



ROOTS IN RESEARCH



Yield of 2022

In This Issue:

We are proud to present you with the first edition of a series of annual newsletters showcasing the diversity of applied research and hands-on educational programming that happen at the University of Maryland Research and Education Centers across the state. These facilities provide a living-laboratory space to carry out research addressing the real-world problems facing our farmers from issues like invasive species, climate change, economics, and environmental conservation. The information produced from these research projects is shared with the scientific community and directly to the public through journal articles, extension newsletters, and many other formats, but compiling summaries of all of the work done at each facility in one publication here gives a snapshot of how many projects are carried out at each research farm every year.

Here, we have compiled reports on the 2022 projects at the Central Maryland Research and Education Center (CMREC) in Beltsville. CMREC-Beltsville is only a short drive from College Park, and so this facility tends to attract a range of faculty from campus. This facility is located on land that is a part of USDA's Beltsville Agricultural Research Center, and has been leased as a partnership between USDA and UMD. This ongoing agreement has helped to foster collaboration between USDA and MDA researchers over the years, including some of the work that was carried out in 2022. We hope you enjoy reading about the breadth of different projects, and gain some insight on the value of the work carried out at the RECs each year.

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Upper Marlboro 3NNW Pr. George's MD.										Beltsville Eastern										
AIR TEMPERATURE										PRECIPITATION										
DATE	24 Hour Ending at Observation				Supplemental Readings at				24 Hour Ending at Observation				Time of Beginning				Time of Ending			
	Max.	Min.	Dry-bulb	Wet-bulb	Dew Point	Dry-bulb	Wet-bulb	Dew Point	Max.	Min.	Time of Beginning	Time of Ending	Time of Beginning	Time of Ending	24 Hour Amount	Max. Hourly Amount	Time of Beginning	Time of Ending		
1	56	45	51	50					54	47					0	5844				
2	65	42	48	48					63	49					0	5845		3.70		
3	74	44	55	50					67	50					0	5850		3.60		
4	78	55	42	42					68	44					0	5816		3.50		
5	73	37	45	45					64	44					0	5877		3.70		
6	68	43	54	52					61	47					0	5825		3.53		
7	65	42	45	37					60	40					0	5957		3.44		
8	54	39	47	41					59	38					0	6039		3.31		
9	65	30	38	37					59	40					0	6066		3.24		
10	67	40	41	36					45	40					0	6052		3.24		
11	46	34	36	36					56	37					0	6106		3.02		
12	58	29	36	33					50	36					0	6189		2.99		
13	50	28	34	29					49	35					0	6325		2.89		
14	53	32	47	38					45	38					.05	6306		2.80		
15	55	45	47	44					55	43					0	6325		2.65		
16	62	38	49	46					62	45					0	6365		2.45		
17	65	38	45	45					50	45					0	6404		3.37		
18	65	43	52	44					50	38					0	6579		3.26		
19	57	30	37	36					56	38					0	6616		3.16		
20	62	37	60	54					58	37					0	6625		3.16		
21	68	37	40	33					44	36					0	6638		3.33		
22	47	35	38	33					43	31					0	6779		3.33		

Beltsville Weather Station

Weather data for Beltsville is displayed on our website. The information can be displayed by month, or by the year in a printable format. To compare weather data averages by the month or year, check out our [website!](#) If your research requires this data in a different format, please contact [Sheila Oscar](#) and he will help to get the information you are requesting.

Fundamentals of Soil Science Course - Catena in the Field

Eni Baballari - Environmental Science and Technology, University of Maryland

Every semester, students of ENST200, Fundamentals of Soil Science, take the drive to the Central Maryland Research and Education Center (CMREC) - Beltsville Facility to study soils in the field.

During this field trip, curious students of soils use augers to dig deep into the many layers of soil, called horizons. They get soil from four different locations, representative of the local topography. They deposit their diggings into a trough and come together with their soil troughs from four locations to see them side-by-side and discuss differences between them. They talk about the 5 soil formation factors (parent material, climate, organisms, topography, and time) and how each of these has influenced the local soil. Importantly, they also talk about the influence that soil properties have on the land use capabilities, such as farming or installation of a septic tank field. Students love this trip and we look forward to continuing to showcase the wonder of soil!



Teacher and students pose for a photo with their soil profiles in white troughs in front of them.

Roots in Research

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Eco-evolutionary Dynamics of Age-specific Resistance

Samuel Slowinski, Allyson Kido, Andrea Shirdon, Emily Bruns (Dept of Biology UMD, College Park).

Mature plant resistance is a well-known phenomenon in many crop species. Older plants tend to have a higher level of resistance, and better tolerance of pathogens than young seedlings. This pattern is not restricted to crop species, but also occurs in wild plants, as well as invertebrates and even vertebrates. Our lab is interested in how these patterns of age-specific resistance evolve in nature. Another way of putting this: why don't plants evolve higher levels of seedling resistance? After all, from an evolutionary perspective it is worse to get infected prior to reproduction than later in life!

Our lab has been using the herbaceous wild species, *Silene latifolia* (Caryophyllaceae) and its naturally occurring obligate anther-smut pathogen (caused by the Basidiomycete fungus: *Microbotryum lychnidis-dioicae*) to test several hypotheses about the evolution of age-specific disease resistance. The fungus, *M. lychnidis-dioicae* is highly specialized to *S. latifolia*. It colonizes the plant's meristems where it grows asymptotically until flowering. When the plant flowers, the fungus sporulates in the anthers, replacing the pollen and sterilizing the flower (Fig 1). In female flowers, the fungus induces anther production and sterilizes the ovary (Fig 1C). Transmission of the spores to mature, flowering plants is facilitated by pollinators. Spore transmission can also occur to non-flowering juvenile plants through localized wind transmission. Both the plant and fungus are native to Europe but were both introduced to the US in the 1800s and have subsequently become naturalized in eastern US. We have previously shown that seedlings are significantly more susceptible to anther-smut disease than adult, flowering plants.



Cost of resistance experiment: One hypothesis for the maintenance of juvenile susceptibility (e.g. low juvenile resistance) is that the cost of resistance is higher at the juvenile stage than at the adult stage. To test this hypothesis, we set up a common garden experiment at the MAES facility in Beltsville, to quantify fitness components of 45 families of the host plant in the absence of disease. Plants were reared for two years and scored for survival and flowering every 2 weeks (Fig 2a). These families were simultaneously reared to four ages in the greenhouse and directly challenged with spores of *M. lychnidis-dioicae* to determine age-specific susceptibility.

Fig 2. A) Common garden experiment at Beltsville MAES. B-C) Examples of flower number differences among families of *S. latifolia* in common garden.



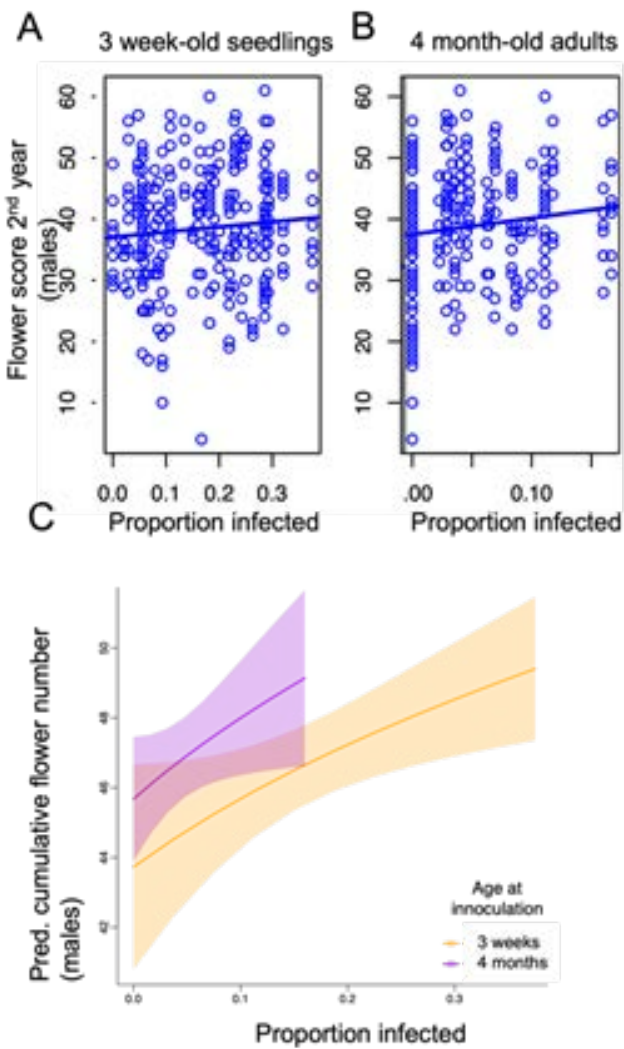


Fig 3. Results from the cost of resistance experiment. Relationship between greenhouse-measured seedling (A) or adult (B) resistance and total flower production in the field in the absence of disease. Each circle is a replicate male plant in the field. Both lines have a significant, positive slope indicating that more resistant plant families on the left hand side of the graphs (low proportion infected) produce fewer flowers than highly susceptible families. C) Results of aster-life history statistical models that integrate plant survival and flowering into a cumulative measure of fitness

Significance: Age-specific resistance is a widespread phenomenon in plants, and fruitful avenue for crop improvement. However, we know very little about the genetic and ecological factors driving the evolution of this important trait in natural plant populations. Our work so far has shown that natural populations of the weedy species, *S. latifolia* harbor both seedling and adult resistance, that both are potentially costly for the host to maintain, and that the evolution of this trait in nature is molded by both the costs and the level of exposure.

Results: We found that there was a significant trade-off between family-level disease resistance at both juvenile and adult stages, with more susceptible plants producing more flowers over the course of the season (Fig 2b). However, both juvenile and adult resistance were similarly costly (as evidenced by similar slopes; Fig 2c).

Transmission experiment: A second explanation for the maintenance of juvenile susceptibility is that the strength of natural selection for disease resistance is higher for adults than juveniles. To test this we put 175 potted *S. latifolia* plants inoculated with *M. lychnidis-dioicae* into our common garden experiment and monitored transmission to the adult plants over the course of two years. We found that floral traits such as sex and number of flowers were important predictors of infection risk in the field. Male plants produced more flowers than females and had a significantly higher probability of infection. Infection risk likely increases with flower number because pollinators are a major route of transmission to adult plants. We also found that plant families with higher adult resistance (measured in the greenhouse) had significantly lower infection rates. Taken together, our results show that the strength of natural selection on adult resistance in the field is also mediated by floral traits that affect the level of disease exposure.

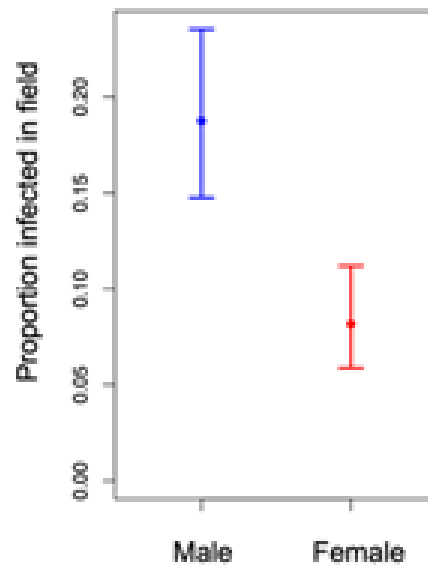


Fig 4. Proportion of male and female plants that became infected in the transmission experiment.

Evaluation of different rates of insecticide Plinazolin® Sc200 for control of fruitworms and other fruit-feeding insect pests in staked tomato production

Galen P. Dively and Terry Patton - Department of Entomology, University of Maryland

In cooperation with:

Erin Hitchner -Research and Development Field Scientist

Syngenta Crop Protection

PLINAZOLIN® technology is the trademark of a new active ingredient that provides a novel mode of action that helps growers manage a range of resistant and difficult to control insect pests, through targeted spray programs. The University of Maryland has been working with Syngenta to determine the minimum dosage of the insecticide required to effectively control fruitworms, as well as to generate the necessary data required by EPA for product registration. Over the last four years, trials have been conducted at the Central Maryland Research and Education Center, Beltsville, MD.

In 2022, a field experiment evaluated three application rates of plinazolin SC200 for control of fruit-feeding lepidopteran pests of tomato. Other insect pests evaluated included stinkbugs and thrips. Different rates of plinazolin were compared to the following commercial standard insecticides at their labelled rates: Radiant, Coragen, Besiege, and Intrepid. Bedding trays of tomato seedlings ('Fresh Mountain Plus') were grown in the University greenhouse and transplanted on black plastic mulch on June 16. The field site consisted of Hammonton loamy sand soil and was previously planted for many years in various vegetable crops, most of which served as host plants for lepidopteran pests. The experiment represented a typical late-season production of tomato and was timed for fruiting to coincide with peak fruitworm activity. Plots were laid out in a randomized complete block design with four rows, each treated as a replicate block and divided into nine plots. Seven insecticide treatments and two untreated controls were randomized within each row. Each plot consisted of one row 20 ft long and spaced 6 feet apart. Ten plants were spaced 24" apart in each plot. Tomato growth was managed according to commercial trellis practices, including staking between every two plants, pruning suckers and axil shoots to encourage apical growth, and stringing three times to support vertical plant growth. Irrigation were applied as needed through drip lines under the plastic mulch to maintain recommended soil moisture. Fertility requirements consisted of 60 lbs/acre of nitrogen incorporated into the soil prior to applying the plastic mulch and then followed up with additional nutrient feeding through the drip lines. Fungicides were applied weekly five times starting August 2 using an air blast sprayer to control foliar diseases. Different classes of fungicide products were tank mixed and rotated during the last four applications to control leaf blight infection and reduce the risk of disease resistance.

Overall population pressure of lepidopteran pests was monitored with pheromone lures of tomato fruitworm (*Helicoverpa zea*) and yellow striped armyworm (*Spodoptera ornithogalli*), in Texas wire cone traps and green bucket traps, respectively. Traps were placed next to the experiment site, and moth captures were recorded daily during weekdays during the treatment and harvest periods. Prior to initiation of treatments, plots were visually inspected weekly for evidence of any defoliation and feeding on green fruit. On August 8, the first application of each treatment was applied when the crown green fruit reached 75% of its mature size. The rationale for this early timing was to initiate control of lepidopteran larvae on the foliage before they started feeding on the fruit. Four subsequent applications were applied weekly on August 15, August 22, August 29 and September 5. Each treatment was applied using a CO2 backpack sprayer using a drop nozzle boom with five hollow cone nozzles covering each row, two directed on each side of the foliage and one over the top. The applicator walking time to cover each plot was calibrated to deliver 33 gallons/acre at 40 psi, and the amount of each chemical was added proportionately to one gallon in the spray tank. All treatments were applied with a modified vegetable oil surfactant blend DYNE-AMIC at the rate of 0.25% of the spray volume.

Plants were examined for symptoms of phytotoxicity after each application. Direct assessment of fruit damaging insects was not performed because the canopy structure of the trellis plants made it impractical to visually inspect and count the number of larvae. Sampling for damaged fruit commenced on September 2 when one-third of the tomatoes reached marketable maturity, characterized by attaining pink-red color and maximum size. Repeated harvests of similar fruit maturity were made on September 9 and 16. At each harvest, samples of tomatoes were removed and examined for damage caused by fruitworms, stink bugs, and thrips. Data were also recorded on the number of fruit with rot symptoms unrelated to insect feeding. Data from the two untreated controls were averaged for each replicate by sampling date prior to analysis. Because of differences in the number of tomatoes harvested per plot, damaged fruit counts were converted to percentages of each pest injury category and transformed using the arsin function to normalize data if necessary. For each pest group, the mixed model ANOVA procedure tested for treatment, harvest date and treatment by harvest date effects with replicate block treated as a random factor. The pdiff option was used to test for significance among multiple mean comparisons at the 5% probably level.



Fruit maturation and yield were considered normal for trellis tomato production. However, high temperatures caused sun scalding on exposed fruit in the top canopy, leading to some splitting and discoloration around the stem region of the fruit, particularly during the last harvest date. All pink-red tomatoes were removed and examined during the first harvest date, averaging 37.3 fruit per plot (ranging from 16 to 68). A random sample of 50 marketable fruit were harvested in most plots during the last two harvest dates. No signs of phytotoxicity effects on the overall plant health and vigor were evident in any plots that could be related to the treatments. On the last assessment date, there was moderate levels of necrosis-type injury on the top canopy due to late blight infection and environmental stress; however, this injury was equally present in all treated and untreated plots.



Fruitworm injury was caused almost entirely by the yellow striped armyworm, with no evidence of tomato fruitworm presence. This was surprising since pheromone captures of *H. zea* moths were very high during the fruiting period, and nearly 100% of the ears in adjacent untreated sweet corn plots were damaged by corn earworm. Averaged over sampling dates, fruitworm injury was recorded on $13.5 \% \pm 1.71 \text{ SE}$ of the harvested fruit in the untreated plots. Injury by stinkbugs (mainly *Euschistus servus*, *Halyomorpha halys*) and thrips was also recorded on an overall average of $9.8 \% \pm 1.67 \text{ SE}$ and $1.6 \% \pm 0.57 \text{ SE}$ of the tomatoes in the untreated plots, respectively. Thrips injury was highly variable among plots and lower than the normal infestation levels previously experienced at this site. Altogether, the combined feeding injury of all fruit-feeding insects affected $24.9 \% \pm 2.78 \text{ SE}$ of the marketable fruit, although many tomatoes exhibited

more than one type of injury. Fruit showing symptoms of rot (unrelated to insect feeding) ranged from 1.62% to 6.38%. However, there were no treatment or treatment by date effects on the number or percentage of rotted fruit ($F(7,81) = 1.50, P = 0.180$).

The treatment by date interaction effect was not statistically significant for any of the pest injury variables. The main effect for sampling date was also not significant, except for the percentage of stinkbug injury which decreased over the three sampling dates. Table 1 summarizes the treatment effects for each of the three fruit feeding insects, based on data pooled over all sampling dates. For fruitworms, all insecticide treatments significantly reduced the percentage of fruit injury by 53.5% to 80.1% compared to the untreated control ($F(7,95) = 10.12, P < 0.001$). The plinazolin treatments showed no significant trend of increasing control with higher rates and also overall control of ca. 75% was not significantly different from any of the standard insecticides. Besiege provided the highest level of control (80.1%) but was only significantly different from levels of control by Coragen (56.0 %) and Intrepid (53.5%).

For stinkbugs, only plinazolin treatments and Besiege significantly reduced the percentage of fruit injury compared to the untreated control ($F(7,95) = 4.5, P < 0.001$). Rates of plinazolin significantly reduced stinkbug injury by 50.7 to 80.2 % but there were no significant differences among rates and only weak numerical evidence of better control at the high rate. All plinazolin rates also performed significantly better than the standard insecticides, except for Radiant (40.9% control) and Besiege (67.0 % control) which provided levels of stinkbug control comparable to the plinazolin treatments. As expected, Coragen (1.5% control) and Intrepid (9.6% control) were clearly the least effective against stinkbugs. For thrips, despite the highly variable data due to the low infestations, all treatments except for Radiant and Intrepid significantly reduced the percentage of fruit injury compared to the untreated control ($F(7,95) = 2.47, P = 0.023$), and there was no evidence of a plinazolin rate response.

In summary, the key objective was to determine if increasing the rate of plinazolin will result in increased control of lepidopteran pests in tomato. Altogether, although overall infestations were considered light to moderate, results showed no evidence of a rate response against fruitworms, stinkbugs and thrips.

Table 1. Effects of different rates of plinazolin SC200 compared with standard commercial insecticides for suppression of fruitworms, stinkbugs and thrips causing tomato fruit injury. Beltsville Research and Education Center. 2022.

Treatments ^a	Rate/A	Mean percentage of fruit injured ^a		
		Fruitworm	Stinkbug	Thrips
Plinazolin SC200	4.11 fl oz	3.3 bc	3.5 b	0.00 b
Plinazolin SC200	5.13 fl oz	3.3 bc	4.8 ab	0.33 b
Plinazolin SC200	6.16 fl oz	3.4 bc	1.9 b	0.17 b
Radiant 120 SC	10 oz	5.0 bc	5.8 ab	.50 ab
Coragen 1.67 SC	5 oz	6.0 b	9.7 a	0.17 b
Besiege 1.25 ZC	8 oz	2.7 c	3.2 b	0.17 b
Intrepid 2F	10 oz	6.3 b	8.9 a	0.83 ab
Untreated Control		13.5 a	9.8 a	1.55 a

^a Mean percentages are based on the combined data over the three harvest dates; means within columns followed by the same letter are not significantly different ($P = 0.05$).

^b All treatments were mixed with DYNE-AMIC 0.25 %V/V.

Enhanced Cover Cropping for Nutrient Management - Two Fields

Ray Weil, Professor of Soil Science

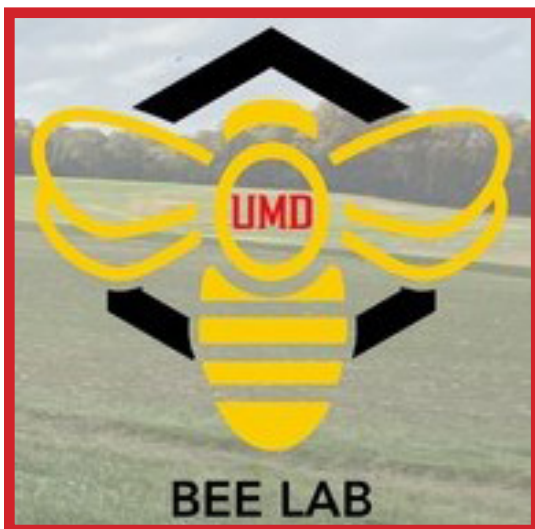
Below are two videos showing no-till planting into a typical rye cover crop terminated in mid-April, 3 weeks before planting compared to an enhanced cover cropping practice of "planting Green" into a much bigger living multi-species green cover crop.

The enhanced cover crop promises to fight climate change and improve soil health by sequestering 4-5 times as carbon from the atmosphere into the soil, as well as reducing fertilizer needs by fixing 50 to 100 lbs of nitrogen per acre.

Click here to view [video 1](#) and [video 2](#)

UMD Bee Lab and the New UMD Bee Squad

<https://www.umdbeelab.com/> <https://umdbeesquad.com/>



About The Lab

The Honey Bee Lab at the University of Maryland has diverse personnel with multidisciplinary scientific backgrounds who bring a fresh perspective to solving problems. Research in the laboratory is focused on an epidemiological approach to honey bee health. We are proud to share our research into the major mechanisms that are responsible for recurring high loss levels in honey bee populations, such as pests and pathogens associated with honey bees, loss of natural forage habitat due to large monocultural croplands, and pressure from human induced changes in the environment. Our team has led and managed the [USDA APHIS National Honey Bee Disease Survey](#) since 2009. We are also a major partner and founding member of the [Bee Informed Partnership](#) (BIP), who collaborates closely with beekeepers from across the country to study and better

understand the loss in honey bee colonies in the United States.

You can find Realtime results about these efforts at our database portals:

https://research.beeinformed.org/state_reports/

Click [here](#) to purchase UMD Honey

Donations

If you are able to help support our mission to improve honey bee health, we greatly appreciate whatever you can give.

You may donate online using the [University of Maryland "Giving to Maryland" Honey Bee Lab Donation Site](#).

Thank you for your support!



Grain Yield is not Impacted by Early Defoliation of Maize: Implications for Fall Armyworm¹ Action Thresholds

Carlos A. Blanco², Kevin Conover³, Gerardo Hernandez⁴, Giseli Valentini⁵, Maribel Portilla⁵,
Craig A. Abel⁵, Paul Williams⁵, Urbano Nava-Camberos⁶, William D. Hutchison⁷, and Galen P. Dively³

Abstract. The fall armyworm, *Spodoptera frugiperda* (J.E. Smith), now is arguably the most important global insect pest of maize, *Zea mays* L., in the world. Maize growers in the Americas have battled the pest for centuries, and control recommendations have been adapted for Africa and Asia, based on contrasting results of the impact on yield when the pest infests young maize plants. Important control decision-making tools such as action thresholds, or economic thresholds, are not completely developed to control fall armyworms, and insecticide applications are still recommended at low levels of infestation on young plants. To further assess the damage-yield relationship for fall armyworm, we manually removed 0, 33, and 66% of foliage when maize had 1-2 (V1-V2), and 3-4 (V3-V4) fully developed leaves. The amount of defoliation did not reduce maize yield potential when compared with nondefoliated plants, regardless of the defoliation timing: V1-V2 or V3-V4. Fertilizing defoliated plants significantly yielded more grain than non-fertilized plants, and these obvious results showed that smallholder maize growers that can afford investing in either fertilizer or insecticide will benefit more from the former. Our results add to the number of reports that indicate young maize plants can compensate for large amounts of defoliation without reducing yields.

Introduction

Defoliation of maize, *Zea mays* L., by abiotic and biotic factors during early developmental stages produced contrasting impacts on grain yield. Researchers evaluated natural herbivory and tried different techniques to mimic gastropod, arthropod, and hail damage, the most frequent cause of defoliation in young maize plants. Hail damages maize, and when it occurs during early developmental stages, yields have not been negatively or consistently impacted (Klein and Shapiro 2011, Battaglia et al. 2019, Thomason and Battaglia 2020). Among numerous arthropod pests of maize, the black cutworm, *Agrotis ipsilon* Hufnagel; beet armyworm *Spodoptera exigua* (Hübner); and fall armyworm, *Spodoptera frugiperda* (J. E. Smith); are the most common defoliators of early-stage maize in the Americas, with several control tactics developed for each pest (Purdue University 2009, Blanco et al. 2016, Capinera 2020, Ostlie and Potter 2021).

There is wide discrepancy among studies designed to quantify herbivory and yield impact of fall armyworms during early-stage vegetative maize (V1- V6, Abendroth et al. 2011, ISU 2022). Several studies demonstrated substantial variability in yield impact, including 12-100% potential yield reduction when the pest feeds on early stages of maize (Cruz and Turpin 1983, Willink et al. 1993, Dal Pogetto et al. 2012, Sunil Kumar et al. 2020, Deshmukh et al. 2020). By contrast, others found that fall armyworm does not cause significant or negative effect on yield (Morrill and Greene 1974, Andrews 1988, Marenco et al. 1992, Thomason and Battaglia 2020, Babendreier et al. 2020). Crookston and Hicks (1978) reported as much as 100% defoliation of V1-V4 maize might even increase grain yield potential, suggesting a compensatory response (Pedigo et al. 2021). Recently, Overton et al. (2021) reviewed seven published articles regarding infestation and negative effects by fall armyworm on maize yield. Unfortunately, they concluded the relationship was unclear between fall armyworm herbivory and yield loss during early plant growth stages.

Protecting young, vegetative maize by applying insecticides against infestation by fall armyworms produced variable results. Several applications of insecticides at early vegetative maize stages resulted in doubled grain

¹*Spodoptera frugiperda* Smith (Lepidoptera: Noctuidae)

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yield (Deshmukh et al. 2020), but other studies showed no significant increase in grain yield (Morrill and Greene 1974, Lima et al. 2010, Sunil Kumar et al. 2020). Knowing when to control fall armyworms requires understanding its potential impact at different stages of maize development. Unfortunately, according to Prasanna et al. (2018), 'in practice, true economic thresholds and economic injury levels have not been determined for most crops. Instead, nominal thresholds (or action thresholds), are calculated based on expert opinion and experience coupled with accurate field scouting assessments.'



Growers around the world apply insecticides to control fall armyworm larvae in early, vegetative (V1-V4) maize development (Blanco et al. 2010, 2014, 2016; ICAR- IIMR 2019, Chimweta et al. 2020). This creates a significant economic burden to growers and potentially negative impacts on the environment. In Mexico alone control of fall armyworms on maize, generally treated at V1-V4, with one to three applications amounts 3,200 tons of insecticidal active ingredient per year (Blanco et al. 2010). The recent global invasion of fall armyworm is likely to increase the use of insecticide, production costs, and environmental impacts, because government aid has

already supported increased insecticide use in some regions of Africa (Hruska 2019). A substantial share of the 56 million hectares of maize grown in Asia might also be treated for fall armyworms (Yang et al. 2021). Because most maize-growing areas of the world are now under pressure by fall armyworms (FAO 2022), almost 200 million hectares (FAOSTAT 2021) could be affected by the pest. Consequently, many hectares of maize during vegetative stages of development are treated with insecticide because the practice continues to be recommended.

Discrepancy between the high cost and putative effect of insecticide on greater maize yields also requires better assessment. The impact of early defoliation in corn continues to be reinforced around the world indicating the action threshold for fall armyworms during early whorl stage is 20% (range 10-30%) of plants infested with larvae, or defoliated seedlings. Insecticide application is recommended above this action threshold. Crop consultants in some instances choose to spray maize with 5 10% damaged plants (ICAR- IIMR 2019), while other recommendations endorse to 40% damaged plants, without specifying the crop development stage (du Plessis et al. 2020).

Maize is increasing in importance throughout the world. A decade ago, about 73% of the crop-producing area was in the developing world (Prasanna 2011). A fundamental first step to meet proposed agro-ecological alternatives to control the pest (Harrison et al. 2019) is to thoroughly evaluate the validity of recommending insecticide applications against fall armyworm in early stages of maize. In this study, we researched maize defoliation with two specific objectives. We simulated fall armyworm herbivory during V1-V4 growth stages and then compared the effect of fertilization and defoliation on maize yield to evaluate the degree to which such application could assist plants in compensating for potential detrimental effect of foliage removal.

Materials and Methods

A field corn hybrid (P0506AM, P0) and four sequential generations of replanted P0506AM progeny for 5 consecutive years (F1 to F4), harvested in 2020, were planted at 74,165 seeds per hectare in plots of eight (0.75 m centers) rows, 44 m long on 12 May, 21 June, and 8 July 2021 (replicates) at the University of Maryland Research Experiment Station, Beltsville, MD. Plots were managed using current agronomic practices, divided lengthwise into two subplots, half receiving side-dress application of 45 kg/ha of nitrogen at planting, and 112 kg of N and 22 kg of sulfur per hectare. Weeds were controlled with a preemergence, tank mix application of glyphosate, atrazine, pyroxasulfone, and mesotrione, immediately after planting. Insect pests were scarce during the experiment; therefore, no insecticides were applied. The experimental field received 7.6, 12.4, 8.9, 22.3, 12.7, and 11.7 cm of monthly precipitation between May and October. Irrigation was not provided.

At V1-V2 developmental stages, 33% of foliage of all fertilized and non-fertilized plants in a single row per plot was removed with scissors by cutting 33% of foliage. In another row, 66% of the foliage was removed by cutting the leaf area necessary for 66% defoliation. At V3-V4, 33 and 66% of the foliage was removed in additional rows. The two central rows of each plot were the nontreated check, where foliage was not removed, while rows 2, 3, 6, and 7 were assigned at random for defoliation. At harvest (~20% grain moisture), a final plant population per subplot (fertilized or non-fertilized) was counted, and 40 ears from each subplot were removed by hand during mid-October to early November, weighed, and grain weight calculated per hectare.

Grain weight per hectare was, as expected, significantly greater in fertilized than non-fertilized plots ($p = 0.0009$). Therefore, the two treatments were analyzed separately using the same procedure. Because the research studied the effect of defoliation, a one-way ANOVA compared the effect of three amounts of defoliation (0, 33, and 66%) on yield. To seek further reduction of variance associated with the stage of development at which defoliation occurred, and the variety of maize used -- and possibly finding interactions of effects-- a two-way independent ANOVA for factor pairs defoliation-development stage and defoliation-variety, followed by Tukey's test was planned. For the pair defoliation-stage, only two levels of defoliation, 33, and 66% were considered. R software was used for the tests and exploratory analysis.

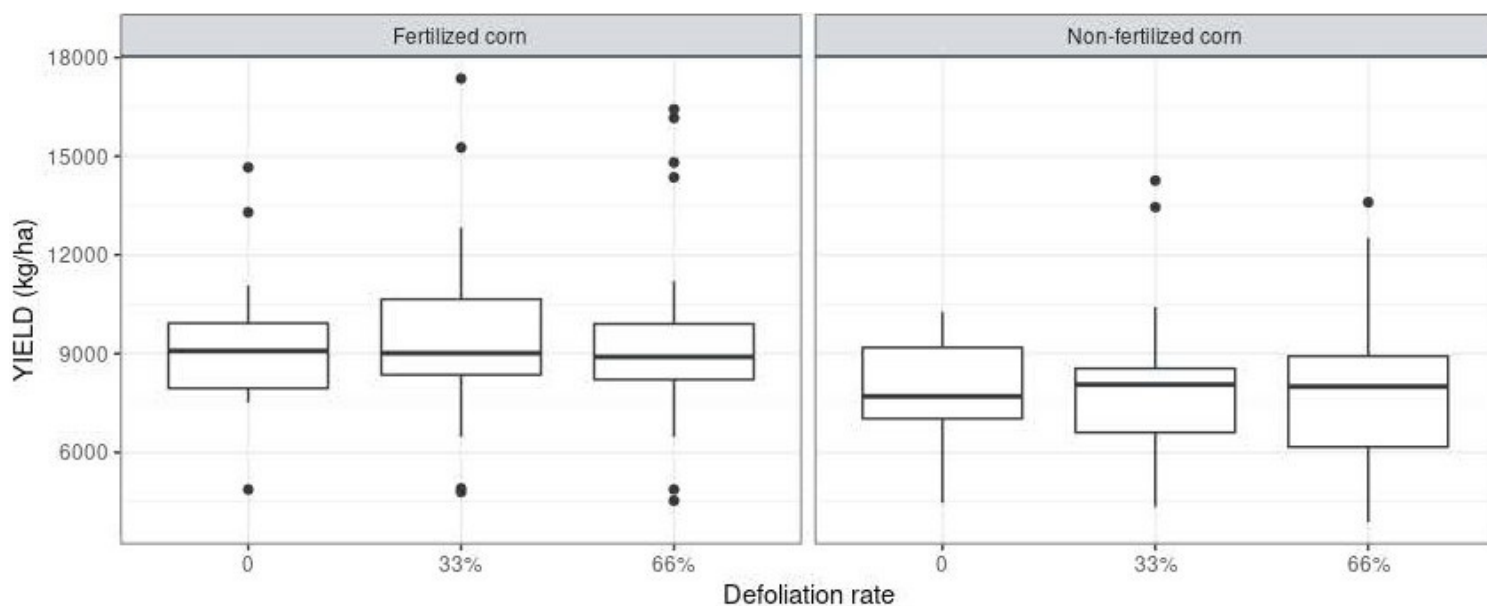


Fig. 1. Fertilized and non-fertilized maize yield of five generations under three artificial defoliation rates at V1-V2 and V3-V4 developmental stages.

Results and Discussion

The uncertainty surrounding the putative yield detriment by infestations of fall armyworms in young maize plants creates confusion among farmers that spray fields without solid knowledge of the beneficial effect of their investment in insecticide (Babendreier et al. 2020). Lack of basic knowledge has produced indiscriminate insecticide use with dubious results (Blanco et al. 2010, Harrison et al. 2019). Our experimental design addressed large amounts of defoliation of maize plants, with results indicating that 33 or 66% defoliation during V1-V2 and V3-V4 in plots of fertilized ($F_{(2,72)} = 0.011$, $P = 0.98$) or non-fertilized ($F_{(2,72)} = 0.55$, $P = 0.95$) maize did not reduce maize yields (Fig. 1). We used standard information contained in boxplots: lower and upper lines corresponded to first and third quartiles with the median in between, maximum, and minimum values of the set at the extreme of the whiskers, and outliers appear as open circles.

The developmental stage at which defoliation occurred (V1-V2 and V3-V4) did not significantly affect maize yield ($F_{(1,56)} = 0.043$, $P = 0.83$), or non-fertilized plots ($F_{(1,56)} = 0.000$, $P = 0.99$) (Fig. 2). Interactions between defoliation percentage and developmental stage were also non-significant in fertilized ($F_{(1,56)} = 0.071$, $P = 0.79$) and non-fertilized plots ($F_{(1,56)} = 0.039$, $P = 0.84$).

Previous reports of early-stage (<V4) defoliation produced similar results (Brown and Mohamed 1972, Mahmoodi et al. 2008, Lima et al. 2010, Klein and Shapiro 2011, Battaglia et al. 2019, Thomason and Battaglia 2020), or only 15% yield reduction (Hanway 1969). However, artificial defoliation might raise the question of whether cutting leaves once would have the same effect on yield as gradual herbivory by fall armyworms that eventually cause 66% foliage loss in a few days. Accumulation of foliage loss during gradual herbivory under more natural conditions amounts to less area loss over time than instant foliage loss. Furthermore, because the apical meristem of maize is below or at ground level before it reaches V6 (Fortin et al. 1994), maize can compensate for foliar damage before it reaches the whorl stage, which indicates leaf herbivory might produce a similar response on maize than artificial defoliation. By contrast, some results showed greater yields in maize plants protected not exclusively from fall armyworm using multiple sequential applications of insecticide (Dal Pogetto et al. 2012, Babendreier et al. 2020, Deshmukh et al. 2020). The studies indicated yield increased to 100%, including use of multiple sprays when plants reached $\geq V6$, a developmental stage sensitive to yield decrease because, at this time, the apical meristem is at the whorl level. Because insecticides used in the experiments control multiple pests, their effect might have masked control of insects that do not produce apparent damage caused by fall armyworm on foliage (e.g., corn rootworms, thrips, aphids) but also have potential to reduce yield.

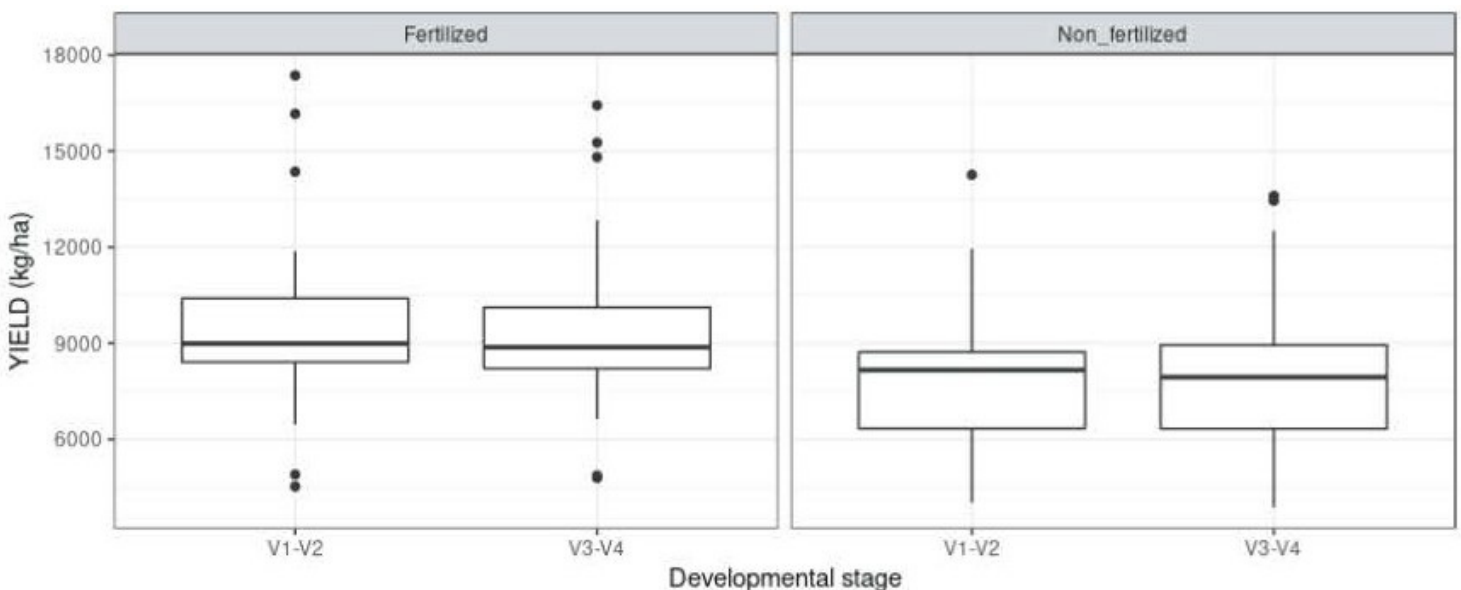


Fig. 2. Combined effect of three defoliation rates at two developmental stages of five maize generations.

The cost of multiple insecticide applications might exceed the economic losses produced by pests. The current international maize grain price is ~\$150 per ton, which is close to the cost of three insecticide applications (per hectare basis). Early season pests including fall armyworms are sprayed multiple times and late-season pests require additional control (Blanco et al. 2014, 2016). Hruska (2019) calculated that a smallholder maize grower, the most prevalent producer around the world (Prasanna 2011), should not spend more than US\$8.00 per hectare to make insecticidal control economically rational. Because average corn yield in the world is 5.6 tons per hectare and its price in 2019-2020 was \$140 (USDA FAS 2021), \$100 spent on insecticide applications should produce at least 700 extra kilos to make the cost of fall armyworm control economically feasible for growers. Unfortunately, many maize growers might not be familiar with control of fall armyworms or proper use of insecticides and might not have financial resources to invest \$100/ha for insect control (Jones-García and Krishna 2021). Recent invasion by fall armyworms in Ghana cost \$52/ha for control (Kwasi Bannor and Oppong-Kyeremeh 2022).

Smallholders around the world might not have access or purchasing power to invest in hybrid seed or be able to invest an additional \$200 in fertilizer per hectare. In Mexico, maize yields for smallholders under dryland conditions using open pollinated varieties average 1,200 kg/ha, while commercial growers able to invest in hybrid seed, fertilizer, and irrigated fields might harvest 18,000 kg/ha (Blanco unpublished). Our results showed that 0, 33, and 66% defoliated hybrid and four non- hybrid field maize consecutive generations with fertilizer produced significantly different yields ($F_{(4,70)} = 45.54, P < 0.0001$) (Fig. 3). However, interaction between maize generations and defoliation percentage was not significant ($F_{(8,60)} = 0.626, P = 0.75$).

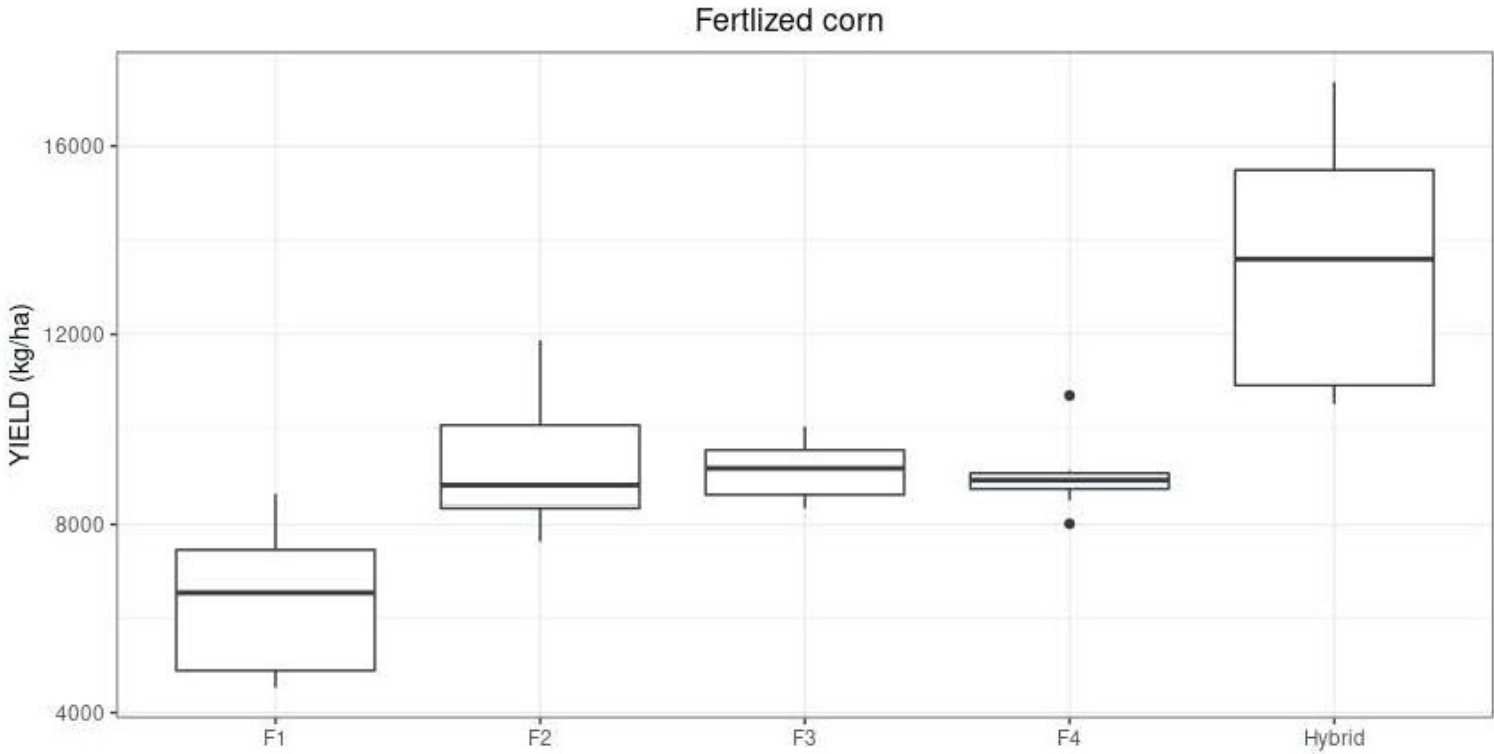


Fig. 3. Yield of five fertilized maize generations with a combined effect of 0, 33, and 66% defoliation at V1-V2 and V3-V4 developmental stages.

Therefore, if the smallholder grower would have \$200 to invest either in hybrid seed, fertilizer, or insecticide, (s)he would obtain 2 tons more by planting hybrid seed without fertilizer (9 tons per hectare) (Fig. 4) or fertilizing non-hybrid seed and obtain a similar yield (8.8 tons/ha) (Fig. 3). The difference between hybrid and subsequent generations when plots did not receive fertilization is less pronounced (Fig. 4). Still, it indicates that a \$200 investment in hybrid seed, rather than \$5 per hectare investment in open-pollinated

varieties or saved seed, would produce higher yields and more profitable return on investment (and still statistically significant ($F_{(4,60)} = 12.58, P < 0.0001$), without significant interaction between variety and defoliation ($F_{(8,60)} = 0.516, P = 0.84$).

Yield loss produced by fall armyworm in Africa has been estimated at ~11% (Baudron et al. 2019), while in the Americas a wide range of yield impact has been reported. Appropriate recommendations, such as described by Prasanna et al. (2018), should be followed, including that fall armyworms should not be controlled until after the V6 developmental stage. Unfortunately, insecticide treatments at low fall armyworm infestation is commonly recommended (Durocher-Granger et al. 2018, Bessin 2019) without specifying the appropriate maize development stage, while a threshold of 20% of plants infested with fall armyworms continues to be recommended (Kumar et al. 2020). As noted by Overton et al. (2021), additional research is critically needed to better define the yield-loss relationship for fall armyworm and vegetative maize, so reliable action or economic thresholds can be developed (see Nault and Shelton 2010, Pedigo et al. 2021). Because of the range of maize hybrids and open-pollinated varieties grown globally, action thresholds that are hybrid or variety specific might be needed.

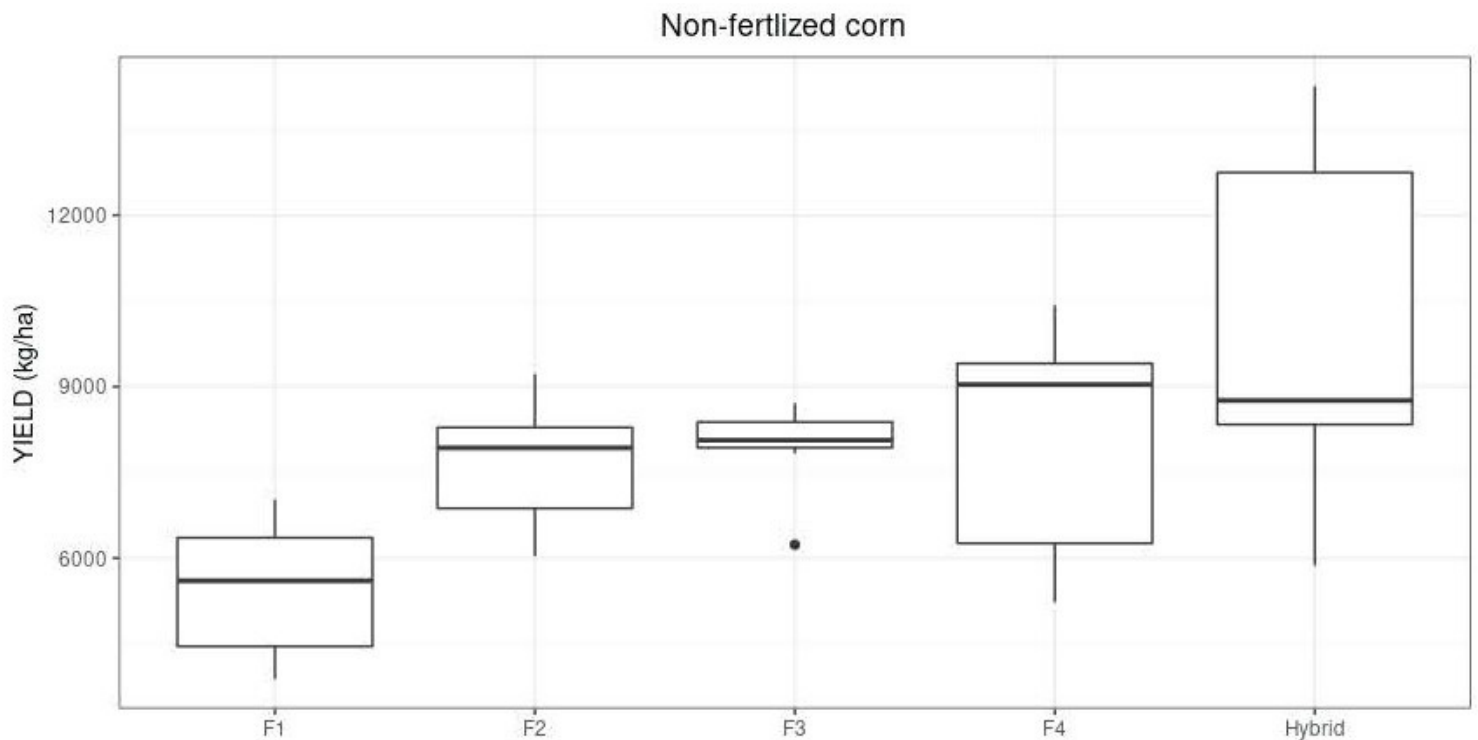


Fig. 4. Yield of five non-fertilized maize generations with a combined effect of 0, 33, and 66% leaf defoliation at V1-V2 and V3-V4 developmental stages.

For a printable PDF of this article, to include some Spanish, Acknowledgments and References Cited, click [here](#).

FACTSHEET DISEASE DATA 2022

[Maryland Wheat Varieties](#)

[Maryland Barley Varieties](#)

Impact of Cover Crop Termination Method on Soil Moisture

CMREC – Beltsville Field Experiment

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To prepare for spring planting, farmers rely on mechanical (e.g., roller-crimping, mowing, tilling) and chemical methods to terminate their winter cover crops. Most growers using cover crops in conventional grain production systems terminate their cover crops in the spring by spraying broad spectrum post-emergent herbicides. Additionally, farmers in both conventional and organic production systems might roller-crimp their winter cover crop, effectively flattening the cover crop biomass into a mulch layer. Recent research has focused on herbicide selection and roller-crimper timing for effective cover crop termination, however there is limited knowledge about the impact of these choices on spring soil moisture dynamics and cover crop residue decomposition.

Herbicide selection, specifically the choice between a contact and systemic product, could lead to differences in the plant senescence, evapotranspiration, and decomposition rates of the living and dead cover crop. The application of a systemic herbicide, such as glyphosate, results in a gradual senescence of the plant tissue and maintenance of the plant structure, meaning transpiration through the plant could potentially continue for a sufficient time after cover crop termination to result in drier soil moisture levels than a similar field of cover crops sprayed with a faster-acting herbicide. In contrast, rapid disintegration of plant cell membranes and the ensuing loss of plant structure after exposure to a contact herbicide may lead to a quick decline in cover crop water uptake, although this has not yet been documented in the scientific literature. Regarding mechanical termination, flattening cover crops with a roller-crimper reduces evapotranspiration and conserves soil moisture. Expedited contact with the moist soil surface and microbes after roller-crimping will hasten tissue decomposition and nutrient release compared to cover crop residue that remains upright.

A field study is underway to quantify the cover crop evapotranspiration, and decomposition rates of a cereal rye (*Secale cereale L.*) cover crop terminated with a systemic herbicide (glyphosate) versus a contact herbicide (paraquat), with an additional roller-crimper treatment. With increasing variability in spring precipitation due to climate change, optimizing these cover crop termination methods for both dry and wet conditions is essential to increasing agroecosystem resiliency.



Standing

Roller crimped

Cara Peterson, 2022

Immediately after rolling

May 12, 2022

CMREC Hayden Farm

Experimental design

Experimental plots were established in both 2022 and 2023 at the CMREC-Beltsville facility. The two field sites are on very sandy and well-drained soil, and the experiment is simultaneously being executed at sites with heavier, slower-draining soils at the USDA BARC facility nearby. When the cereal rye winter cover crop reached anthesis, the optimal growth stage for termination by roller-crimping, half of the cover crop plots were rolled. One week later, the cereal rye plots were sprayed with the two herbicide treatments in perpendicular direction to the roller-crimper path to achieve four termination treatments: Rolled + Paraquat; Standing + Paraquat; Rolled + Glyphosate; and Standing + Glyphosate. Two control treatments without a cover crop were also established: bare fallow and straw mulch.

Time domain reflectometry (TDR) sensors were installed at surface level, 10 in., 20 in., and 30 in. depths to continuously measure and record soil moisture and temperature. To quantify cover crop decomposition, a litterbag study was also included in the experiment. In residue decomposition studies, the cover crop biomass substrate is typically collected at termination, however that would negate the termination treatments put in place in this experiment. Therefore, the biomass substrate material was collected two weeks after the herbicide treatments were sprayed. The litterbags were then placed back in the field plots and moved to a nearby corn field after fertilizer side-dressing had occurred in order to provide realistic conditions for cover crop residue during the remainder of the production season.

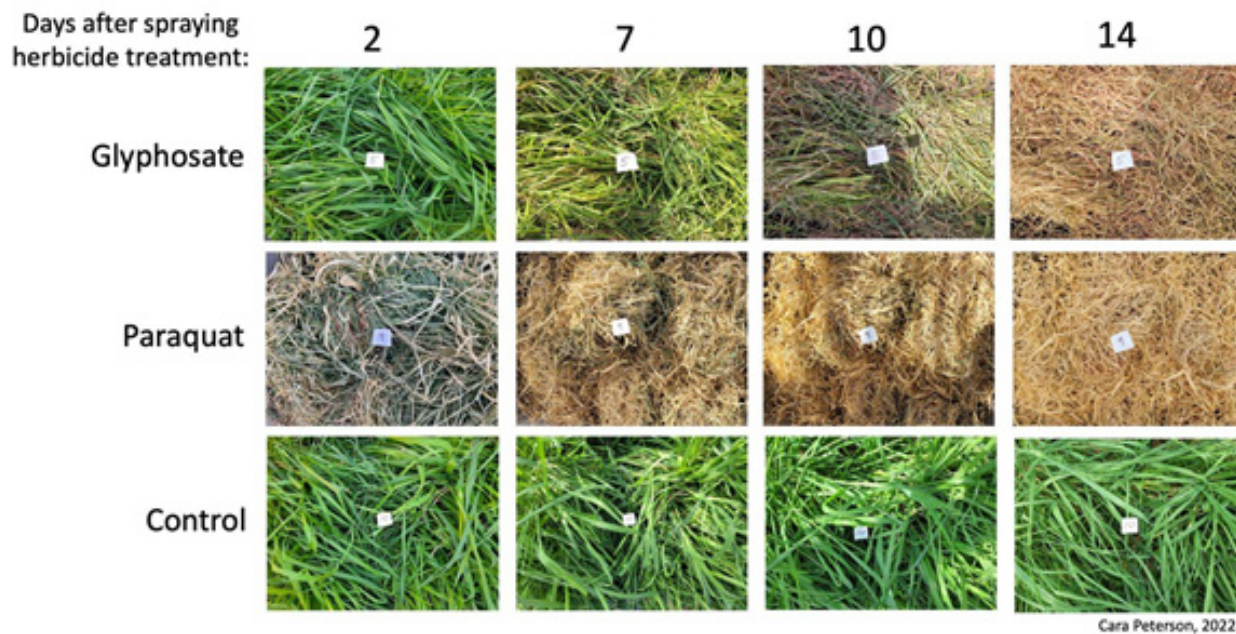
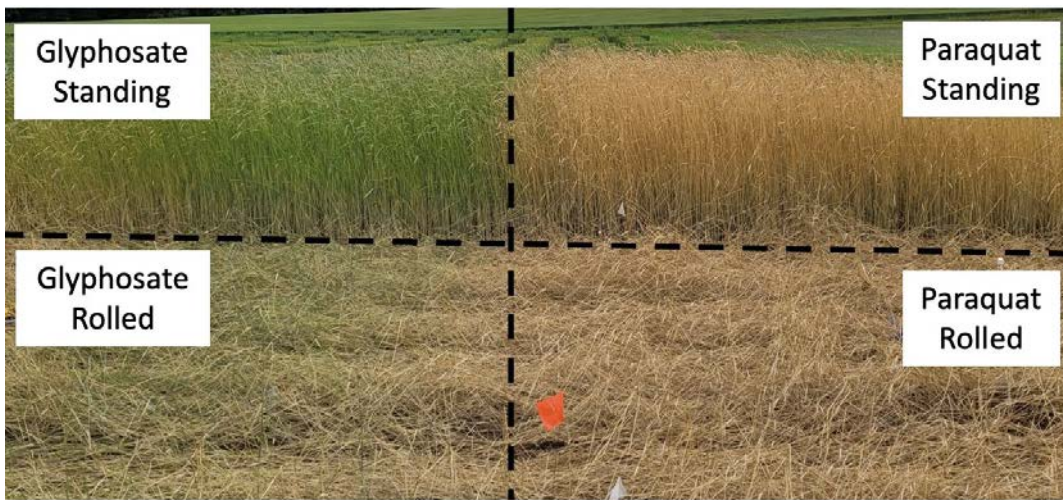


Image 2: Test plots of cereal rye sprayed with glyphosate and paraquat, shown alongside a control treatment, demonstrating the different efficacy rates of the two herbicides.

Preliminary results

While data collection and analysis are still underway for the 2023 field study, there are some preliminary observations from the 2022 season. With very heavy rainfall throughout the 2022 experimental period, soil moisture levels were relatively similar across the termination treatment plots. At the CMREC-Beltsville location with sandy soil, any rainfall drained away so quickly that no treatment differences in soil moisture emerged. The field site at USDA-BARC drained very slowly, and soil moisture remained high throughout the spring. During some dry-down periods, a slight effect of mechanical termination could be seen, with the roller-crimped plots remaining wetter than the plots where the cover crop residues remained standing. This year's drier spring with minimal precipitation will likely draw out any differences in soil moisture among treatments if they exist, with the roller-crimper plots likely to reduce evaporation during the dry periods.



May 25, 2022
6 days after spraying
13 days after rolling



June 15, 2022
27 days after spraying
34 days after rolling

Image 3: Termination method treatments in cereal rye cover crop plots at CMREC-Beltsville.



Results from the 2022 residue decomposition study component demonstrated no differences in decomposition rates among the termination treatments. This could likely be a result of terminating the cereal rye cover crop at a later growth stage in order to accommodate the roller-crimper treatment. As cereal rye matures, the carbon to nitrogen ratio of the plant tissue residue decreases, which slows the residue decomposition in comparison to cereal rye terminated at earlier growth stages.

At this time, soil moisture and biomass decomposition data collection are underway for the 2023 field experiment and we look forward to sharing our final experimental results when the study has concluded.

Image 4: Cereal rye biomass in litterbags for biomass decomposition component of field study. At set times throughout the season, one litterbag is collected from each treatment and replicate group to assess biomass loss over time. Cara Peterson, 2022.

Field evaluation of the efficiency of DDI concentrate for weed control and residual activity

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Figure 1. Overview of farm lane prior to plot establishment on May 11, 2022.

An experimental field trial was conducted in 2022 at the Central Maryland Research and Education Center, Beltsville facility, to evaluate the efficacy of an experimental herbicide (DDI) for immediate burndown and residual weed control. Treatment plots were established along a 200 m farm lane with a mixture of weeds growing between the wheel tracks on a gravel+soil substrate and compared directly next to the lane with weeds growing on a soil substrate (**Fig. 1**). Four replicate blocks of plots were laid out along the farm lane at selected sites with similar sunlight exposure and weed composition. Each block consisted of five plots in the gravel+soil substrate, paired directly with five plots on one side of the lane in the soil substrate (**Fig. 2**). Each plot measured 1 m x 2 m.

Pretreatment counts of weed cover by weed type were recorded in each plot on May 23, when most active growing weeds were less than 5 cm and winter annuals were beginning to yellow and die. Weed cover was visually estimated as the percent of surface area covered by weed vegetation; however, the proportion of ground covered by senesced winter annuals was not included. Results of the pretreatment abundance of weeds are given in **Table 1**. Overall weed cover averaged 54.5 and 61.0% in the gravel+soil and soil substrates, respectively.

Only a very low percentage of the weeds present were summer species that were just beginning to germinate and thus difficult to identify. The dominant species present prior to treatment included white clover, annual bluegrass, and goose grass.



Figure 2. Layout of a replicate block showing the paired treatment plots in the soil substrate (left side of lane) and gravel+soil substrate (center of farm lane). Blue marker lines are shown to delineate the paired plots. Photo was taken on June 7 one week after the first treatment. Note the untreated control plots in each substrate in the upper right corner of the

Treatments were assigned to the plots in both substrates as follows: 1) a single application of Ortho GC RTU applied at the rate of 1 gallon per 300 ft.²; 2) two applications of Ortho GC RTU applied at the rate of 1 gallon per 300 ft.²; 3) a single application of DDI applied at the rate of 1 gallon per 500 ft.²; 4) two applications of DDI applied at the rate of 1 gallon per 500 ft.²; and 5) untreated control. Each treatment in both substrates was arranged side-by-side in each block as a split plot design (**Fig. 2**). The first application was applied on May 31 (Day 0), using a backpack CO₂ sprayer with a three-nozzle boom delivering specified rates of gallons per 300 or 500 ft.² at 40 psi. The speed of the boom over the 2 m length of each plot differed by treatment and was timed in seconds with a stop watch. The second application of treatments #2 and #4 was applied on August 23 (Day 84), using the same methods.

Table 1. Mean (minimum and maximum) percentage weed cover¹ by weed species and substrate estimated on May 11 prior to first treatment.

Weed Species	Substrate	
	Gravel+Soil	Soil
White clover, <i>Trifolium repens</i>	45.3 (20,70)	26.7 (5,60)
Knotweed, <i>Fallopia japonica</i>	0.3 (0,1)	2.4 (0,30)
Pennsylvania Smartweed, <i>Persicaria pensylvanica</i>	0.3 (0,2)	9.6 (1,33)
Annual bluegrass, <i>Poa annua</i>	9.5 (0,20)	9.0 (5,19)
Cleaver grass, <i>Galium aparine</i>	3.2 (0,15)	1.9 (0,8)
Chickweed, <i>Stellaria media</i>	2.1 (0,10)	0.3 (0,4)
Buttercup, <i>Ranunculus bulbosus</i>	0.6 (0,3)	0.1 (0,1)
Fleabane, <i>Erigeron bonariensis</i>	1.6 (0,8)	0.8 (0,4)
Hairy vetch, <i>Vicia villosa</i>	0.1 (0,2)	0.0
Dandelion, <i>Taraxacum officinale</i>	0.3 (0,1)	1.7 (0,8)
Broadleaf plantain, <i>Plantago major</i>	0.4 (0,4)	1.2 (0,15)
Festuca grasses, <i>Festuca spp</i>	0.0	1.0 (0,13)
Smooth brome grass, <i>Bromus inermis</i>	0.7 (0,4)	0.2 (0,1)
Fall panicum grass, <i>Panicum dichotomiflorum</i>	2.2 (0,6)	9.0 (0,50)
Goosegrass, <i>Eleusine indica</i>	3.0 (0,7)	15.8 (0,60)
Common henbit, <i>Lamium amplexicaule</i>	3.0 (0,12)	0.3 (0,3)

¹ Estimated percentage weed cover does not include senesced winter annuals.

During the 60 days following the first treatment, the initial burndown effects were recorded by visually estimating the percentage of dead weed cover, relative to the plot area covered with weeds. Data were recorded at 1, 3 and 24 hours after the first application on May 31. Thereafter, additional assessments of percent dead cover were made on June 7 (7 days PT), June 20 (15 days PT), July 3 (30 days PT), and August 3 (60 days PT). Means of percent dead weed cover are given in **Table 2**. A factorial analysis of variance procedure was performed on the averaged data of each pair of Ortho and DDI treated plots, excluding data from the untreated control plots. The arsin function was used to transform and normalize the data before analysis. The single application of both herbicides provided significantly better overall weed control ($F_{(1,81)} = 81.0, P < 0.001$) in the gravel/soil plots (89.8%; SE=3.31) compared to weed control in the soil plots (78.8%; SE=4.00). The gravel/soil plots contained mainly smaller broadleaf weeds and less hard-to-kill grass species. As evident by a significant treatment by time interaction effect ($F_{(6,81)} = 40.0, P < 0.001$), the initial burndown effect of the Ortho treatment was significantly greater than the DDI treatment, but differences between treatments decreased after 7 days PT. Pooled over assessment times, dead weed cover averaged 85.9% and 71.6% in the soil substrate, compared to 96.2% and 83.5% in the soil substrate for the Ortho and DDI treatments, respectively. However, this substrate by treatment interaction was not statistically significant ($P = 0.31$).

Table 2. Mean weed control expressed as the percentage of dead weed cover by substrate, treatment, and post-treatment assessments up to 60 days.

Substrate	Treatment (sprays)	Post-treatment assessment time						
		1 Hr	3 Hr	1 Day	7 Day	15 Day	30 Day	60 Day
Soil	Ortho (1)	44.9	80.0	86.1	92.2	98.9	99.7	99.8
	DDI (1)	1.6*	50.3*	55.2*	94.3	99.8	100.0	100.0
	Untreated	0	0	0	0	0	0	0
Gravel/ Soil	Ortho (1)	90.6	92.0	94.4	97.1	100.0	100.0	99.0
	DDI (1)	6.3*	80.8*	97.5	100.0	100.0	100.0	100.0
	Untreated	0	0	0	0	0	0	0

*Indicates the major differences between treatments due a significant treatment by time interaction effect ($F_{(6,81)} = 40.0, P < 0.001$).

After the second application of both herbicides on August 23 (Day 84), assessments recorded as a percentage of weed-free plot area were made on August 31 (90 days PT), September 30 (120 days PT), November 3 (150 days PT) and December 2 (180 days PT) to evaluate the residual activity of the treatments. The results showing differences in residual activity are given in **Table 3**. An analysis of variance was performed on the transformed data, excluding the data from the untreated control plots. Significant effects were revealed by the treatment by time interaction ($F_{(3,93)} = 4.08, P = 0.0002$) and substrate by treatment interaction ($F_{(3,93)} = 4.46, P = 0.006$). Overall, percent weed-free differences among treatments steadily increased over time, indicating that the single application of DDI provided significantly better residual activity compared to the single Ortho treatment, particularly in the soil substrate plots. Additionally, the second application of DDI provided relatively less of an increase in weed control compared to the second application of the Ortho herbicide.

Although both herbicides had a significant impact on all weed species, the gravel/soil plots developed a dense mat of moss over more than 80% of the plot area during the fall, indicating that both treatments had no residual activity against this non-vascular plant.

Table 3. Mean weed control expressed as the percentage of weed-free plot area by substrate, treatment, and post-treatment assessments at 90, 120, 150 and 180 days.

Substrate	Treatment (sprays)	Post-treatment assessment time			
		90 Day	120 Day	150 Day	180 Day
Soil	Ortho (1)	85.5	57.3*	36.5*	30.8*
	Ortho (2)	94.4	100.0	81.3	81.3
	DDI (1)	98.6	97.5	89.8	76.9
	DDI (2)	100.0	100.0	100.0	100.0
	Untreated	0.0	2.5	1.3	0.0
Gravel/Soil	Ortho (1)	92.5	73.8*	75.0*	62.5*
	Ortho (2)	92.5	100.0	98.8	95.0
	DDI (1)	98.8	98.8	96.3	82.5
	DDI (2)	100.0	100.0	100.0	98.8
	Untreated	0.0	0.0	0.0	0.0

* Indicates the major differences between treatments due to the treatment by time interaction ($F_{(3,93)} = 4.08, P = 0.0002$) and substrate by treatment interaction ($F_{(3,93)} = 4.46, P = 0.006$).

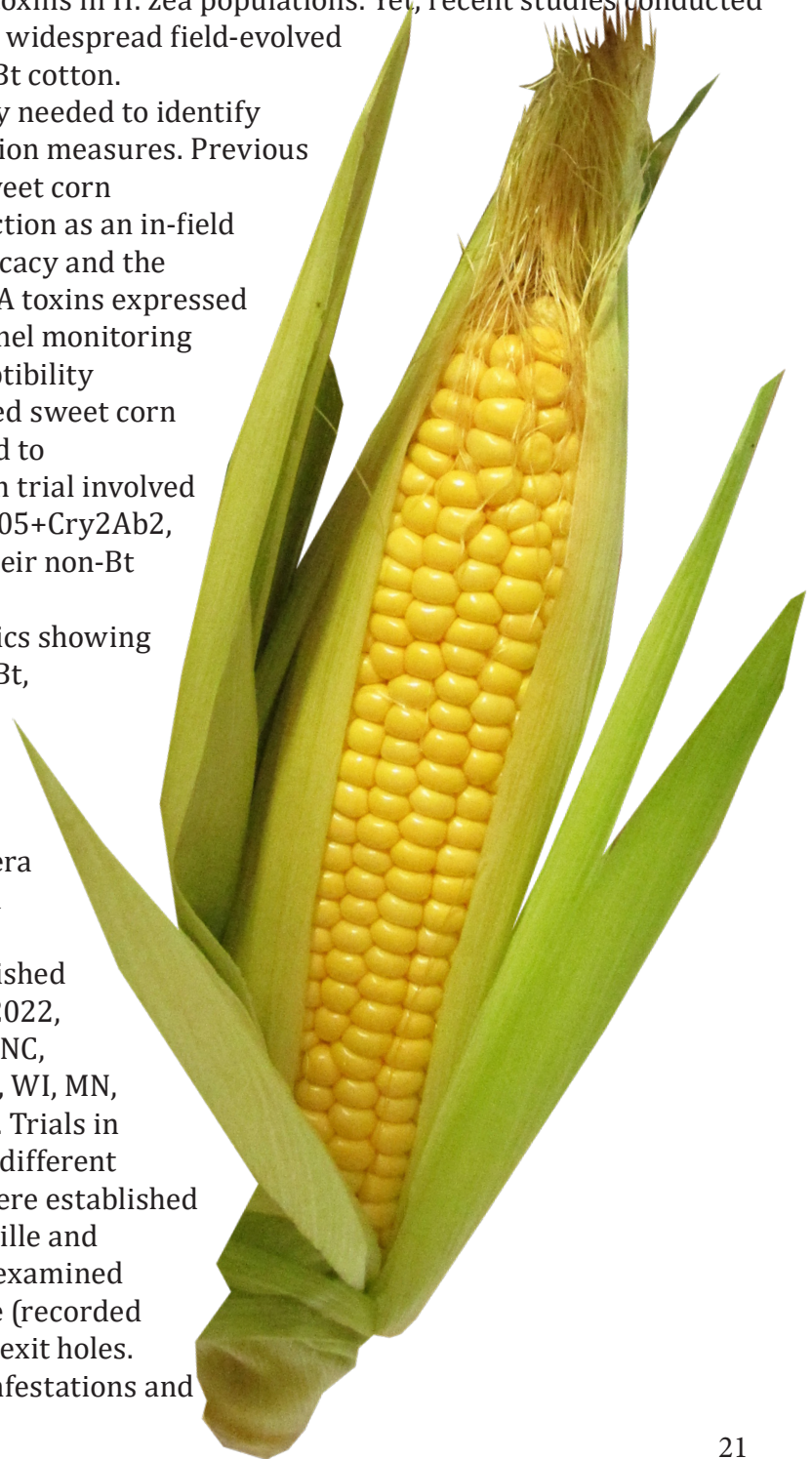
Sweet Corn Sentinel Monitoring Network

Galen P. Dively, Emeritus Professor, Department of Entomology

Bt corn and Bt cotton producing insecticidal toxins derived from *Bacillus thuringiensis* (Bt) are widely adopted in the U.S. to control lepidopteran pests, which have resulted in major benefits to growers and the general public. However, resistance evolution in corn earworm/bollworm (*Helicoverpa zea*) populations has become a major threat to the sustainability of these crops. To detect resistance and implement mitigation measures before control failures occur, industry registrants of Bt crops are required to annually monitor resistance in target pest populations. For *H. zea*, the monitoring approach consists of discriminating dose bioassays of larvae collected from non-Bt host plants in major production areas, and investigations of unexpected pest damage in Bt crop fields. So far, industry monitoring has not reported any significant changes in the baseline level of susceptibility to Bt toxins in *H. zea* populations. Yet, recent studies conducted in Maryland and several southeastern states report widespread field-evolved resistance in *H. zea* to all Cry toxins in Bt corn and Bt cotton.

More effective monitoring approaches are clearly needed to identify resistance early enough to enable proactive mitigation measures. Previous work in Maryland demonstrated that sentinel Bt sweet corn planted side-by-side with its non-Bt isolate can function as an in-field diagnostic screen to monitor changes in control efficacy and the phenotypic frequency of resistance to Cry and Vip3A toxins expressed in Bt field corn and cotton. Starting in 2017, a sentinel monitoring network has been tracking changes in *H. zea* susceptibility each year. Syngenta and Seminis companies provided sweet corn seed that is repackaged in Maryland and distributed to volunteer collaborators to establish field trials. Each trial involved Bt sweet corn hybrids (expressing Cry1Ab, Cry1A.105+Cry2Ab2, and Cry1Ab and Vip3A) planted side by side with their non-Bt isolines. All trials used the same ear sampling/data collection protocol to generate metrics showing differences in control efficacy between Bt and non-Bt, changes in the density and age of surviving larvae, and resultant kernel damage. Additionally, the network simultaneously monitored susceptibility changes and regional differences in European corn borer (*Ostrinia nubilalis*), fall armyworm (*Spodoptera frugiperda*), and western bean cutworm (*Striacosta albicosta*) populations.

During the past three years, collaborators established 41 trials in 2020, 52 trials in 2021, and 53 trials in 2022, located in 26 states (TX, LA, AL, MS, AZ, FL, GA, SC, NC, VA, MD, DE, PA, NJ, NY, NH, VT, OH, IN, IA, IL, NE, SD, WI, MN, MI) and 5 Canadian provinces (ON, QC, PEI, NS, NB). Trials in 11 states, ON and NS included multiple plantings at different times and/or locations. In MD, multiple plantings were established on research farms at Salisbury, Queenstown, Beltsville and Keedysville. Altogether, a total of 47,905 ears were examined to record the location and amount of kernel damage (recorded as cm²), larval density by instar stage, and signs of exit holes. Overall, 109 of the 146 trials reported high *H. zea* infestations and



infestations and kernel consumption in more than 50% of the non-Bt ears. Highest infestations occurred at the southeastern and mid-Atlantic locations where successful *H. zea* overwintering occurs, whereas the lowest infestations were mainly recorded in the North Central and Northeast states and Canadian provinces, where populations are sourced by migrant moths. Overall levels of *H. zea* infestations and larval densities in Cry expressing ears were slightly lower relative to the non-Bt isolines. *O. nubilalis* feeding injury (<1.5%) was recorded at only 30 of the 146 trials and associated with either missing or very few live larvae. Trials with consistent year-to-year *O. nubilalis* infestations were located where the surrounding landscape likely contained relatively less Bt field corn acreage. The absence of *O. nubilalis* infestations concurs with reports of areawide suppression of populations due to the high adoption of Bt field corn. More importantly, no *O. nubilalis* survival or feeding injury was found in a total of 32,786 ears examined from the Bt sweet corn plots. *S. frugiperda* infested only 2.1% of all non-Bt ears sampled and at only 41 of the 146 trials. Ear infestations varied widely across trial locations and monitoring year, depending on the seasonal recruitment of *S. frugiperda* populations in the south and the frequency and direction of storm fronts that enabled migrant moths to reach northern locations. Highest ear infestations (16 to 29%) were consistently recorded in TX. Although data on this pest are limited, Cry1A.105+Cry2Ab2 appeared to be more effective against *S. frugiperda* than Cry1Ab. Ear infestations of *S. albicosta* larvae were uncommon, as only recorded in 1.4% of all non-Bt ears sampled and at 14 of the 146 trials, all located in NE, MI and the Canadian Provinces.

Phenotypic frequencies of resistance (PFR) for Cry1Ab, Cry1A.105+Cry2Ab2, and Cry1Ab+Vip3A were estimated as the ratio of mean number of surviving *H. zea* larvae per Bt ear to the mean number per non-Bt isolate ear. We assumed that any live larvae associated with kernel damage in a Bt ear indicates some level of resistance to the expressed toxins, which could result in mature larvae surviving to contribute resistance alleles in the next generation. The following summarizes the phenotypic frequencies for each single or pyramided Bt toxin compared to previous sentinel monitoring results.

Cry1Ab: The level of *H. zea* phenotypic resistance has significantly increased, since Cry1Ab sweet corn was commercially introduced in 1996. Based on trials each year in Maryland, overall PFRs averaged 0.28 during 1996-2003 and 0.64 during 2004-2016. Now, PFRs averaged 1.07 in 2022, compared to 1.06 (2021), 0.95 (2020), 0.76 (2019), and 0.85 (2018) and 0.99 (2017). The percentage of damaged ears and kernel consumption per Bt ear, along with larval development delays, have remained about the same during the last three years. However, the most disconcerting finding is that 51% of the 2022 trials reported higher *H. zea* densities per Bt ear compared to densities per non-Bt ear (PFR>1). This larval density difference is the result of cannibalistic behavioral changes in larvae receiving sublethal doses of Cry1Ab. Although many young larvae feed together initially in an ear, they become aggressively cannibalistic once they reach the 4th instar stage, and thus often only one mature larva is found in a non-Bt ear. Sublethal Cry intoxication is known to inhibit the cannibalistic behavior of late instars, allowing more larvae to feed and survive together in Bt ears. If this behavioral inhibition continues as resistance increases, it is possible that a Bt plant could produce more *H. zea* moths emerging compared to recruitment from a non-Bt plant. Obviously, this would have serious resistance management implications; however, it is still unknown as to how many larvae develop to pupate and successfully emerge as normal reproductive adults; and, more importantly, contribute resistant alleles in the next generation. Given this high frequency of phenotypic resistance and widespread decline in Cry1Ab control efficacy against *H. zea*, most field corn hybrids expressing only Cry1Ab have been phased out of commercial use and replaced by pyramided Bt hybrids expressing multiple toxins. However, one remaining concern is that the cross resistance of Cry1Ab with other Cry toxins may continue to reduce the durability of the pyramided hybrids.

Cry1A.105+Cry2Ab2: These pyramided toxins expressed in corn were registered for use in 2010 and initially provided effective control of *H. zea*. However, phenotypic frequencies have steadily increased since 2010, averaging 0.19 during 2010-2013 and 0.41 during 2014-2016. Sentinel network results continue to show further resistance development, with PFRs averaging 0.67 (2017), 0.93 (2018), 0.70 (2019), 0.89 (2020), 0.95 (2021), and 0.92 (2022). Thirty-two % of the trials since 2020 reported *H. zea* densities per Bt ear greater than densities in non-Bt ears. Over the last three years, there has been a slight but consistent increase in

phenotypic frequency, kernel consumption, and older instars surviving per ear, suggesting that *H. zea* populations continue to develop higher levels of resistance to these Cry toxins. These findings concur with recent studies reporting high resistance ratios and increased field failure of the Cry1A.105 and Cry2Ab2 toxins in controlling *H. zea* infestations in Bt corn and Bt cotton. Unfortunately, the widespread *H. zea* resistance to Cry toxins make it difficult for any regulatory mitigation action by EPA or industry registrants to reduce or prevent further *H. zea* resistance to these toxins.

Cry1Ab and Vip3A: Previous studies in MD and MN during 2013-2016 found virtually no *H. zea* survival or damage in Vip3A-expressing sweet corn ears. However, sentinel trials starting in 2017 began to report larval survival with the expansion of the monitoring network to more southern locations. During 2017-2019, 0.72% of the 9,369 Vip3A ears sampled had minor tip damage associated primarily with 2th-3rd instars. Furthermore, results by year show a small but noticeable increase in the number and age of surviving larvae. Of the 20,312 ears sampled during 2020-2022, 156 ears (0.77%) had minor damage (<0.5 cm², primarily on the tip), but only 25 of these ears (0.12%) were infested with a total of 82 live larvae (78% early instars). Trials reporting most of the ear damage and older larvae were southern locations (TX, LA, MS, AL, NC). Assuming all ears with live larvae were expressing Vip3A, the overall PFR estimated from trials conducted during 2020-2022 is 0.0044, based on a total of 82 larvae found in 20,163 Vip3A ears compared to 10,682 larvae found in 11,622 non-Bt isoline ears sampled. This level of phenotypic resistance is consistent with laboratory studies reporting an estimated frequency of 0.0065 for Vip3Aa resistance alleles in Texas *H. zea* populations. These studies and sentinel monitoring results show evidence of an increase in phenotypic resistance since 2017, indicating early signs of *H. zea* resistance to Vip3A, particularly in the southern locations. However, the Vip3A expressed in sweet corn, field corn and cotton still provides excellent ear protection against *H. zea*. Nevertheless, given the high levels of *H. zea* resistance to Cry toxins and their ineffectiveness against this pest, the redundancy control advantage of the pyramided Bt crops is likely compromised, which may lead to faster evolution of Vip3A resistance, especially when considering multiple generations of selection per season and increased use of Vip3A field corn and cotton to improve control of *H. zea* in the South. In short, the time for proactive measures for the Vip3A toxin is passing quickly, so we urgently need best management practices implemented to delay further Vip3A resistance.



Flower power: floral diversity attracts beneficial arthropods in an edamame agroecosystem

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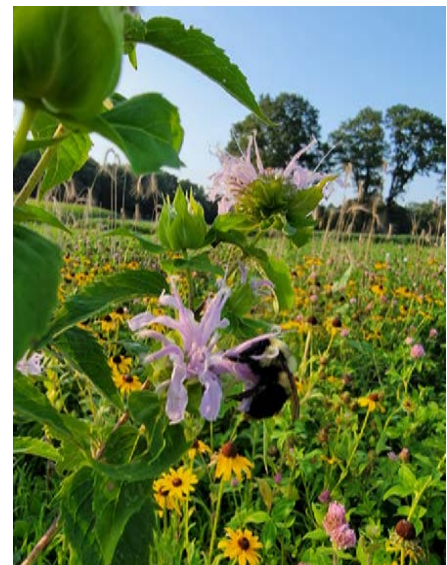
Increased biodiversity within a habitat often enhances ecosystem services (e.g., pollination, natural enemy efficacy) and cropping systems are no exception. Studies show that crops benefit from diverse plant communities through enhanced services such as pest suppression, pollination and soil fertility. This helps explain why losses of natural habitat in agroecosystems and an associated reduction in floral diversity negatively affect beneficial arthropod populations while benefiting pests. An ecosystem-friendly response to this problem is to enhance floral diversity (e.g., wildflower strips, intercropping) and consequently biological services in cropping systems. Although floral additions may restore ecosystem services within a crop that were lost as a result of reduced plant diversity, little attention has been given to how these floral additions within a cropping system affect ecosystem services in neighboring habitats (e.g., grassland, forest). Further, virtually no research has concomitantly quantified the effects of enhanced floral diversity on natural enemy and pollinator diversity and their efficacy within the crop field and adjacent habitats. As such, objectives of this project are to quantify effects of floral diversification on (i) beneficial arthropod abundance and diversity within the crop and surrounding habitats; (ii) reproductive output of crops and wild plants in neighboring habitats, and (iii) pest control and pollination efficacy.



Kathleen Evans hand pollinating edamame flowers to measure the benefits or cross pollination in soybean



Bmsb sentinel eggs deployed to measure biocontrol efficacy



Bumble bee visiting a *Monarda fistulosa*, wild bergamot, in the wildflower strip. Pic by Kathleen Evans



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