	2.73	0.035
Proportion root lodging (normal)	3 Oct.	7, 20	1.46	0.238
Proportion stalk lodging (normal)	3 Oct.	7, 21	0.76	0.625
Yield (lognormal) [a]	10 Oct.	7, 21	4.92	0.002

[a] Effect is significant at α = 0.05.

Table 4. Mean (± Standard error [SE]) stand in number of plants per 17.5 ft. of row. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	23 May 2024 (V1)	29 May 2024 (V3)
1	VT DoublePro	34.8 ± 1.1 a	36.6 ± 1.0 a
2	VT Double Pro + Force Evo (8 oz/a)	35.5 ± 0.5 a	36.0 ± 0.5 a
3	SmartStax	35.8 ± 0.7 a	36.8 ± 0.7 a
4	SmartStax + Force Evo (8 oz/a)	34.4 ± 0.6 a	36.9 ± 0.7 a
5	SmartStax Pro	36.0 ± 0.7 a	36.8 ± 0.6 a
6	SmartStax Pro + Force Evo (8 oz/a)	35.4 ± 0.7 a	36.5 ± 0.5 a
7	VT4 Pro	35.8 ± 0.6 a	36.1 ± 0.5 a
8	VT4 Pro + Force Evo (8 oz/a)	35.9 ± 0.8 a	36.4 ± 0.4 a

Table 5. Mean (± SE) node-injury rating (0-3 scale) of corn rootworm larval feeding injury. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	17 July 2024 (R1)
1	VT DoublePro	0.33 ± 0.07 a
2	VT Double Pro + Force Evo (8 oz/a)	0.13 ± 0.06 bc
3	SmartStax	0.16 ± 0.04 ab
4	SmartStax + Force Evo (8 oz/a)	0.03 ± 0.01 c
5	SmartStax Pro	0.04 ± 0.01 bc
6	SmartStax Pro + Force Evo (8 oz/a)	0.03 ± 0.01 c
7	VT4 Pro	0.10 ± 0.04 bc
8	VT4 Pro + Force Evo (8 oz/a)	0.03 ± 0.01 c

Table 6. Mean (± SE) percentage of roots with a node-injury rating (0-3 scale) of less than 0.25. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	17 July 2024 (R1)
1	VT DoublePro	55 ± 21 b
2	VT Double Pro + Force Evo (8 oz/a)	95 ± 5 a
3	SmartStax	80 ± 14 ab
4	SmartStax + Force Evo (8 oz/a)	100 ± 0 a
5	SmartStax Pro	100 ± 0 a
6	SmartStax Pro + Force Evo (8 oz/a)	100 ± 0 a
7	VT4 Pro	85 ± 10 a
8	VT4 Pro + Force Evo (8 oz/a)	100 ± 0 a

Table 7. Mean (± SE) percent root lodging ("goosenecked" lodging) per plot. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	3 October 2024 (R6)
1	VT DoublePro	0 ± 0 a
2	VT Double Pro + Force Evo (8 oz/a)	1 ± 1 a
3	SmartStax	0 ± 0 a
4	SmartStax + Force Evo (8 oz/a)	0 ± 0 a
5	SmartStax Pro	0 ± 0 a
6	SmartStax Pro + Force Evo (8 oz/a)	0 ± 0 a
7	VT4 Pro	0 ± 0 a
8	VT4 Pro + Force Evo (8 oz/a)	2 ± 1 a

Table 8. Mean (± SE) percent stalk lodging per plot. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	3 October 2024 (R6)
1	VT DoublePro	1 ± 1 a
2	VT Double Pro + Force Evo (8 oz/a)	1 ± 1 a
3	SmartStax	0 ± 0 a
4	SmartStax + Force Evo (8 oz/a)	0 ± 0 a
5	SmartStax Pro	0 ± 0 a
6	SmartStax Pro + Force Evo (8 oz/a)	0 ± 0 a
7	VT4 Pro	0 ± 0 a
8	VT4 Pro + Force Evo (8 oz/a)	1 ± 1 a

Table 9. Mean (± SE) corn yield in bushels per acre, corrected to 15.5% moisture. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	10 October 2024 (R6)
1	VT DoublePro	232 ± 7 ab
2	VT Double Pro + Force Evo (8 oz/a)	224 ± 12 ab
3	SmartStax	178 ± 8 d
4	SmartStax + Force Evo (8 oz/a)	183 ± 2 cd
5	SmartStax Pro	256 ± 13 a
6	SmartStax Pro + Force Evo (8 oz/a)	214 ± 14 bc
7	VT4 Pro	217 ± 11 ab
8	VT4 Pro + Force Evo (8 oz/a)	246 ± 27 ab

Standard Evaluation of Soil Insecticides and Bt Traits for Corn Rootworm Control, Monmouth 2024

Location: University of Illinois Northwestern Illinois Agricultural Research and Demonstration Center, Monmouth, IL (40.935285, -90.725937)

Study directors: Nicholas Seiter and Ashley Decker

Objective

To assess the performance of Bt trait packages with and without a soil insecticide for control of corn rootworm (particularly western corn rootworm, Diabrotica virgifera virgifera) larval damage.

Materials and Methods

Field experiments were established in a randomized complete block design with 4 replicate blocks and 8 treatments. The experimental units were plots of corn (Table 1) that were 4 rows wide and 30 ft. long with 5 ft. of unplanted alley separating plots vertically. Treatments (Table 2) were two corn hybrids with each of four different corn rootworm trait packages (VT Double Pro, SmartStax, SmartStax PRO, VT4 PRO), either with or without Force Evo (8 oz/a) applied in-furrow. Plant stands were assessed on 6 June 2024 (growth stage V4). Larval corn rootworm damage was rated on 24 July 2024 (R1) by digging 5 root masses per plot from rows 1 and 4, removing all soil using an electric high-pressure water sprayer, and rating damage using the 0-3 Node-injury scale. Percent lodging was estimated for each plot on 10 October 2024 (R6). Yields were assessed for each plot on 17 October 2024 by harvesting rows 2 and 3 using a small-plot combine (Massey Ferguson 8XP, Kincaid Equipment, Haven, KS) with a built-in weight and moisture monitor (HarvestMaster, Logan, UT).

Data Analysis

Percent consistency of root ratings for each plot was set equal to the percentage of roots that were given a node-injury rating of less than 0.25. Weights per plot were corrected to a standard weight at 15.5% moisture, then converted to bushels per acre using the standard bushel weight of 56 pounds. Consistency and lodging are reported as percentages but were analyzed as proportions. Plant stand (lognormal), root injury rating (gamma), proportion consistency (normal), proportion stalk lodging (normal) and yield (lognormal) were analyzed separately using a generalized linear mixed model (PROC GLIMMIX, SAS version 9.4, SAS Institute, Cary, NC; probability distribution indicated in parentheses for each response variable) where treatment was considered a fixed effect and replicate block was considered a random effect. Because no root lodging was observed (i.e., all plots had root lodging = 0 percent), this response variable was not analyzed and is not displayed.

Summary

A soil insecticide resulted in reduced node-injury ratings when applied to VT Double Pro or SmartStax, but not when applied to SmartStax Pro or VT4 Pro. The SmartStax hybrid suffered a high amount of "green snap" stalk lodging due to a major wind event, resulting in much higher stalk lodging scores and lower yields than the other hybrids. (Note: this was not related to corn rootworm feeding). Yield differences among hybrids were due to factors other than corn rootworm, which was at relatively low densities in this trial.

Funding

Seed was provided by Bayer Crop Science. Force Evo was supplied by Syngenta.

Acknowledgements

We thank Greg Steckel and Marty Johnson for assisting with planting and plot maintenance, academic hourly Grayce Montano, graduate students Yony Callohuari Quispe, and Will Foulke, and undergraduate students Melissa Wahlen, Jason Ballard, Shengnan Wang, Joe Schmid, and Karina Escobedo for assisting with plot maintenance and data collection. In addition, we thank Dr. Joseph Spencer (Illinois Natural History Survey) and his undergraduate research assistants for their help with root damage assessments.

Table 1. Plot information.

Input	Value
Previous crop	Trap crop: late-planted, non-Bt field corn inter-seeded with pumpkins
Soil type	Muscatune silt loam
Tillage	Conventional
Row spacing	30 inches
Seeding Rate	35,000 seeds per acre
Planting date	May 17 2024
Emergence date	May 23 2024
Herbicide	Pre-emerge: Harness Xtra [s] (2.5 qt/ac)
	Post-emerge: Laudis [a] (3 oz/ac)
Plot size	4 rows (10 ft) wide by 30 ft long, 5 ft unplanted alleys

[a] Bayer CropScience, St. Louis, MO

Table 2. Corn rootworm treatments

Trt	Treatment	Variety	Trait Package	Insecticide	Seed Treatment
1	VT DoublePro	DKC62-70 [a]	None	None	Clothianadin (0.50 mg ai/seed) Acceleron [FALEH2VQ]
2	VT Double Pro + Force Evo [b] (8 oz/a)	DKC62-70	None	Tefluthrin, 2.1 lbs active ingredient per gallon, emulsifiable concentrate (EC)	Clothianadin (0.50 mg ai/seed) Acceleron [FALEH2VQ]
3	SmartStax	DKC64-34 [a]	Cry3Bb1+Cry34/35Ab1	None	Clothianadin (0.50 mg ai/seed) Acceleron [FALEH2VQ]
4	SmartStax + Force Evo (8 oz/a)	DKC64-34	Cry3Bb1+Cry34/35Ab1	Tefluthrin, 2.1 lbs active ingredient per gallon, EC	Clothianadin (0.50 mg ai/seed) Acceleron [FALEH2VQ]
5	SmartStax Pro	DKC111-33 [a]	Cry3Bb1 + Cry34/35Ab1 + DvSnf7 dsRNA	None	Clothianadin (0.50 mg ai/seed) Acceleron [FALEKH2VQ]
6	SmartStax Pro + Force Evo (8 oz/a)	DKC111-33	Cry3Bb1 + Cry34/35Ab1 + DvSnf7 dsRNA	Tefluthrin, 2.1 lbs active ingredient per gallon, EC	Clothianadin (0.50 mg ai/seed) Acceleron [FALEKH2VQ]
7	VT4 Pro	DKC114-99 [a]	Cry3Bb1 + DvSnf7 dsRNA	None	Clothianadin (1.25 mg ai/seed) Acceleron [FALEKH2VQ]
8	VT4 Pro + Force Evo (8 oz/a)	DKC114-99	Cry3Bb1 + DvSnf7 dsRNA	Tefluthrin, 2.1 lbs active ingredient per gallon, EC	Clothianadin (1.25 mg ai/seed) Acceleron [FALEKH2VQ]

[a] Dekalb, Bayer CropScience, St. Louis, MO; [b] Syngenta Crop Protection, Greensboro, NC.

Table 3. Generalized linear mixed model statistics. Probability distribution is listed in parentheses for each response variable.

Dependent Variable	Date	df (numerator, denominator)	*F*	*P*
Plant stand (lognormal)	6 June	7, 21	2.35	0.061
Root injury rating (gamma) [a]	24 July	7, 21	13.43	< 0.001
Proportion consistency (normal) [a]	24 July	7, 21	18.60	< 0.001
Proportion stalk lodging (normal) [a]	10 Oct.	7, 21	81.27	< 0.001
Yield (lognormal) [a]	17 Oct.	7, 21	117.18	< 0.001

[a] Effect is significant at α = 0.05.

Table 4. Mean (± Standard error [SE]) stand in number of plants per 17.5 ft. of row. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	6 June 2023 (V4)
1	VT DoublePro	36.8 ± 0.6 a
2	VT Double Pro + Force Evo (8 oz/a)	35.8 ± 0.6 a
3	SmartStax	37.0 ± 0.5 a
4	SmartStax + Force Evo (8 oz/a)	38.5 ± 0.9 a
5	SmartStax Pro	37.8 ± 0.4 a
6	SmartStax Pro + Force Evo (8 oz/a)	36.8 ± 0.6 a
7	VT4 Pro	36.6 ± 0.4 a
8	VT4 Pro + Force Evo (8 oz/a)	36.3 ± 0.6 a

Table 5. Mean (± SE) node-injury rating (0-3 scale) of corn rootworm larval feeding injury. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	24 July 2024 (R1)
1	VT DoublePro	0.56 ± 0.08 a
2	VT Double Pro + Force Evo (8 oz/a)	0.21 ± 0.05 b
3	SmartStax	0.14 ± 0.05 b
4	SmartStax + Force Evo (8 oz/a)	0.03 ± 0.01 de
5	SmartStax Pro	0.05 ± 0.02 cde
6	SmartStax Pro + Force Evo (8 oz/a)	0.02 ± 0.01 e
7	VT4 Pro	0.10 ± 0.03 bc
8	VT4 Pro + Force Evo (8 oz/a)	0.06 ± 0.02 cd

Table 6. Mean (± SE) percentage of roots with a node-injury rating (0-3 scale) of less than 0.25. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	24 July 2024 (R1)
1	VT DoublePro	20 ± 12 d
2	VT Double Pro + Force Evo (8 oz/a)	70 ± 10 c
3	SmartStax	80 ± 8 bc
4	SmartStax + Force Evo (8 oz/a)	100 ± 0 a
5	SmartStax Pro	95 ± 5 ab
6	SmartStax Pro + Force Evo (8 oz/a)	100 ± 0 a
7	VT4 Pro	90 ± 6 ab
8	VT4 Pro + Force Evo (8 oz/a)	95 ± 5 ab

Table 7. Mean (± SE) percent stalk lodging per plot. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	10 October 2024 (R6)
1	VT DoublePro	3 ± 1 c
2	VT Double Pro + Force Evo (8 oz/a)	5 ± 3 c
3	SmartStax	75 ± 7 b
4	SmartStax + Force Evo (8 oz/a)	89 ± 5 a
5	SmartStax Pro	4 ± 2 c
6	SmartStax Pro + Force Evo (8 oz/a)	2 ± 1 c
7	VT4 Pro	5 ± 2 c
8	VT4 Pro + Force Evo (8 oz/a)	4 ± 1 c

Table 8. Mean (± SE) corn yield in bushels per acre, corrected to 15.5% moisture. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	17 October 2024 (R6)
1	VT DoublePro	266 ± 10 a
2	VT Double Pro + Force Evo (8 oz/a)	269 ± 14 a
3	SmartStax	62 ± 16 c
4	SmartStax + Force Evo (8 oz/a)	53 ± 10 c
5	SmartStax Pro	276 ± 6 a
6	SmartStax Pro + Force Evo (8 oz/a)	278 ± 9 a
7	VT4 Pro	201 ± 4 b
8	VT4 Pro + Force Evo (8 oz/a)	221 ± 8 b

Evaluation of Poncho and Cruiser at different rates for corn rootworm control, 2024

Location: University of Illinois Agricultural and Biological Engineering Farm, Urbana, IL (40.06971, -88.21116)

Study directors: Nicholas Seiter and Ashley Decker

Objective

To compare the performance different rates of commercially available insecticide seed treatments for control of corn rootworm (particularly western corn rootworm, *Diabrotica virgifera virgifera*) larval damage.

Materials and Methods

Field experiments were established in a randomized complete block design with 4 replicate blocks and 9 treatments. The experimental units were plots of corn (Table 1) that were 4 rows wide and 30 ft. long with 5 ft. of unplanted alley separating plots vertically. Treatments (Table 2) were different rates of Poncho and Cruiser insecticide seed treatments. Plant stands were assessed on 23 May 2024 (growth stage V1), and 29 May 2024 (growth stage V3). Larval corn rootworm damage was rated on 17 July 2024 (R1) by digging 5 root masses per plot from rows 1 and 4, removing all soil using an electric high-pressure water sprayer, and rating damage using the 0-3 Node-injury scale. Percent root and stalk lodging were estimated for each plot on 4 October 2024 (R6). Yields were assessed for each plot on 10 October 2024 by harvesting rows 2 and 3 using a small-plot combine (Massey Ferguson 8XP, Kincaid Equipment, Haven, KS) with a built-in weight and moisture monitor (HarvestMaster, Logan, UT).

Data Analysis

Percent consistency of root ratings for each plot was set equal to the percentage of roots that were given a node-injury rating of less than 0.25. Weights per plot were corrected to a standard weight at 15.5% moisture, then converted to bushels per acre using the standard bushel weight of 56 pounds. Consistency and lodging are reported as percentages but were analyzed as proportions. Plant stand (normal), root injury rating (gamma), proportion consistency (normal), proportion lodging (normal), and yield (normal) were analyzed separately using a generalized linear mixed model (PROC GLIMMIX, SAS version 9.4, SAS Institute, Cary, NC; probability distribution indicated in parentheses for each response variable) where treatment was considered a fixed effect and replicate block was considered a random effect.

Summary

Each seed treatment followed a general trend of reduced pruning as the rate was increased. Only the highest rate of each seed treatment resulted in node-injury ratings that were lower than the untreated plots. Stands, lodging, and yields were not affected by seed treatment.

Funding

Project funding and treated seed for this trial were provided by BASF.

Acknowledgements

We thank Tim Lecher (Farm Manager) for assisting with planting and plot maintenance, academic hourly Grayce Montano, graduate students Yony Callohuari Quispe, and Will Foulke, and undergraduate students Melissa Wahlen, Jason Ballard, Shengnan Wang, Joe Schmid, and Karina Escobedo for assisting with plot maintenance and data collection. In addition, we thank Dr. Joseph Spencer (Illinois Natural History Survey) and his undergraduate research assistants for their help with root damage assessments.

Table 1. Plot information.

Input	Value
Variety	KSC 6205VT2P [a]
Seed treatment	Treatment specific
Previous crop	Trap crop: late-planted, non-Bt field corn inter-seeded with pumpkins
Soil type	Drummer silty clay loam
Tillage	Conventional
Row spacing	30 inches
Seeding Rate	35,000 seeds per acre
Planting date	May 12 2024
Emergence date	May 20 2024
Pre-emerge herbicide	32% UAN (52 gal/ac), Harness Xtra[b] (2 qt/ac)
Post-emerge herbicide	Acuron[c] (3 qt/ac)
Plot size	4 rows (10 ft) wide by 30 ft long, 5 ft unplanted alleys

[a] Kitchen Seed Company, Arthur, IL; [b] Bayer CropScience, St. Louis, MO; [c] Syngenta Crop Protection, Greensboro, NC

Table 2. Corn rootworm treatments

Trt	Insecticide treatment	Active ingredient
1	Fungicide Only	n/a
2	Poncho 600 [a] (0.25 mg ai/seed)	clothianidin, 5 lbs active ingredient (AI) per gallon
3	Poncho 600 (0.5 mg ai/seed)	clothianidin, 5 lbs AI per gallon
4	Poncho 600 (0.75 mg ai/seed)	clothianidin, 5 lbs AI per gallon
5	Poncho 600 (1.25 mg ai/seed)	clothianidin, 5 lbs AI per gallon
6	Cruiser 5 FS [b] (0.25 mg ai/seed)	thiamethoxam, 5 lbs AI per gallon
7	Cruiser 5 FS (0.50 mg ai/seed)	thiamethoxam, 5 lbs AI per gallon
8	Cruiser 5 FS (0.75 mg ai/seed)	thiamethoxam, 5 lbs AI per gallon
9	Cruiser 5 FS (1.25 mg ai/seed)	thiamethoxam, 5 lbs AI per gallon

[a] BASF Corporation, Research Triangle Park, NC; [b] Syngenta Crop Protection, Greensboro, NC

Table 3. Generalized linear mixed model statistics. Probability distribution of each response variable is listed in parentheses.

Dependent Variable	Date	df (numerator, denominator)	*F*	*P*
Plant stand	23 May	8, 24	0.60	0.770
	29 May	8, 24	0.66	0.717
Root injury rating [a]	17 July	8, 24	2.40	0.047
Percent consistency	17 July	8, 24	1.28	0.298
Percent root lodging	4 Oct.	8, 24	0.66	0.717
Percent stalk lodging	4 Oct.	8, 24	0.66	0.725
Yield	10 Oct.	8, 24	0.66	0.722

[a] Effect is significant at $\alpha = 0.05$.

Table 4. Mean (± Standard error [SE]) stand in number of plants per 17.5 ft. of row. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference ($\alpha = 0.05$).

Trt	Treatment	23 May 2024 (V1)	29 May 2024 (V3)
1	Fungicide Only	35.0 ± 0.7 a	35.5 ± 0.8 a
2	Poncho (0.25 mg ai/seed)	36.3 ± 0.6 a	37.4 ± 0.6 a
3	Poncho (0.5 mg ai/seed)	35.0 ± 1.1 a	35.5 ± 1.1 a
4	Poncho (0.75 mg ai/seed)	35.0 ± 0.8 a	35.3 ± 0.9 a
5	Poncho (1.25 mg ai/seed)	36.6 ± 1.1 a	36.8 ± 0.8 a
6	Cruiser (0.25 mg ai/seed)	37.1 ± 0.6 a	37.6 ± 0.7 a
7	Cruiser (0.5 mg ai/seed)	35.9 ± 1.8 a	35.6 ± 1.7 a
8	Cruiser (0.75 mg ai/seed)	35.8 ± 1.0 a	36.4 ± 1.0 a
9	Cruiser (1.25 mg ai/seed)	35.3 ± 0.9 a	34.9 ± 1.4 a

Table 5. Mean (± SE) node-injury rating (0-3 scale) of corn rootworm larval feeding damage. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference ($\alpha = 0.05$).

Trt	Treatment	17 July 2024 (R1)
1	Fungicide Only	1.19 ± 0.18 a
2	Poncho (0.25 mg ai/seed)	0.66 ± 0.15 abc
3	Poncho (0.5 mg ai/seed)	0.60 ± 0.13 abc
4	Poncho (0.75 mg ai/seed)	0.52 ± 0.10 abc
5	Poncho (1.25 mg ai/seed)	0.33 ± 0.10 c
6	Cruiser (0.25 mg ai/seed)	0.99 ± 0.17 ab
7	Cruiser (0.5 mg ai/seed)	1.08 ± 0.19 ab
8	Cruiser (0.75 mg ai/seed)	0.66 ± 0.16 abc
9	Cruiser (1.25 mg ai/seed)	0.47 ± 0.08 bc

Table 6. Mean (± SE) percentage of roots with a node-injury rating (0-3 scale) of less than 0.25. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference ($\alpha = 0.05$).

Trt	Treatment	17 July 2024 (R1)
1	Fungicide Only	15 ± 10 a
2	Poncho (0.25 mg ai/seed)	40 ± 8 a
3	Poncho (0.5 mg ai/seed)	30 ± 13 a
4	Poncho (0.75 mg ai/seed)	30 ± 10 a
5	Poncho (1.25 mg ai/seed)	60 ± 16 a
6	Cruiser (0.25 mg ai/seed)	20 ± 14 a
7	Cruiser (0.5 mg ai/seed)	30 ± 17 a
8	Cruiser (0.75 mg ai/seed)	35 ± 13 a
9	Cruiser (1.25 mg ai/seed)	45 ± 10 a

Table 7. Mean (± SE) percent root lodging (“goosenecked” lodging) per plot. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	4 October 2024 (R6)
1	Fungicide Only	4 ± 2 a
2	Poncho (0.25 mg ai/seed)	2 ± 1 a
3	Poncho (0.5 mg ai/seed)	3 ± 1 a
4	Poncho (0.75 mg ai/seed)	4 ± 2 a
5	Poncho (1.25 mg ai/seed)	5 ± 3 a
6	Cruiser (0.25 mg ai/seed)	7 ± 3 a
7	Cruiser (0.5 mg ai/seed)	4 ± 2 a
8	Cruiser (0.75 mg ai/seed)	4 ± 2 a
9	Cruiser (1.25 mg ai/seed)	2 ± 1 a

Table 8. Mean (± SE) percent stalk lodging per plot. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	4 October 2024 (R6)
1	Fungicide Only	8 ± 3 a
2	Poncho (0.25 mg ai/seed)	9 ± 4 a
3	Poncho (0.5 mg ai/seed)	10 ± 2 a
4	Poncho (0.75 mg ai/seed)	10 ± 3 a
5	Poncho (1.25 mg ai/seed)	14 ± 5 a
6	Cruiser (0.25 mg ai/seed)	15 ± 3 a
7	Cruiser (0.5 mg ai/seed)	10 ± 2 a
8	Cruiser (0.75 mg ai/seed)	8 ± 2 a
9	Cruiser (1.25 mg ai/seed)	8 ± 4 a

Table 9. Mean (± SE) corn yield in bushels per acre, corrected to 15.5% moisture. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	10 October 2024 (R6)
1	Fungicide Only	179 ± 9 a
2	Poncho (0.25 mg ai/seed)	195 ± 11 a
3	Poncho (0.5 mg ai/seed)	185 ± 13 a
4	Poncho (0.75 mg ai/seed)	193 ± 7 a
5	Poncho (1.25 mg ai/seed)	184 ± 15 a
6	Cruiser (0.25 mg ai/seed)	175 ± 12 a
7	Cruiser (0.5 mg ai/seed)	173 ± 18 a
8	Cruiser (0.75 mg ai/seed)	185 ± 9 a
9	Cruiser (1.25 mg ai/seed)	185 ± 12 a

Evaluation of liquid in-furrow insecticides for corn rootworm control, 2024

Location: University of Illinois Agricultural and Biological Engineering Farm, Urbana, IL (40.06957, -88.21125)

Study directors: Nicholas Seiter and Ashley Decker

Objective

To evaluate the performance of liquid in-furrow soil-applied insecticides for control of corn rootworm (particularly western corn rootworm, *Diabrotica virgifera virgifera*) larval damage on a non-CRW Bt hybrid with no insecticide seed treatment.

Materials and Methods

Field experiments were established in a randomized complete block design with 4 replicate blocks and 8 treatments. The experimental units were plots of corn (Table 1) that were 4 rows wide and 30 ft. long with 5 ft. of unplanted alley separating plots vertically. Treatments (Table 2) were combinations of trait packages and soil-applied insecticides using a liquid fertilizer as a carrier. Plant stands were assessed on 23 May (growth stage V1), and 29 May 2024 (growth stage V3). Larval corn rootworm damage was rated on 31 July 2024 (R1) by digging 5 root masses per plot from rows 1 and 4, removing all soil using an electric high-pressure water sprayer, and rating damage using the 0-3 Node-injury scale. Percent lodging was estimated for each plot on 3 October 2024 (R6). Yields were assessed for each plot on 10 October 2024 by harvesting rows 2 and 3 using a small-plot combine (Massey Ferguson 8XP, Kincaid Equipment, Haven, KS) with a built-in weight and moisture monitor (HarvestMaster, Logan, UT).

Data Analysis

Percent consistency of root ratings for each plot was set equal to the percentage of roots that were given a node-injury rating of less than 0.25. Weights per plot were corrected to a standard weight at 15.5% moisture, then converted to bushels per acre using the standard bushel weight of 56 pounds. Consistency and lodging are reported as percentages but were analyzed as proportions. Plant stand (lognormal), root injury rating (gamma), proportion consistency (normal), proportion gooseneck lodging (normal), proportion stalk lodging (normal) and yield (lognormal) were analyzed separately using a generalized linear mixed model (PROC GLIMMIX, SAS version 9.4, SAS Institute, Cary, NC; probability distribution indicated in parentheses for each response variable) where treatment was considered a fixed effect and replicate block was considered a random effect.

Summary

Index, Aztec HC, and Force Evo all resulted in node-injury ratings that were reduced compared with the untreated plots and those treated with Plinazolin; Index resulted in ratings that were further reduced compared with both Force Evo and Aztec HC, and Force Evo resulted in ratings that were reduced compared with both Nurizma and Capture LFR. Corn yields were not affected by the insecticide treatments.

Funding

Project funding was provided by Syngenta; insecticide materials for testing were provided by Syngenta and FMC. Seed was provided by Bayer Crop Science.

Acknowledgements

We thank Tim Lecher (Farm Manager) for assisting with planting and plot maintenance, academic hourly Grayce Montano, graduate students Yony Callohuari Quispe, and Will Foulke, and undergraduate students Melissa Wahlen, Jason Ballard, Shengnan Wang, Joe Schmid, and Karina Escobedo for assisting with plot maintenance and data collection. In addition, we thank Dr. Joseph Spencer (Illinois Natural History Survey) and his undergraduate research assistants for their help with root damage assessments.

Table 1. Plot information.

Input	Value
Seed variety	NK1188-Aa[a]
Previous crop	Trap crop: late-planted, non-Bt field corn inter-seeded with pumpkins
Soil type	Drummer silty clay loam
Tillage	Conventional
Row spacing	30 inches
Seeding Rate	35,000 seeds per acre
Planting date	May 12 2024
Emergence date	May 20 2024
Herbicide	Pre-emerge: 32% UAN (52 gal/ac), Harness Xtra[b] (2 qt/ac)
	Post-emerge: Acuron[a] (3 qt/ac)
Plot size	4 rows (10 ft) wide by 30 ft long, 5 ft unplanted alleys

[a] Syngenta Crop Protection, Greensboro, NC; [b] Bayer CropScience, St. Louis, MO

Table 2. Corn rootworm treatments

Trt	Treatment	Insecticide
1	Untreated Check	n/a
2	Index [a] (12.5 fl. oz/a)	clorethoxyfos (25.8%) + bifenthrin (4.2%), 2.8 lbs active ingredient (AI) per gallon, capsule suspension
3	Nurizma [b] (1.03 fl. oz/a)	broflanilide, 2.5 lbs AI per gallon, suspension concentrate (SC)
4	Aztec HC [a] (1.63 lb/a)	8.9% tebupirimphos + 0.44% cyfluthrin, high concentration granules
5	Force Evo [c] (8 fl. oz/a)	Tefluthrin, 2.1 lb AI per gallon, emulsifiable concentrate
6	Plinazolin [c] (5.25 fl. oz/a)	Pre-commercial
7	Capture LFR [d] (12 fl. oz/a)	bifenthrin, 1.5 lbs AI per gallon, SC

[a] AMVAC Chemical Corporation, Los Angeles, CA; [b] BASF Corporation, Research Triangle Park, NC; [c] Syngenta Crop Protection, Greensboro, NC; [d] FMC Corporation, Philadelphia, PA.

Table 3. Generalized linear mixed model statistics. Probability distribution is listed in parentheses after each dependent variable.

Dependent Variable	Date	df (numerator, denominator)	*F*	*P*
Plant stand (lognormal)	23 May	6, 18	1.08	0.411
Plant stand (lognormal)	29 May	6, 18	2.09	0.106
Root injury rating (gamma) [a]	31 July	6, 18	13.32	< 0.001
Percent consistency (normal) [a]	31 July	6, 18	17.05	< 0.001
Percent root lodging (normal)	3 Oct.	6, 18	2.15	0.097
Percent stalk lodging (normal)	3 Oct.	6, 18	1.70	0.179
Yield (lognormal)	10 Oct.	6, 18	2.42	0.068

[a] Effect is significant at $\alpha = 0.05$.

Table 4. Mean (± Standard error [SE]) stand in number of plants per 17.5 ft. of row. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	23 May 2024 (V1)	29 May 2024 (V3)
1	Untreated	35.6 ± 0.6 a	35.4 ± 0.6 a
2	Index (12.5 oz/a)	36.9 ± 0.3 a	36.4 ± 0.3 a
3	Nurizma (1.03 oz/a)	36.0 ± 0.4 a	35.8 ± 0.6 a
4	Aztec HC (1.63 lb/a)	36.4 ± 0.6 a	35.8 ± 0.5 a
5	Force Evo (8 oz/a)	36.6 ± 0.3 a	35.9 ± 0.2 a
6	Plinazolin (5.25 oz/a)	37.0 ± 0.8 a	37.0 ± 0.6 a
7	Capture LFR (12 oz/a)	36.8 ± 0.3 a	37.4 ± 0.7 a

Table 5. Mean (± SE) node-injury rating (0-3 scale) of corn rootworm larval feeding damage. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	31 July 2024 (R1)
1	Untreated	1.22 ± 0.20 a
2	Index (12.5 oz/a)	0.10 ± 0.025 d
3	Nurizma (1.03 oz/a)	0.79 ± 0.20 ab
4	Aztec HC (1.63 lb/a)	0.44 ± 0.17 bc
5	Force Evo (8 oz/a)	0.22 ± 0.04 c
6	Plinazolin (5.25 oz/a)	1.29 ± 0.20 a
7	Capture LFR (12 oz/a)	0.81 ± 0.12 ab

Table 6. Mean (± SE) percentage of roots with a node-injury rating (0-3 scale) of less than 0.25. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	31 July 2024 (R1)
1	Untreated	15 ± 10 c
2	Index (12.5 oz/a)	90 ± 6 a
3	Nurizma (1.03 oz/a)	30 ± 13 c
4	Aztec HC (1.63 lb/a)	65 ± 13 b
5	Force Evo (8 oz/a)	70 ± 10 ab
6	Plinazolin (5.25 oz/a)	10 ± 6 c
7	Capture LFR (12 oz/a)	10 ± 6 c

Table 7. Mean (± SE) percent root lodging (“goosenecked” lodging) per plot. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	3 October 2024 (R6)
1	Untreated	9 ± 5 a
2	Index (12.5 oz/a)	4 ± 3 a
3	Nurizma (1.03 oz/a)	14 ± 7 a
4	Aztec HC (1.63 lb/a)	9 ± 2 a
5	Force Evo (8 oz/a)	5 ± 3 a
6	Plinazolin (5.25 oz/a)	6 ± 2 a
7	Capture LFR (12 oz/a)	19 ± 3 a

Table 8. Mean (± SE) percent stalk lodging per plot. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	3 October 2024 (R6)
1	Untreated	0.3 ± 0.3 a
2	Index (12.5 oz/a)	0 ± 0 a
3	Nurizma (1.03 oz/a)	0 ± 0 a
4	Aztec HC (1.63 lb/a)	0.3 ± 0.3 a
5	Force Evo (8 oz/a)	0 ± 0 a
6	Plinazolin (5.25 oz/a)	1 ± 0.3 a
7	Capture LFR (12 oz/a)	0 ± 0 a

Table 9. Mean (± SE) corn yield in bushels per acre, corrected to 15.5% moisture. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	10 October 2024 (R6)
1	Untreated	202 ± 13 a
2	Index (12.5 oz/a)	234 ± 8 a
3	Nurizma (1.03 oz/a)	235 ± 3 a
4	Aztec HC (1.63 lb/a)	219 ± 9 a
5	Force Evo (8 oz/a)	229 ± 4 a
6	Plinazolin (5.25 oz/a)	210 ± 8 a
7	Capture LFR (12 oz/a)	220 ± 5 a

Evaluation of 3RIVE insecticide formulations for control of corn rootworm larvae – 2024

Location: University of Illinois Agricultural and Biological Engineering Farm, Urbana, IL (40.06947, -88.21122)

Study directors: Nicholas Seiter and Ashley Decker

Objective

To evaluate the performance of soil pesticides applied in-furrow using a research-scale 3RIVE applicator compared with standard liquid formulations for control of corn rootworm (particularly western corn rootworm, *Diabrotica virgifera virgifera*) larval damage.

Materials and Methods

Field experiments were established in a randomized complete block design with 4 replicate blocks and 5 treatments. The experimental units were plots of corn (Table 1) that were 4 rows wide and 30 ft. long with 5 ft. of unplanted alley separating plots vertically. Treatments (Table 2) were soil insecticides applied in-furrow at planting, along with an untreated control. Plant stands were assessed on 23 May (growth stage V1), 29 May (growth stage V3), and 4 June 2024 (growth stage V5). Plot vigor was assessed on 6 June 2024 (growth stage V4) using a 1-10 scale where 10 is best. Larval corn rootworm damage was rated on 2 August 2024 (R1) by digging 5 root masses per plot from rows 1 and 4, removing all soil using an electric high-pressure water sprayer, and rating damage using the 0-3 node-injury scale. Percent lodging was estimated for each plot on 4 October 2024 (R6). Yields were assessed for each plot on 10 October 2024 by harvesting rows 2 and 3 using a small-plot combine (Massey Ferguson 8XP, Kincaid Equipment, Haven, KS) with a built-in weight and moisture monitor (HarvestMaster, Logan, UT).

Data Analysis

Percent consistency of root ratings for each plot was set equal to the percentage of roots that were given a node-injury rating of less than 0.25. Weights per plot were corrected to a standard weight at 15.5% moisture, then converted to bushels per acre using the standard bushel weight of 56 pounds. Consistency and lodging are reported as percentages but were analyzed as proportions. No phytotoxicity or stalk lodging was observed, and no differences in plot vigor were observed (i.e. all plots received a vigor score of '7'); therefore, these response variables were not analyzed and are not displayed. Plant stand (lognormal), root injury rating (gamma), proportion consistency (normal), proportion gooseneck lodging (normal), and yield (lognormal) were analyzed separately using a generalized linear mixed model (PROC GLIMMIX, SAS version 9.4, SAS Institute, Cary, NC; probability distribution indicated in parentheses for each response variable) where treatment was considered a fixed effect and replicate block was considered a random effect.

Summary

Only Force Evo resulted in root injury that was reduced compared with the untreated control (whether measured by node-injury or by percent consistency) – the other treatments we tested were no different from the untreated control. While the rootworm pressure we observed was enough to separate treatments, it did not result in reductions in yield.

Funding

FMC Corporation provided project funding and pesticide materials. Syngenta Crop Protection provided seed.

Acknowledgements

We thank Tim Lecher (Farm Manager) for assisting with planting and plot maintenance, academic hourly Grayce Montano, graduate students Yony Callohuari Quispe, and Will Foulke, and undergraduate students Melissa Wahlen, Jason Ballard, Shengnan Wang, Joe Schmid, and Karina Escobedo for assisting with plot maintenance and data collection. In addition, we thank Dr. Joseph Spencer (Illinois Natural History Survey) and his undergraduate research assistants for their help with root damage assessments.

Table 1. Plot information.

Input	Value
Seed variety	NK1188-AA[a]
Seed treatment	fungicide only (Vayantis + Vibrance Cinco)[a]
Previous crop	Trap crop: late-planted, non-Bt field corn inter-seeded with pumpkins
Soil type	Drummer silt loam/ Elburn silt loam
Tillage	Conventional
Row spacing	30 inches
Seeding Rate	34,500 seeds per acre
Planting date	13 May 24
Emergence date	20 May 24
Herbicide	Pre-emerge: 32% UAN (52 gal/ac), Harness Xtra[b] (2 qt/ac)
	Post-emerge: Acuron[a] (3 qt/ac)
Plot size	4 rows (10 ft) wide by 30 ft long, 5 ft unplanted alleys

[a] Syngenta Crop Protection, Greensboro, NC; [b] Bayer CropScience, St. Louis, MO

Table 2. Corn rootworm treatments

Trt	Treatment	Rate	Insecticide active ingredient
1	Untreated		n/a
2	XSK03-R003 3D[a]	8.8 fl oz/a	Pre-commercial, suspension concentrate (SC)
3	Capture 3Rive[a]	8 fl oz/a	Bifenthrin, 1.6 lbs active ingredient (AI) per gallon, SC
4	Ethos 3D[a]	9.1 fl oz/a	Bifenthrin (1.4 lbs AI per gallon) + *Bacillus amyloliquefaciens* strain D747 (1.0×10^{10} colony-forming units per ml), SC
5	Force Evo[b]	10 fl oz/a	Tefluthrin, 2.1 lb AI per gallon, emulsifiable concentrate

[a] FMC Corporation, Philadelphia, PA; [b] Syngenta Crop Protection, Greensboro, NC

Table 3. Generalized linear mixed model statistics.

Dependent Variable	Date	df (numerator, denominator)	*F*	*P*
Phytotoxicity	4 Jun	-	-	-
Vigor	6 Jun	-	-	-
Plant stand (lognormal)	23 May	4, 12	1.78	0.198
Plant stand (lognormal)	29 May	4, 12	0.53	0.72
Plant stand (lognormal)	4 Jun	4, 12	0.75	0.574
Root injury rating (gamma)	2 Aug	4, 12	13.73	< 0.001[a]
Proportion consistency (normal)	2 Aug	4, 12	9.67	0.001[a]
Proportion root lodging (normal)	3 Oct	4, 12	1.05	0.424
Proportion stalk lodging	3 Oct	-	-	-
Yield (lognormal)	10 Oct	4, 12	1.51	0.261

[a] Effect is significant at α = 0.05

Table 4. Mean (± Standard error [SE]) stand in number of plants per 17.5 ft. of row. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05)

Trt	Treatment	23 May 2024 (V1)	29 May 2024 (V3)	4 June 2024 (V5)
1	Untreated	32.1 ± 0.5 a	33.0 ± 0.9 a	33.3 ± 0.6 a
2	XSK03-R003 3D (8.8 oz/a)	31.1 ± 0.6 a	32.0 ± 0.7 a	33.0 ± 0.6 a
3	Capture 3RIVE 3D (8 oz/a)	31.5 ± 1.1 a	33.0 ± 0.6 a	33.0 ± 0.7 a
4	Ethos 3D (9.10 oz/a)	33.8 ± 0.6 a	33.4 ± 0.5 a	34.1 ± 0.4 a
5	Force Evo (10 oz/a)	33.3 ± 0.7 a	33.1 ± 0.5 a	33.6 ± 0.7 a

Table 5. Mean (± SE) node-injury rating (0-3 scale) of corn rootworm larval feeding injury. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05)

Trt	Treatment	2 August 2024 (R1)
1	Untreated	0.74 ± 0.14 a
2	XSK03-R003 3D (8.8 oz/a)	1.15 ± 0.16 a
3	Capture 3RIVE 3D (8 oz/a)	0.91 ± 0.17 a
4	Ethos 3D (9.10 oz/a)	0.90 ± 0.17 a
5	Force Evo (10 oz/a)	0.18 ± 0.03 b

Table 6. Mean (± SE) percentage of roots with a node-injury rating (0-3 scale) of less than 0.25. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05)

Trt	Treatment	2 August 2024 (R1)
1	Untreated	30 ± 13 b
2	XSK03-R003 3D (8.8 oz/a)	5 ± 5 b
3	Capture 3RIVE 3D (8 oz/a)	15 ± 10 b
4	Ethos 3D (9.10 oz/a)	25 ± 15 b
5	Force Evo (10 oz/a)	75 ± 5 a

Table 7. Mean (± SE) percent root lodging ("goosenecked" lodging) per plot. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05)

Trt	Treatment	4 October 2024 (R6)
1	Untreated	35 ± 13 a
2	XSK03-R003 3D (8.8 oz/a)	51 ± 17 a
3	Capture 3RIVE 3D (8 oz/a)	51 ± 16 a
4	Ethos 3D (9.10 oz/a)	78 ± 9 a
5	Force Evo (10 oz/a)	52 ± 18 a

Table 8. Mean (± SE) corn yield in bushels per acre, corrected to 15.5% moisture. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05)

Trt	Treatment	10 October 2024 (R6)
1	Untreated	233 ± 7 a
2	XSK03-R003 3D (8.8 oz/a)	234 ± 7 a
3	Capture 3RIVE 3D (8 oz/a)	250 ± 4 a
4	Ethos 3D (9.10 oz/a)	264 ± 20 a
5	Force Evo (10 oz/a)	233 ± 14 a

Evaluation of MBI-306 and Capture LFR applied in-furrow using 10-34-0 starter fertilizer for control of corn rootworm, 2024

Location: University of Illinois Agricultural and Biological Engineering Farm, Urbana, IL (40.006954, -88.21233)

Study directors: Nicholas Seiter and Ashley Decker

Objective

To assess the performance of MBI-306 for control of corn rootworm (particularly western corn rootworm, *Diabrotica virgifera virgifera*) larval damage.

Materials and Methods

Field experiments were established in a randomized complete block design with 4 replicate blocks and 4 treatments. The experimental units were plots of corn (Table 1) that were 4 rows wide and 30 ft. long with 5 ft. of unplanted alley separating plots vertically. Treatments (Table 2) were soil insecticides applied in-furrow using liquid starter fertilizer (10-34-0) or water as a carrier. Plant stands were assessed on 29 May (growth stage V1), and 21 June 2024 (growth stage V6). Larval corn rootworm damage was rated on 23 July 2024 (R1) by digging 5 root masses per plot from rows 1 and 4, removing all soil using an electric high-pressure water sprayer, and rating damage using the 0-3 Node-injury scale. Percent lodging was estimated for each plot on 3 October 2024 (R6). Yields were assessed for each plot on 10 October 2024 by harvesting rows 2 and 3 using a small-plot combine (Massey Ferguson 8XP, Kincaid Equipment, Haven, KS) with a built-in weight and moisture monitor (HarvestMaster, Logan, UT).

Data Analysis

Percent consistency of root ratings for each plot was set equal to the percentage of roots that were given a node-injury rating of less than 0.25. Weights per plot were corrected to a standard weight at 15.5% moisture, then converted to bushels per acre using the standard bushel weight of 56 pounds. Consistency and lodging are reported as percentages but were analyzed as proportions. Plant stand (lognormal), root injury rating (gamma), proportion consistency (normal), and yield (lognormal) were analyzed separately using a generalized linear mixed model (PROC GLIMMIX, SAS version 9.4, SAS Institute, Cary, NC; probability distribution indicated in parentheses for each response variable) where treatment was considered a fixed effect and replicate block was considered a random effect. Because no root or stalk lodging was observed in any of the plots, these data are not displayed.

Summary

Capture LFR resulted in lower node-injury ratings than either the untreated plots or MBI-306 applied in liquid fertilizer. However, overall root injury was low, and yield was not affected by our treatments.

Funding

Project funding and insecticide materials were provided by Pro Farm Group. Additional material was provided by FMC Corporation. Seed was provided by Bayer CropScience.

Acknowledgements

We thank Tim Lecher (Farm Manager) for assisting with planting and plot maintenance, academic hourly Grayce Montano, graduate students Yony Callohuari Quispe, and Will Foulke, and undergraduate students Melissa Wahlen, Jason Ballard, Shengnan Wang, Joe Schmid, and Karina Escobedo for assisting with plot maintenance and data collection. In addition, we thank Dr. Joseph Spencer (Illinois Natural History Survey) and his undergraduate research assistants for their help with root damage assessments.

Table 1. Plot information.

Input	Value
Seed Variety	DKC 62-70 (VT Double Pro) [a]
Seed Treatment	Clothianadin (0.50 mg ai/seed) Acceleron [FALEH2VQ] [a]
Previous crop	Trap crop: late-planted, non-Bt field corn inter-seeded with pumpkins
Soil type	Drummer silt loam/Elburn silt loam
Tillage	Conventional
Row spacing	30 inches
Seeding Rate	35,000 seeds per acre
Planting date	May 20 2024
Emergence date	May 28 2024
Herbicide	Pre-emerge: 32% UAN (52 gal/ac), Harness Xtra[a] (2 qt/ac)
	Post-emerge: Acuron[b] (3 qt/ac)
Plot size	4 rows (10 ft) wide by 30 ft long, 5 ft unplanted alleys

[a] Bayer CropScience, St. Louis, MO; [b] Syngenta Crop Protection, Greensboro, NC

Table 2. Corn rootworm treatments.

Trt	Soil Insecticide	Formulation
1	Liquid fertilizer only	N/a
2	Capture LFR [a] (17 oz/a) in liquid fertilizer	Bifenthrin, 1.5 lbs active ingredient per gallon, suspension concentrate (SC)
3	MBI-306 [b] (20 oz/a) in liquid fertilizer	Pre-commercial, SC
4	MBI-306 (20 oz/a) in water	Pre-commercial, SC

[a] FMC Corporation, Philadelphia, PA; [b] Pro Farm Group, Davis, CA

Table 3. Generalized linear mixed model statistics. Probability distribution of each response variable is listed in parentheses.

Dependent Variable	Date	df (numerator, denominator)	*F*	*P*
Plant stand (lognormal)	29 May	3, 9	2.23	0.154
Plant stand (lognormal)	21 June	3, 9	0.23	0.875
Root injury rating (gamma) [a]	23 July	3, 9	4.12	0.043
Proportion consistency (normal)	23 July	3, 9	1.53	0.273
Yield (lognormal)	10 Oct.	3, 9	0.41	0.752

[a] Effect is significant at $\alpha = 0.05$

Table 4. Mean (± Standard error [SE]) stand in number of plants per 17.5 ft. of row. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference ($\alpha = 0.05$).

Trt	Treatment	29 May 2024 (V1)	21 June 2024 (V6)
1	Liquid fertilizer only	33.9 ± 0.9 a	35.1 ± 0.8 a
2	Capture LFR (17 oz/a) in liquid fertilizer	35.1 ± 0.5 a	36.1 ± 0.5 a
3	MBI-306 (20 oz/a) in liquid fertilizer	35.3 ± 0.5 a	36.0 ± 0.6 a
4	MBI-306 (20 oz/a) in water	33.5 ± 0.8 a	36.1 ± 1.2 a

Table 5. Mean (± SE) node-injury rating (0-3 scale) of corn rootworm larval feeding injury. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	23 July 2024 (R1)
1	Liquid fertilizer only	0.29 ± 0.07 a
2	Capture LFR (17 oz/a) in liquid fertilizer	0.08 ± 0.02 b
3	MBI-306 (20 oz/a) in liquid fertilizer	0.24 ± 0.06 a
4	MBI-306 (20 oz/a) in water	0.18 ± 0.05 ab

Table 6. Mean (± SE) percentage of roots with a node-injury rating (0-3 scale) of less than 0.25. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	23 July 2024 (R1)
1	Liquid fertilizer only	60 ± 12 a
2	Capture LFR (17 oz/a) in liquid fertilizer	95 ± 5 a
3	MBI-306 (20 oz/a) in liquid fertilizer	65 ± 24 a
4	MBI-306 (20 oz/a) in water	70 ± 10 a

Table 7. Mean (± SE) corn yield in bushels per acre, corrected to 15.5% moisture. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	10 October 2024 (R6)
1	Liquid fertilizer only	273 ± 16 a
2	Capture LFR (17 oz/a) in liquid fertilizer	246 ± 21 a
3	MBI-306 (20 oz/a) in liquid fertilizer	252 ± 21 a
4	MBI-306 (20 oz/a) in water	250 ± 16 a

Assessing insect pest effects on yield and ROI of pest control inputs

Study directors: Nicholas Seiter and Ashley Decker

Locations:

University of Illinois Orr Agricultural Research and Demonstration Center, Baylis, IL (39.790219, -90.827412)

University of Illinois Crop Sciences Research and Education Center, Champaign, IL (40.045759, -88.233149)

University of Illinois Northwestern Illinois Research and Demonstration Center, Monmouth, IL (40.933305, -90.726045)

Illinois Extension Ewing Demonstration Center, Ewing, IL (38.095240, -88.844603)

Illinois Valley Community College Extension Demonstration Plot, Oglesby, IL

Commercial Farm near Bluff City, IL

Objective

To assess how often insecticides applied to soybean seed or to the canopy at R3 and/or R5 result in protected yield.

Materials and Methods

Field experiments were established as a randomized complete block design with 3 or 4 replicate blocks and 2 or 5 treatments. The experimental units were plots of soybeans (Table 1) that were at least 12 rows wide and 100 ft. long. The treatments (Table 2) were different combinations of insecticides applied either as a seed treatment (imidacloprid at 0.091 mg active ingredient per seed) or as a broadcast application to the foliage at beginning pod formation (growth stage R3) or beginning seed formation (R5). Broadcast applications used at each site were as follows: Warrior II Zeon at 1.96 fl oz/a (2.08 lb lambda-cyhalothrin per gallon, Syngenta Crop Protection, Greensboro, NC) was used for all applications at Champaign, Monmouth, Ewing, and Oglesby, and for the R3 application at Bluff City); Baythroid XL at 2.0 fl oz/a (1 lb beta-cyfluthrin per gallon, Bayer CropScience, St. Louis, MO) was used for all applications at Baylis; and Bifen 2EC Select at 6.4 fl oz/a (2 lb bifenthrin per gallon, Prime Source LLC, Middlesex, NC) was used for the R5 application at Bluff City. Plant stands and insect injury were assessed by counting the number of total plants and injured plants in a 17’ 5” section of row until the crop canopy was tall enough to sample using a sweep net (approximately 20-inches high). Subsequently, sweep-net insect counts were taken every other week until beginning maturity (R7) by sweeping a 15-inch diameter net through the canopy 25 times per plot, taking at least one full step between each sweep. All insects collected from each sweep-net sample were stored in a resealable plastic bag and brought back to the lab, where they were frozen until they could be processed. Sample processing consisted of identifying and counting all insect specimens, including pests, beneficial insects, and non-economically important species. When applicable, the percent of the canopy defoliated by insect feeding was visually estimated during stand and/or sweep net evaluations. Plots were harvested using either a 2-row plot combine with built-in weighing system (Baylis, Champaign, Monmouth, Ewing) or using a commercial-scale combine with a yield monitor (Oglesby, Bluff City).

Data Analysis

Weights per plot were corrected to 13% moisture, then converted to bushels per acre using the standard bushel weight of 60 pounds. Insect counts and yield were analyzed separately using a generalized linear mixed model where treatment was considered a fixed effect and replicate block was considered a random effect.

Summary

During the first year of this study, the average treatment counts did not exceed an economic threshold for any insect pest at any of our six locations. Only one individual plot (at Monmouth) exceeded an economic threshold, reaching a peak density of 10 stink bugs per 25 sweeps on 30 August. The only effects on yield caused by our treatments were a negative effect of an R5 application at Baylis where the sprayer did not clear the canopy (Tables 3 and 4).

Baylis

Plots where an insecticide seed treatment were used had higher initial stands than untreated plots (Table 5). Dectes stem borer activity was elevated at this site but was not affected by our treatments. Japanese beetle densities were the highest here out of all sites, but defoliation was below 3% and was not affected by our treatments. Stink bugs were also elevated but did not reach an economic threshold. Yields were reduced by the R5 insecticide application because the ground applicator was too low and damaged the soybean canopy (Table 4); otherwise, yields were not impacted by our treatments.

Champaign

High densities of bean leaf beetle adults (up to around 60 in 25 sweeps) were observed late in the season, and the R5 insecticide application reduced their densities compared with the other plots (Table 6). Other insect pests were present at low population densities, and yields were not affected by our insecticide treatments.

Monmouth

This location had the highest stink bug densities out of all our sites, reaching an average of up to 6.5 in 25 sweeps. However, yields were not affected by our insecticide treatments (Table 4).

Ewing

Defoliation due to insect pests was reduced from about 2.5% in untreated plots to approximately 1% in plots that were treated with an insecticide at R3 (Table 7). However, pest pressure overall was low at this site, and yields were not affected by our insecticide treatments (Table 4).

Oglesby

The experimental treatment at this site was an R5 foliar application of a pyrethroid insecticide (applied using a drone) compared with untreated plots. While bean leaf beetles were reduced by the application (Table 8), other pest densities at this site were low and yield was not affected (Table 4).

Bluff City

The experimental treatment at this site was an R5 foliar application of a pyrethroid insecticide that followed an earlier application at R3 (both applied using a drone), while the control plots were only treated at R3. Insect pest densities at this site were extremely low, and yield was not affected by the experimental treatment (Table 4).

Funding

This was Year 1 of a planned multi-year project funded by the Illinois Soybean Association.

Acknowledgements

We thank Luke Merritt, Darrin Joos, Alan Tammen, Greg Steckel, Marty Johnson, Andy Fisher, Jacqueline Kellerman, Willard Mott, Adam Braun, and Dennis Bowman for assisting with planting, plot maintenance, making applications, and/or harvest. We also thank Yony Callohuari Quispe, Will Foulke, Grayce Montano, Joe Schmid, Melissa Wahlen, Shengnan Wang, Karena Escobedo, and Jason Ballard for their assistance with insect sampling, plot maintenance, and data collection.

Table 1. Agronomic information.

Location	Soybean variety	Planting date	Seeding rate	Tillage
Baylis	LGS3216E3[a]	10 Apr	140,000	Conventional
Champaign	LGS3216E3	4 Jun	140,000	Conventional
Monmouth	LGS3216E3	17 May	150,000	Conventional
Ewing	LGS3216E3	7 Jun	143,000	No-till
Oglesby	Channel 2824 RXF[b]	20 May	140,000	Conventional
Bluff City	AG39XF3[c]	20 May	155,000	Conventional

[a] LG Seeds, AgReliant Genetics LLC, Westfield, IN; [b] Channel Soybean Seed, Bayer CropScience, St. Louis, MO; [c] Asgrow Soybean Seed, Bayer CropScience, St. Louis, MO.

Table 2. Experimental design and treatment arrangement by site.

Location	Plot size	Number of replicate blocks	Treatments
Baylis	20 × 150 ft	4	No insecticide; Insecticide seed treatment; R3 foliar application; R5 foliar application; IST + R3 + R5
Champaign	30 × 150 ft	4	No insecticide; Insecticide seed treatment; R3 foliar application; R5 foliar application; IST + R3 + R5
Monmouth	30 × 150 ft	4	No insecticide; Insecticide seed treatment; R3 foliar application; R5 foliar application; IST + R3 + R5
Ewing	30 × 100 ft	3	No insecticide; Insecticide seed treatment; R3 foliar application; R5 foliar application; IST + R3 + R5
Oglesby	40 × 395 ft	3	No insecticide; R5 foliar application
Bluff City	60 × 1,200 ft	3	R3 foliar application; R3 + R5

Table 3. Generalized linear mixed model statistics.

Response variable	Date	df (numerator, denominator)	*F*	*P*
Yield - Combined (lognormal)	-	4, 48	0.76	0.556
Yield - Baylis (lognormal)[a]	29 Sep	4, 12	5.45	0.010
Yield - Champaign (lognormal)	9 Oct	4, 12	0.32	0.861
Yield - Monmouth (lognormal)	10 Oct	4, 12	1.41	0.289
Yield - Ewing (lognormal)	9 Oct	4, 8	0.16	0.952
Yield - Oglesby (lognormal)	23 Oct	1, 2	0.26	0.662
Yield - Bluff City (lognormal)	1 Oct	1, 2	8.87	0.097
Stand - Baylis (lognormal)[a]	8 May	1, 15	7.68	0.014
Stand - Champaign (lognormal)	21 Jun	1, 15	1.38	0.258
Stand - Monmouth (lognormal)	6 Jun	1, 15	0.01	0.913
Stand - Ewing (lognormal)	24 Jun	1, 11	1.25	0.288
Bean leaf beetle counts - Champaign (normal)[a]	6 Sep	4, 12	9.01	0.001
Defoliation - Ewing (normal)[a]	28 Aug	4, 8	6.67	0.012
Bean leaf beetle counts - Oglesby (normal)[a]	28 Aug	1, 2	28.49	0.033

[a] Effect is significant ($\alpha = 0.05$)

Table 4. Yield in mean (± standard error [SE]) bushels per acre at 13% moisture for each individual site, as well as analyzed across trials for the sites located at research centers which had the full complement of experimental treatments. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference ($\alpha = 0.05$).

Treatment	Compiled (Research Centers only)[a]	Baylis	Champaign	Monmouth	Ewing	Oglesby	Bluff City
No Insecticide	61.9 + 2.4 a	68.0 + 1.5 ab	62.9 + 2.0 a	67.1 + 1.3 a	45.6 + 3.3 a	63.6 + 2.8 a	-
Insecticide Seed Treatment	61.2 + 2.7 a	69.4 + 1.6 a	61.7 + 1.6 a	66.5 + 0.8 a	42.7 + 1.9 a	-	-
R3 Application	62.5 + 2.8 a	70.1 + 1.2 a	61.5 + 2.3 a	69.0 + 1.9 a	45.2 + 5.7 a	-	66.4 + 0.6 a
R5 Application	57.1 + 3.1 a	63.0 + 0.6 c	59.9 + 1.4 a	65.5 + 1.2 a	42.1 + 3.2 a	63.9 + 2.2 a	-
IST + R3 + R5	59.0 + 3.2 a	64.9 + 1.8 bc	61.1 + 2.8 a	67.7 + 1.0 a	44.8 + 3.8 a	-	-
R3 + R5	-	-	-	-	-	-	68.3 + 0.2 a

[a] Excludes plots from the two treatments at Baylis where the R5 broadcast application injured the crop, causing yield loss.

Table 5. Mean (± SE) plant stand in number of plants per 17 feet 5 inches of row (a 1/1000th-acre sample) at the sites located at research centers which included insecticide seed treatment as a treatment factor. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Insecticide seed treatment	Baylis (8 May)	Champaign (21 June)	Monmouth (6 June)	Ewing (24 June)
Imidacloprid (0.091 mg ai/seed)	101.9 ± 4.5 a	70.1 ± 3.7 a	139.4 ± 2.0 a	76.5 ± 4.3 a
None	91.8 ± 4.3 b	66.8 ± 2.4 a	139.1 ± 1.3 a	70.3 ± 3.5 a

Table 6. Mean (± SE) number of bean leaf beetles (Cerotoma trifurcata) per 25 sweeps at the Champaign site on 6 September 2024. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Treatment	6 Sept. 2024 (R6)
No Insecticide	51.3 ± 8.0 a
Insecticide Seed Treatment	56.5 ± 13.5 a
R3 Application	60.5 ± 9.6 a
R5 Application	12.8 ± 4.4 b
IST + R3 + R5	7.5 ± 1.2 b

Table 7. Mean (± SE) percent defoliation caused by insect feeding at the Ewing site on 28 August 2024. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Treatment	28 Aug. 2024 (R6)
No Insecticide	2.3 ± 0.3 a
Insecticide Seed Treatment	2.3 ± 0.3 a
R3 Application	1.0 ± 0.0 b
R5 Application	1.7 ± 0.3 ab
IST + R3 + R5	1.0 ± 0.0 b

Table 8. Mean (± SE) number of bean leaf beetles (Cerotoma trifurcata) per 25 sweeps at the Oglesby site on 28 August 2024. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Treatment	28 Aug. 2024 (R5)
No Insecticide	25.7 ± 5.2 a
R5 Application	2.3 ± 0.9 b

Evaluation of foliar-applied insecticides for control of soybean insect pests, 2024

Study directors: Nicholas Seiter and Ashley Decker

Location: University of Illinois Agricultural and Biological Engineering Farm, Urbana, IL (40.069834, -88.218459)

Objective

To evaluate the performance of common foliar-applied, broadcast insecticides for control of bean leaf beetle, green cloverworm, and stink bugs during pod fill.

Materials and Methods

A field experiment was established in a randomized complete block design with 4 replicate blocks and 8 treatments. The experimental units were plots of soybean (Table 1) that were 10 feet wide and 40 feet long; 5 feet of unsprayed border separated plots within a replicate block. The treatments (Table 2) were different rate combinations of conventional and pre-commercial insecticides applied on 22 August 2024 using a CO2-powered backpack sprayer with a 10-foot spray boom (Table 1). Population densities of all insect pests were assessed on 26 August (4 days post-application), 29 August (7 days post-application), 2 September (11 days post-application), and 5 September (14 days post-application) by taking 25 sweeps per plot using a standard 15 inch-diameter polyester sweep net swung perpendicular to the rows through the soybean canopy. Yields were assessed for each plot on 9 October 2024 by harvesting rows 2 and 3 using a small-plot combine (Massey Ferguson 8XP, Kincaid Equipment, Haven, KS) with a built-in weight and moisture monitor (HarvestMaster, Logan, UT).

Data analysis

Insect counts per 25 sweeps (including bean leaf beetle [adults, *Cerotoma trifurcata*], stink bugs [adults and nymphs; green stink bug, *Chinavia hilaris*, brown stink bug, *Euschistus servus*, one-spot stink bug, *Euschistus variolarius*, brown marmorated stink bug, *Halyomorpha halys*], green cloverworm [larvae, *Hypena scabra*]; other pest species were identified and counted, but were not present in sufficient numbers to assess insecticide efficacy) and soybean yields at 13% moisture were analyzed using a generalized linear mixed model where treatment was a fixed effect and replicate block was a random effect. Analyses were performed using SAS (version 9.4, SAS Institute, Cary, NC).

Summary

All insecticides tested reduced densities of bean leaf beetle compared with the untreated control plots at 4-, 7-, and 11-days following application. Brigade, Endigo, Silencer, and Leverage 360 further reduced bean leaf beetle densities compared with the low rate of Asana at 7 days following application. By 14 days following application there were no differences among the treatments, suggesting there was no remaining effective residue from the insecticides we tested and that bean leaf beetles were free to move from plot to plot. While all insecticides reduced green cloverworm densities at 3 days following application, the densities were low in the untreated plots, and meaningful separations among insecticides were not observed. None of the materials affected soybean yield in this experiment, suggesting that the relatively high densities of bean leaf beetles we observed were not sufficient to reduce yield.

Funding

Project funding and insecticide materials were provided by Syngenta and Valent.

Acknowledgements

We thank Tim Lecher (Farm Manager) for assisting with planting and plot maintenance, academic hourly Grayce Montano, graduate students Yony Callohuari Quispe, and Will Foulke, and undergraduate students Melissa Wahlen, Jason Ballard, Shengnan Wang, Joe Schmid, and Karina Escobedo for assisting with plot maintenance and data collection.

Table 1. Plot information

Input	Value
Soybean variety	A33E34[a]
Previous crop	Corn
Soil type	Drummer silty clay loam
Tillage	Conventional
Row spacing	30-inch
Seeding rate	140,000 seeds per acre
Planting date	21-May-24
Herbicide	Pre-emerge: Warrant [a] (3 pt/a), Glory 4L [b] (6 oz/a); Post-emerge: Liberty [c] (36 oz/a), RoundUp PowerMax [a] (32 oz/a), AMS Xtra [d] (2 qt/a), FS Max Supreme [e] (1.2 qt/a)
Plot size	10 feet (4 rows) wide by 40 feet long; 5 feet (2 rows) of unsprayed soybean separated plots within a block
Insecticide treatment application	10 gallons of water per acre applied using a CO2-powered backpack sprayer on 22 Aug. 2024 (R5); 20-inch nozzle spacing, 30 psi, 2.5 mph ground speed, TeeJet TT11001-VP d wide-angle flat spray nozzle tips

[a] Bayer Crop Science, St Louis, MO; [b] ADAMA, Raleigh, NC; [c] BASF Corporation, Research Triangle Park, NC; [d] Drexel Chemical Company, Memphis, TN [e] Growmark Inc., Bloomington, IL

Table 2. Insecticide treatments

Trt	Material and rate	Active ingredient and formulation
1	Untreated	n/a
2	Asana XL [a] (6.4 fl oz/ac)	Esfenvalerate, 0.66 lbs active ingredient per gallon, emulsifiable concentrate (EC)
3	Asana XL (9.6 fl oz/ac)	
4	Brigade 2EC [b] (6.4 fl oz/a)	Bifenthrin, 2 lb active ingredient per gallon, EC
5	Warrior II [c] (1.6 fl oz/a)	Lambda-cyhalothrin, 2.08 lb active ingredient per gallon, capsule suspension (CS)
6	Endigo ZCX [c] (4 fl oz/a)	Lambda-cyhalothrin (0.9 lb AI per gallon) + thiamethoxam (1.8 lb AI per gallon), CS
7	Silencer [d] (2.56 fl oz/a)	Lambda-cyhalothrin (1 lb AI per gallon), EC
8	Leverage 360 [e] (2.8 fl oz/a)	Imidacloprid (2 lb AI per gallon) + Beta-cyfluthrin (1 lb AI per gallon), flowable liquid

[a] Valent USA Corporation, Walnut Creek, CA; [b] FMC Corporation, Philadelphia, PA ; [c] Syngenta Crop Protection, Greensboro, NC; [d] ADAMA, Raleigh, NC; [e] Bayer Crop Science, St Louis, MO

Table 3. Generalized linear mixed model statistics. Insecticide treatment was the lone fixed effect. The probability distribution used in the analysis is listed in parentheses for each dependent variable. All insect species indicate counts in the number of individuals per 25 sweeps.

Dependent variable	Date	Degrees of freedom	*F*	*P*
Green cloverworm (normal) [a]	26 Aug	7, 21	5.26	0.001
Green cloverworm (normal)	29 Aug	7, 21	2.45	0.053
Green cloverworm (normal)	2 Sep	7, 21	2.07	0.093
Green cloverworm (normal)	5 Sep	7, 21	1.58	0.195
Bean leaf beetle (normal) [a]	26 Aug	7, 21	106.92	< 0.001
Bean leaf beetle (normal) [a]	29 Aug	7, 21	27.67	< 0.001
Bean leaf beetle (normal) [a]	2 Sep	7, 21	50.94	< 0.001
Bean leaf beetle (normal)	5 Sep	7, 21	1.32	0.290
Stink bugs (normal)	26 Aug	7, 21	0.87	0.543
Stink bugs (normal)	29 Aug	7, 21	1.60	0.190
Stink bugs (normal)	2 Sep	7, 21	0.98	0.471
Stink bugs (normal)	5 Sep	7, 21	1.29	0.305
Soybean yield (lognormal)	9 Oct	7, 21	0.72	0.655

[a] Effect is significant at $\alpha = 0.05$

Table 4. Mean (± standard error [SE]) bean leaf beetle (*Certotoma trifurcata*, Coleoptera: Chrysomelidae) adults per 25 sweeps. “DAT” = days after treatment application. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference ($\alpha = 0.05$).

Trt	Treatment	4 DAT	7 DAT	11 DAT	14 DAT
1	Untreated	128.8 ± 11.0 a	154.8 ± 24.6 a	62.8 ± 4.4 a	21.5 ± 6.4 a
2	Asana XL (6.4 oz/a)	11.3 ± 4.1 b	51.0 ± 9.5 b	8.3 ± 2.0 bc	45.0 ± 20.6 a
3	Asana XL (9.6 oz/a)	5.8 ± 1.9 b	31.8 ± 7.5 bc	11.5 ± 6.0 b	29.5 ± 11.5 a
4	Brigade (6.4 oz/a)	1.0 ± 0.6 b	7.8 ± 1.9 c	1.3 ± 0.8 c	12.5 ± 5.6 a
5	Warrior II (1.6 oz/a)	6.5 ± 0.3 b	26.3 ± 6.3 bc	5.3 ± 2.2 bc	83.5 ± 37.6 a
6	Endigo ZCX (4 oz/a)	2.5 ± 1.0 b	13.0 ± 3.0 c	2.5 ± 0.6 c	60.0 ± 37.9 a
7	Silencer (2.56 oz/a)	2.3 ± 0.8 b	13.5 ± 1.8 c	5.5 ± 1.2 bc	15.3 ± 2.6 a
8	Leverage 360 (2.8 oz/a)	4.0 ± 0.8 b	23.0 ± 6.7 c	6.0 ± 2.0 bc	29.0 ± 12.1 a

Table 5. Mean (± SE) total green cloverworm (*Hypena scabra*, Noctuidae: Erebidae) larvae per 25 sweeps. "DAT" = days after treatment application. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	4 DAT	7 DAT	11 DAT	14 DAT
1	Untreated	3.3 ± 0.5 a	1.3 ± 0.5 a	1.5 ± 0.6 a	0.5 ± 0.5 a
2	Asana XL (6.4 oz/a)	0.0 ± 0.0 c	0.0 ± 0.0 a	0.0 ± 0.0 a	0.0 ± 0.0 a
3	Asana XL (9.6 oz/a)	0.5 ± 0.5 bc	0.5 ± 0.3 a	0.8 ± 0.5 a	0.3 ± 0.3 a
4	Brigade (6.4 oz/a)	0.0 ± 0.0 c	0.3 ± 0.3 a	0.0 ± 0.0 a	0.0 ± 0.0 a
5	Warrior II (1.6 oz/a)	1.5 ± 1.0 b	0.8 ± 0.3 a	0.0 ± 0.0 a	1.5 ± 0.9 a
6	Endigo ZCX (4 oz/a)	1.3 ± 0.3 bc	0.5 ± 0.3 a	1.3 ± 0.6 a	0.3 ± 0.3 a
7	Silencer (2.56 oz/a)	1.0 ± 0.6 bc	0.8 ± 0.3 a	0.5 ± 0.5 a	1.0 ± 0.7 a
8	Leverage 360 (2.8 oz/a)	0.3 ± 0.3 bc	0.0 ± 0.0 a	1.0 ± 0.4 a	0.0 ± 0.0 a

Table 6. Mean (± SE) total pest stink bug (Hemiptera: Pentatomidae) adults and nymphs per 25 sweeps. Includes green stink bug (Chinavia hilaris), brown stink bug (Euschistus servus), and one-spotted stink bug (Euschistus variolarius). "DAT" = days after treatment application. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	4 DAT	7 DAT	11 DAT	14 DAT
1	Untreated	0.8 ± 0.5 a	0.3 ± 0.3 a	1.3 ± 0.5 a	0.0 ± 0.0 a
2	Asana XL (6.4 oz/a)	0.5 ± 0.3 a	1.0 ± 0.7 a	1.5 ± 1.2 a	0.8 ± 0.3 a
3	Asana XL (9.6 oz/a)	0.3 ± 0.3 a	0.3 ± 0.3 a	1.3 ± 0.8 a	0.8 ± 0.5 a
4	Brigade (6.4 oz/a)	0.0 ± 0.0 a	0.3 ± 0.3 a	0.0 ± 0.0 a	0.0 ± 0.0 a
5	Warrior II (1.6 oz/a)	0.0 ± 0.0 a	1.0 ± 0.6 a	0.3 ± 0.3 a	1.5 ± 0.9 a
6	Endigo ZCX (4 oz/a)	0.3 ± 0.3 a	0.0 ± 0.0 a	0.3 ± 0.3 a	0.5 ± 0.3 a
7	Silencer (2.56 oz/a)	0.3 ± 0.3 a	0.0 ± 0.0 a	0.8 ± 0.3 a	0.5 ± 0.3 a
8	Leverage 360 (2.8 oz/a)	0.3 ± 0.3 a	1.3 ± 0.5 a	0.5 ± 0.5 a	0.8 ± 0.5 a

Table 7. Mean (± SE) soybean yield in bushels per acre, corrected to 13% moisture. Means followed by the same letter within a column are not different based on the Fisher method of least significant difference (α = 0.05).

Trt	Treatment	9 October 2024 (R8)
1	Untreated	70.5 ± 2.9 a
2	Asana XL (6.4 oz/a)	69.9 ± 4.0 a
3	Asana XL (9.6 oz/a)	72.6 ± 3.4 a
4	Brigade (6.4 oz/a)	73.2 ± 6.7 a
5	Warrior II (1.6 oz/a)	80.3 ± 5.0 a
6	Endigo ZCX (4 oz/a)	74.6 ± 6.1 a
7	Silencer (2.56 oz/a)	73.6 ± 3.6 a
8	Leverage 360 (2.8 oz/a)	72.9 ± 1.2 a

The status of Illinois Western Corn Rootworm (*Diabrotica virgifera virgifera*, WCR) resistance to Bt toxins and RNA interference (RNAi).

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Field populations of western corn rootworm beetles (*Diabrotica virgifera virgifera*, WCR) were collected in 2023 from Champaign, Sangamon and Warren counties in Illinois. Adults were maintained in the laboratory as populations by county. Eggs collected from each population were moved to a cold chamber and held under cold (6°C) conditions until summer 2024 when they were moved to room temperature to stimulate hatch. Using the methods of Gassmann et al. (2011), newly-emerged larvae from the eggs were used in single-plant bioassays to measure their resistance to Bt and RNAi traits expressed in corn hybrids.

Methods

Insects

Four WCR populations were collected from fields in three Illinois counties: Champaign (2 populations collected from University of Illinois Agricultural and Biological Engineering Farm), Sangamon (from an agricultural service company), and Warren (from the University of Illinois' Northwestern Illinois Agricultural Research and Demonstration Center at Monmouth). Populations were evaluated separately; however, Bt resistance patterns were similar and data were pooled for analysis and simplicity of presentation.

Procedures

Single plants of Bt and non-Bt corn hybrids (Table 1) were grown in 0.95 L plastic cups in a greenhouse until they were at the 5-6 leaf stage. Groups of n=10 newly-emerged WCR larvae were transferred onto fine roots exposed around the base of each corn plant (n=12 corn plants per hybrid). Treated plants were clipped to a height of 35 cm and held in a growth chamber at 25°C. After 17 days, the surviving larvae in each cup were extracted, counted and their developmental stage was determined by measuring their head capsule widths. Healthy, unstressed larvae should be in the 3rd instar (the final larval stage) after 17 days.

Results and Discussion:

Proportion of WCR larval survival

Illinois WCR populations are resistant to the Cry3Bb1 toxin commonly expressed in a variety of hybrids (Table 2). Larval survival on hybrids expressing just the Cry3Bb1 toxin was not significantly different from survival on non-Bt hybrids. WCR have displayed high levels of resistance to Cry3Bb1 toxin (and Cry3 toxins in general) from all locations for several years. Survival of WCR larvae on hybrids expressing just the Gpp34/Tpp35Ab1 toxin (formerly called Cry34/35Ab1, a.k.a. "Herculex Rootworm") was also not significantly reduced compared to survival on non-Bt hybrids (Table 2). While larval survival patterns on the Gpp34/Tpp35Ab1 toxin vs. non-Bt indicate that resistance is present, significantly delayed development among the survivors (see below) suggests that this mode of action is still providing some value. Gpp34/Tpp35Ab1 toxin efficacy seems to be on a trajectory toward resistance at these sites.

WCR larval survival on hybrids expressing a pyramid of the Gpp34/Tpp35Ab1 + Cry3Bb1 toxins (i.e. SmartStax™ hybrids) was not significantly reduced compared to survival on a non-Bt isoline, indicating that there is likely WCR resistance to the pyramid. Given high WCR larval survival on each of the component toxins, this result is predictable and consistent with those assays. As was seen for the Gpp34/Tpp35Ab1 toxin, significantly delayed development among the survivors (see below) suggests that this pyramid is still capable of providing some efficacy against WCR larvae. Delayed development on the pyramid may reasonably be attributed to the effect of the Gpp34/Tpp35Ab1 toxin.

Low WCR survival on the more recently commercialized (2023) SmartStax PRO™ pyramid (Gpp34/Tpp35Ab1 + Cry3Bb1 with the RNAi trait "DvSnf7") demonstrate that Illinois' WCR populations are still highly susceptibility to the RNAi mode of action. There were zero larval survivors of SmartStax PRO™ exposure from the USDA susceptible population. At a more granular level, WCR larval survival on the SmartStax PRO™ pyramid ranged from 1.7%-3.7% in the Champaign Co. populations, 2.5% in the Sangamon Co. population, to 0.0% in the Warren Co. population. Among the n=14 survivors from SmartStax PRO™ plants, 0.857 were third instars indicating that most survivors had developed at a normal rate. If this is consistent among survivors, it could mean that SmartStax PRO™ survivors will escape penalties that have likely slowed the development of resistance to Gpp34/Tpp35Ab1 toxin.

Given that neither of the single trait Bt toxins has significant activity against WCR, it appears that the efficacy of the SmartStax PRO™ pyramid is largely dependent on expression of the RNAi trait (with some potential contribution from Gpp34/Tpp35Ab1 toxin effects on larval development). These findings underscore the importance of adopting the SmartStax PRO™ pyramid only where potentially injurious populations are likely. In areas with poor efficacy of the Bt-based modes of action, the SmartStax PRO™ pyramid may function as a single trait hybrid which is not ideal. The rapid evolution of WCR resistance to the Cry3Bb1 toxin following its 2003 commercialization in "YieldGard Rootworm" hybrids can be attributed, in part, to its deployment as a single trait hybrid, that was planted widely in an environment with inadequate compliance with refuge requirements designed to slow resistance evolution (Gassmann et al., 2011).

Larval survival on different traits or a pyramid of traits can be put on a common scale that enables direct comparison. This is done by correcting survival on Bt for variation in baseline larval survival on the non-Bt hybrid(s) (i.e. corrected survival). If larvae survive in the presence of a Bt toxin at the same level as they do on a non-Bt hybrid, then corrected survival would be 100% for that toxin (e.g. 80% survival on Bt/80% survival on non-Bt =0.80/0.80 = 1.00, 100% corrected survival), an indication that the population was fully resistant to the Bt toxin. When WCR corrected survival was calculated for all the traits/hybrids, we found that for single trait hybrids, *ca*. ≥100% of WCR survive exposure to Cry3Bb1 and 78±23% (mean + SE) survive exposure to Gpp34/Tpp35Ab1. On the pyramided hybrids, 86±22% survive exposure to the Cry3Bb1 + Gpp34/Tpp35Ab1 toxins expressed in SSX™. For SmartStax PRO™, corrected larval survival for the combined four 2023-collected WCR populations was 13±0.05%. Low corrected survival on SmartStax™ PRO™ shows that WCR are highly susceptible to this pyramid.

Developmental rates of surviving larvae

While larval survival patterns are the focus when measuring resistance, documenting development rates among the survivors can add to the understanding of resistance. If larval development has proceeded normally during bioassays, surviving WCR larvae recovered from non-Bt corn hybrids at the end of single-plant Bt resistance bioassays should all be in the 3rd instar. This is the final mature feeding stage before larvae pupate in the soil prior to adult emergence. If a treatment negatively affects their development, fewer larvae may be present and/or a greater proportion of survivors will be underdeveloped. Slowed development among resistant and/or susceptible larvae is a common consequence of exposure to Bt toxins, indicating that the larvae are not insensitive to the effects of the toxin. Among Bt resistant larvae, development may proceed at a normal rate and a high proportion of 3rd instars will be recovered from the bioassay.

Among surviving WCR larvae, the proportion of recovered 3rd instars was not different between the Cry3Bb1 and non-Bt hybrids (Table 2). The proportions of 3rd instars were significantly lower among survivors from the Gpp34/Tpp35Ab1 hybrid compared to the non-Bt hybrid. There were significantly fewer 3rd instars recovered from the SmartStax hybrid than from the SmartStax PRO™ hybrid. However, neither of these proportions was significantly different from the proportion of 3rd instars recovered from the non-Bt control population. These patterns illustrate that survival on Bt doesn't mean larvae are unaffected by the toxins/traits. Developmental delays among survivors (which prolong larval exposure to soil pathogens and predators and may lead to later adult emergence that is out-of-sync with food resources or mating opportunities) may make them less likely to reproduce.

Elevated larval survival proportions accompanied by high proportions of 3rd instar larvae among survivors on a Bt hybrid indicate that a population is Bt resistant or nearly so. This scenario is increasingly present in the WCR where there is high larval survival on Cry3Bb1 and Gpp34/Tpp35Ab1 hybrids with near normal proportions of 3rd instars among the Cry3Bb1 survivors; WCR are resistant to Cry3Bb1 at many locations around the Corn Belt. Though WCR survival on Gpp34/Tpp35Ab1 is high, the presence of developmental delays among many survivors shows that this Bt may still possess some usable efficacy. Overcoming developmental delays associated with Bt toxin exposure may be an important factor that allows resistance to become fixed (i.e. when there are no remaining susceptible gene variants in the population); this may be the case for Cry3Bb1 resistance in WCR.

Summary and conclusions

Ongoing selection and Bt resistance limit growers' choices and options for corn hybrids that may prevent economic WCR injury. Recent periods of low to very low (non-economic) WCR abundance present growers with opportunities to forego the use of Bt or Bt+RNAi hybrids. Not only does this reduce seed costs, but because larvae are not exposed to and killed by Bt, it relaxes selection for resistance to Bt. Thus, opting for non-Bt corn (or non-Bt corn with a soil insecticide) helps to prolong the lifespan of traits that are indispensable when rootworm populations are high and crop rotation is not an option. Paying attention to WCR and NCR abundance, using monitoring and thresholds to justify use of Bt (or any management tactic), and avoiding Bt hybrids that don't perform well on your farm will help prolong the efficacy of a declining number of traits on which most growers depend.

Table 1. Bt corn hybrid information for seed used in 2024 single-plant, Bt-resistance bioassays of 2023 Illinois field-collected populations of the western corn rootworm (WCR) (*Diabrotica v. virgifera* LeConte) and northern corn rootworm (NCR) (*Diabrotica barberi* (Smith and Lawrence)). All non-Bt hybrids except for 2H723 are isogenic with the other hybrids in their bioassay group.

Bioassay group	Corn hybrid	Hybrid type	Rootworm traits expressed	Seed source
1	DKC 61-88[a]	Single trait Bt	Cry3Bb1	Bayer
1	DKC 61-86[b]	non-Bt isoline	None	Bayer
2	P1417[c]	Single trait Bt	Gpp34/Tpp35Ab1	Pioneer
2	2H723[d,e]	non-Bt	None	Mycogen
3	DKC 111-023[f]	Pyramided Bt + RNAi	Cry3Bb1 + Gpp34/Tpp35Ab1 + DvSnf7	Bayer
3	DKC 58-998[g]	Pyramided Bt	Cry3Bb1 + Gpp34/Tpp35Ab1	Bayer
3	DKC 58-032[b]	non-Bt isoline	None	Bayer

[a]YieldGard RW [b]VT Double Pro [c]AcreMax Xtra [d]AcreMax [e]Due to poor germination of the planned AcreMax Xtra (AMX) hybrid, 2H695, associated with the AcreMax 2H723 isoline, we substituted a different AMX hybrid, P1417; it was not isogenic with 2H723. [f]SmartStax PRO [g]SmartStax

Table 2. Proportion larval survival and proportion 3rd instar larvae from single-plant, Bt-resistance bioassays conducted during 2024 on three Illinois populations of the western corn rootworm (WCR) (*Diabrotica v. virgifera* LeConte) collected in 2023 from open fields in Champaign, Sangamon and Warren counties.

Bioassay group	Rootworm traits expressed	WCR test population	n	Proportion larval survival (mean ± SEM) [a]	n	Proportion 3rd instar larvae (mean ± SEM) [a]
1	Cry3Bb1	Illinois field populations	57	0.332 ± 0.030 a	43	0.707 ± 0.046 a
1	Cry3Bb1	USDA Bt susceptible pop.	25	0.032 ± 0.015 c	5	0.500 ± 0.224 a
1	None	Illinois field populations	59	0.276 ± 0.027 ab	53	0.609 ± 0.053 a
1	None	USDA Bt susceptible pop.	23	0.157 ± 0.029 b	17	0.451 ± 0.094 a
2	Gpp34/Tpp35Ab1	Illinois field populations	56	0.187 ± 0.021 ab	46	0.462 ± 0.059 b
2	Gpp34/Tpp35Ab1	USDA Bt susceptible pop.	24	0.100 ± 0.034 c	10	0.029 ± 0.029 c
2	None	Illinois field populations	55	0.260 ± 0.027 a	45	0.829 ± 0.043 a
2	None	USDA Bt susceptible pop.	24	0.163 ± 0.032 ab	18	0.584 ± 0.100 ab
3	Cry3Bb1 + Gpp34/ Tpp35Ab1 + DvSnf7	Illinois field populations	60	0.025 ± 0.006 b	14	0.857 ± 0.097 a
3	Cry3Bb1 + Gpp34/ Tpp35Ab1 + DvSnf7	USDA Bt susceptible pop.	24	0.000 ± 0.000 b	0	no larvae
3	Cry3Bb1 + Gpp34/ Tpp35Ab1	Illinois field populations	57	0.123 ± 0.013 a	43	0.455 ± 0.071 b
3	Cry3Bb1 + Gpp34/ Tpp35Ab1	USDA Bt susceptible pop.	24	0.013 ± 0.007 b	3	0.000 ± 0.000 b
3	None	Illinois field populations	52	0.160 ± 0.024 a	33	0.549 ± 0.074 ab
3	None	USDA Bt susceptible pop.	27	0.167 ± 0.035 a	15	0.689 ± 0.064 ab

[a] Proportion WCR larval survival and proportion 3rd instar larvae data were non-normal and were analyzed using the non-parametric Kruskal-Wallis test, with multiple comparisons performed for all data pairs within a Bt trait family using the Steel-Dwass method (a non-parametric version of Tukey's method that protects the overall α=0.05 error rate) (JMP Pro 17 (2023 SAS Institute)). Mean proportions sharing the same letter within a trait family are not significantly different.

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The status of Illinois Northern Corn Rootworm (*Diabrotica barberi*, NCR) resistance to Bt toxins and RNA interference (RNAi) with Notes on the Prevalence of NCR Prolonged Diapause.

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Field populations of northern corn rootworm beetles (*Diabrotica barberi*, NCR) were collected in late 2023 from Henry, Peoria, and Warren counties in Illinois. Adults were maintained in the laboratory as populations by county. Eggs collected from each population were moved to a cold chamber and held under cold (6°C) conditions until summer 2024 when they were moved to room temperature to stimulate hatch. Using the methods of Gassmann et al. (2011), newly-emerged larvae from the eggs were used in single-plant bioassays to measure their resistance to Bt and RNAi traits expressed in corn hybrids. Egg development and hatching patterns were used to investigate the county-level prevalence of a phenomenon called prolonged diapause (PD). In NCR populations, a proportion of the eggs are capable of prolonging their normal egg diapause beyond one winter and surviving two or more cold periods in the soil before they hatch. PD allows NCR to circumvent crop rotation and injure rotated corn.

Methods

Insects

Field populations of NCR were collected in late 2023 from the edges of commercial cornfields in Henry and Peoria counties and from a rootworm trap crop field at the University of Illinois' Northwestern Illinois Agricultural Research and Demonstration Center at Monmouth, IL in Warren county.

Procedures

Single plants of Bt and non-Bt corn hybrids (Table 1) were grown in 0.95 L plastic cups in a greenhouse until they were at the 5-6 leaf stage. Groups of n=10 newly-emerged NCR larvae were transferred onto fine roots exposed around the base of each corn plant, larvae were added to twelve plants/ hybrid. Treated plants were clipped to a height of 35 cm and held in a growth chamber at 25°C. After 17 days, the surviving larvae in each cup were extracted, counted and their developmental stage was determined by measuring their head capsule width. Healthy, unstressed larvae should be in the 3rd instar (the final larval developmental stage) after 17 days. Populations were evaluated separately; however, because Bt resistance patterns did not differ significantly among them, data were combined for analysis.

Results and Discussion

Single-plant Bt resistance bioassays: Proportion of larval survival.

Illinois NCR populations retain some susceptibility to the Cry3Bb1 toxin ("YieldGard Rootworm" trait) commonly expressed in a variety of hybrids (Table 2). Larval survival on hybrids expressing just the Cry3Bb1 toxin was significantly reduced compared to survival on non-Bt hybrids. This indicates that the Cry3Bb1 toxin retains some efficacy against NCR. Survival of NCR larvae on hybrids expressing just the Gpp34/Tpp35Ab1 toxin (formerly named Cry34/35Ab1, a.k.a. "Herculex Rootworm" trait) was also significantly reduced compared to survival on non-Bt hybrids, though the surviving proportion was lower, suggesting that the Gpp34/Tpp35Ab1 toxin has greater efficacy against NCR than the Cry3Bb1 toxin.

NCR larval survival on hybrids expressing a pyramid of the Gpp34/Tpp35Ab1 + Cry3Bb1 toxins (i.e. SmartStax™ hybrids) was significantly reduced compared to survival on a non-Bt isoline, indicating that the pyramid has significant efficacy against NCR larvae. The proportion of larval survival on the SmartStax pyramid was equivalent to survival on the single-trait hybrid expressing Gpp34/Tpp35Ab1. This suggests that the contribution of the Cry3Bb1 toxin to the pyramid efficacy is less important than that of the Gpp34/Tpp35Ab1 toxin. These data show that efficacy of Cry3Bb1 against NCR larvae is more limited than the Gpp34/Tpp35Ab1 toxin.

Low NCR survival on the more recently commercialized (2023) SmartStax PRO™ pyramid (Gpp34/Tpp35Ab1 + Cry3Bb1 with the RNAi trait "DvSnf7") demonstrate that Illinois' NCR populations are still highly susceptibility to the RNAi mode of action. The presence of the RNAi trait significantly reduced larval survival compared to SmartStax alone.

Equivalent NCR larval survival on the single trait hybrid expressing Gpp34/Tpp35Ab1 toxin and the SSX pyramid of Gpp34/Tpp35Ab1 + Cry3Bb1 toxins suggests that the Gpp34/Tpp35Ab1 trait is likely responsible for efficacy of the SmartStax™ pyramid. The efficacy of the Cry3Bb1 toxin is limited against NCR. This underscores the importance of the Gpp34/Tpp35Ab1 trait wherever it is pyramided with other modes of action. Gpp34/Tpp35Ab1 efficacy against NCR prevents the SmartStax PRO™ pyramid with RNAi from being a functionally single trait hybrid. The rapid evolution of WCR resistance to the Cry3Bb1 toxin following its 2003 commercialization can be attributed, in part, to its deployment as a single trait hybrid, that was planted widely in an environment with heavy corn rootworm pressure and inadequate compliance with the refuge requirements designed to slow resistance evolution. (Gassmann et al., 2011). Hybrids that express two or more effective modes of action against rootworms are much harder for larvae to overcome than single toxin/mode of action hybrids. In the former case, larvae must survive simultaneous exposure to two different modes of action. If the toxins in a pyramid are novel in the environment, the probability that larvae survive exposure to either toxin would be low. Their likelihood of surviving exposure to BOTH would be extremely low.

Larval survival on different traits or a pyramid of traits can be put on a common scale that enables direct comparison. This is done by correcting survival on Bt for variation in baseline larval survival on the non-Bt hybrid(s) (i.e. corrected survival). If larvae survive in the presence of a Bt toxin at the same level as they do on a non-Bt hybrid, then corrected survival would be 100% for that toxin (e.g. 80% survival on Bt/80% survival on non-Bt = 0.80/0.80 = 1.00, 100% corrected survival) an indication that the population was fully resistant to the Bt toxin. When NCR corrected survival was calculated for all the traits/hybrids, we found that for single trait hybrids, *ca*. 66% of NCR survive exposure to Cry3Bb1 and 40% survive exposure to Gpp34/Tpp35Ab1. On the pyramided hybrids, 30% survive exposure to the Cry3Bb1 + Gpp34/Tpp35Ab1 toxins expressed in SSX™, but just 2% of NCR survive exposure to the SmartStax PRO™ pyramid of Cry3Bb1, Gpp34/Tpp35Ab1, + RNAi. Low corrected survival on SmartStax™ PRO™ shows that NCR are highly susceptible to this pyramid.

Single-plant Bt resistance bioassays: Development of surviving larvae.

Larval survival is the key metric when measuring rootworm Bt resistance. However, documenting development rates among the survivors can add to the understanding of resistance. If larval development has proceeded normally during bioassays, surviving NCR larvae recovered from non-Bt corn hybrids at the end of single-plant Bt resistance bioassays should all be in the 3rd instar. This is the final mature feeding stage before larvae pupate in the soil prior to adult emergence. If a treatment negatively affects their development, fewer larvae may be present and/or a greater proportion of survivors will be underdeveloped. Slowed development among resistant and/or susceptible larvae is one outcome of exposure to Bt toxins. When larvae are resistant to Bt toxins, their development may proceed at a normal rate and a high proportion of 3rd instars will be recovered from the bioassay. A portion of the larvae that survive exposure to a Bt toxin often exhibit slowed development. This suggests that resistance is present, but that the larvae are not completely insensitive to the effects of the toxin.

Among recovered NCR larvae, the proportion in the 3rd instar was not significantly reduced (vs. larvae recovered on non-Bt) for the Bt hybrids that expressed the Cry3Bb1 toxin (Table 2). In contrast, the proportions of 3rd instars were significantly lower among survivors from the Gpp34/Tpp35Ab1 hybrid, the SmartStax™ pyramid, and the SmartStax PRO™ Bt+RNAi pyramid than on the non-Bt controls. These findings indicate that most NCR survivors from Bt hybrids suffer reduced development rates. This shows that survival on Bt doesn't mean larvae are unaffected by the toxins/traits. Developmental delays among survivors (which prolong larval exposure to soil pathogens and predators and may lead to later adult emergence that is out-of-sync with food resources or mating opportunities) may make them less likely to reproduce.

Elevated larval survival proportions accompanied by high proportions of 3rd instar larvae among survivors on a Bt hybrid indicate that a population is Bt resistant or nearly so. This scenario is increasingly present in the western corn rootworm (WCR) where there is high larval survival on Cry3Bb1 hybrids with near normal proportions of 3rd instars among the survivors; WCR are resistant to Cry3Bb1 at many locations around the Corn Belt. There are also populations with high larval survival on Gpp34/Tpp35Ab1 hybrids, but there are only low to modest proportions of 3rd instars among the survivors. Overcoming developmental delays associated with Bt toxin exposure may be an important factor that allows resistance to become fixed (i.e. when there are no remaining susceptible gene variants in the population); this may be the case for Cry3Bb1 resistance in WCR. In NCR populations, we see growing evidence that the Cry3Bb1 trait has limited efficacy – a high proportion of NCR larvae can survive on roots expressing the trait and many of the survivors are developing at normal or nearly normal rates.

Prevalence of NCR prolonged egg diapause in field populations.

Once NCR eggs are deposited in the soil, they will endure cold winter conditions in a state of arrested development called "diapause". Once springtime soil temperatures warm above *ca*. 50°F/10°C, most NCR eggs will resume development and predictably hatch during the spring/summer of the year after they were laid. However, a significant proportion of NCR eggs are capable of a prolonged diapause (PD). PD eggs do not hatch until they experience two *or more* wintertime chill periods. Levine et al. (1992) showed the proportion of PD in the eggs of Illinois NCR was 0.14 - 0.51. PD is also found in NCR from other states. Its prevalence is associated with the adoption of annual crop rotation as a corn rootworm management tactic. The first evidence of PD was recorded in an Illinois NCR population in the late 1920s (Bigger, 1932) and only explained in the mid-1960s (Chaing, 1965). Widespread annual rotation created conditions that favored the survival of NCR eggs expressing naturally variable hatching patterns that allowed some to remain unhatched in the soil for two or more years. PD allows eggs to "sit out" the growing season when corn is not planted/available in the field where they were originally laid. PD illustrates how natural selection, acting on genetically-based variation in a population, changed pest biology in a way that allowed the NCR to overcome a management tool. PD makes it difficult to forecast the future economic injury in corn because the number of eggs in the soil that will hatch and potentially yield larvae is uncertain year-to-year.

Understanding PD is important because it affects interpretation of NCR abundance. However, developing IPM-based monitoring guidance for growers in areas where NCR are present is complicated by a lack of current information on its prevalence in Illinois populations. The last Illinois assessment of PD was reported by Levine et al. in 1992 based on NCR collected in 1987. During the intervening ≥37 years, changes in farming practices, NCR and WCR abundance, corn rootworm resistance, etc. may have affected the prevalence of NCR PD.

In addition to monitoring Bt resistance in the NCR collected in 2023, patterns of NCR egg hatch (and non-hatching) were also recorded to document the current prevalence of PD in field populations (this was also done with one NCR population in 2022). Briefly, a portion of the NCR eggs destined for Bt bioassays were removed from cold storage and observed in groups of 100-300 eggs as they developed at room temperature. As eggs warm, those destined to hatch will soon contain a developing embryo/larva. Rather than waiting for each egg to hatch, we took advantage of the easily observed developing larvae to count eggs that were developing normally and would likely hatch soon – these were eggs expressing a normal 1-year diapause. We also noted the number of eggs that did not develop at all during the summer, but remained intact and retained their normal creamy coloration – these eggs were likely expressing a PD of ≥2 years. They were returned to cold storage. In summer 2025, they will again be assessed for development. We also recorded dead eggs, which had either collapsed or were infested with fungi or other pathogens that caused the egg to change color.

We calculated the proportion of normal, 1-year diapause eggs by dividing the total number of eggs that hatched by the sum total of eggs in all classes within a sample. We also *estimated* the number of PD eggs by dividing the number of intact eggs that did not hatch by the sum total of eggs in all classes. Our calculated PD proportion is a liberal estimate of the eggs that will hatch in year 2 because it includes some eggs that will ultimately die during the next cold period or may not hatch until 3 or 4 years after they were laid.

We found that the proportion of PD eggs from Peoria County, Illinois (0.430 ± 0.033, mean ± SEM) was significantly greater that for Henry (0.270

± 0.042) or Warren (0.275 ± 0.038) Counties ($F_{(2, 26)}$=6.241; P=0.007). PD was not previously reported for these counties by Levine et al. (1992), though the proportions measured in 2024 fall within the 0.14-0.51 range of PD proportions they reported for 2-year PD.

A 2008-2009 University of Nebraska study on PD demonstrated significant geographic variation in the proportion of eggs that hatched the year after they were laid ("first-year-eggs") within and among locations (4.5% – 42.5%)(Geisert and Meinke, 2013). The Nebraska sites with the lowest proportions of first-year-eggs (and thus potentially the highest proportions of PD eggs that will hatch two-years after they were laid) were located in areas with a history of higher use of annual crop rotation. This is consistent with the presumed role of rotation in selecting for PD. Their data imply that PD at the Nebraska sites could range from ca. 57% to >90%. Exploring the relationship between historical use of crop rotation across Illinois counties and current PD levels, may help predict Illinois locations likely to face higher risks from PD.

While PD makes NCR monitoring more challenging, it may also be slowing NCR Bt resistance evolution. Because portions of a NCR population with PD take more than one year (as long as 3+ years) to complete their lifecyle, there are sub-groups within the population that are no longer annually exposed to Bt (or other management tactics). Lengthening the time between generations (and exposure to Bt) slows the process of selection and resistance evolution. Tabashnik et al. (2023) reported the number of years between commercialization of Cry3Bb1 and Gpp34/Tpp35Ab1 toxins and first documentation of NCR field resistance to those toxins is nearly twice that for the WCR (a species where the population has a 1-year lifecycle). As a result, NCR populations are not currently as resistant to Bt toxins as most WCR populations in the same fields. Illinois WCR corrected survival on Cry3Bb1 toxin is ca. ≥100%, while NCR corrected survival on the same toxin is *ca*. 66% but continues to rise.

Summary and conclusions

Bt resistance limits growers' choices and options for corn hybrids that may prevent economic NCR injury. PD makes it difficult to predict how current NCR abundance may affect injury in subsequent continuous or rotated cornfields. There are no easy solutions to this problem. It can be made more tractable by monitoring adult NCR (and WCR) populations and consulting economic thresholds (ETs) to make decisions about whether Bt hybrids are appropriate for the expected rootworm larval pressure. PD adds another layer of uncertainty to the application of ETs for NCR management. Our data show that PD is present in Illinois and may result in up to 50% of NCR eggs hatching two or more years after they were laid. Until PD is better studied, growers measuring high current NCR abundance in cornfields should be aware that (1) some of the current year eggs will not become larvae for ≥2 years and (2) a portion of the NCR eggs laid in a field during the previous 2 years may hatch in the current year and compound the expected pressure based solely on last year's NCR abundance.

With WCR populations generally lower than usual over the last 10 years and NCR abundance (and problems) growing, studying the current biology/ecology of the NCR is becoming a priority. This is important not only from a management perspective, but we also need reliable information that can help us avoid planting Bt and Bt+RNAi hybrids when they are unnecessary or ineffective. Paying attention to NCR abundance, using ETs, and avoiding selection for Bt resistance, by not planting Bt hybrids when/where circumstances don't warrant their use will prolong the efficacy of a declining number of traits on which most growers depend.

Table 1. Bt corn hybrid information for seed used in 2024 single-plant, Bt-resistance bioassays of 2023 Illinois field-collected populations of the western corn rootworm (WCR) (*Diabrotica v. virgifera* LeConte) and northern corn rootworm (NCR) (*Diabrotica barberi* (Smith and Lawrence)). All non-Bt hybrids except for 2H723 are isogenic with the other hybrids in their bioassay group.

Bioassay group	Corn hybrid	Hybrid type	Rootworm traits expressed	Seed source
1	DKC 61-881[a]	Single trait Bt	Cry3Bb1	Bayer
1	DKC 61-862[b]	non-Bt isoline	None	Bayer
2	P14173[c]	Single trait Bt	Gpp34/Tpp35Ab1	Pioneer
2	2H7234[d,e]	non-Bt	None	Mycogen
3	DKC 111-0235[f]	Pyramided Bt + RNAi	Cry3Bb1 + Gpp34/Tpp35Ab1 + DvSnf7	Bayer
3	DKC 58-9986[g]	Pyramided Bt	Cry3Bb1 + Gpp34/Tpp35Ab1	Bayer
3	DKC 58-0322[b]	non-Bt isoline	None	Bayer

[a]YieldGard RW [b]VT Double Pro [c]AcreMax Xtra [d]AcreMax [e]Due to poor germination of the planned AcreMax Xtra (AMX) hybrid, 2H695, associated with the AcreMax 2H723 isoline, we substituted a different AMX hybrid, P1417; it was not isogenic with 2H723. [f]SmartStax PRO [g]SmartStax

Table 2. Proportion larval survival and proportion 3rd instar larvae from single-plant, Bt-resistance bioassays conducted during 2024 on three Illinois populations of the northern corn rootworm (NCR) (*Diabrotica barberi*) collected in 2023 from open fields in Henry, Peoria and Warren counties.

Bioassay group	Rootworm traits expressed	n	Proportion larval survival (mean ± SEM) [a]	n	Proportion 3rd instar larvae (mean ± SEM) [a]
1	Cry3Bb1	34	0.418 ± 0.031 b	34	0.647 ± 0.051 bc
1	None	34	0.635 ± 0.031 a	34	0.821 ± 0.035 ab
2	Gpp34/Tpp35Ab1	59	0.253 ± 0.026 c	49	0.222 ± 0.043 d
2	None	34	0.641 ± 0.034 a	34	0.851 ± 0.033 a
3	Cry3Bb1 + Gpp34/Tpp35Ab1 + DvSnf7	76	0.012 ± 0.004 d	8	0.063 ± 0.063 d
3	Cry3Bb1 + Gpp34/Tpp35Ab1	76	0.174 ± 0.020 c	58	0.023 ± 0.047 d
3	None	77	0.590 ± 0.023 a	76	0.631 ± 0.037 c

[a] Proportion WCR larval survival and proportion 3rd instar larvae data were non-normal and were analyzed using the non-parametric Kruskal-Wallis test, with multiple comparisons performed for all data pairs using the Steel-Dwass method (a non-parametric version of Tukey's method that protects the overall α=0.05 error rate) (JMP Pro 17 (2023 SAS Institute)). Mean proportions sharing the same letter are not significantly different.

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