Title: Developing an IPM program for western bean cutworm, a new corn and dry bean pest in the Northeast Region

Summary

This is a Research Project. Western bean cutworm (WBC; *Striacosta albicosta*) has invaded the Northeast Region in recent years. This pest species new to the Northeast attacks corn (*Zea mays*; including field & sweet corn) and both dry beans and snap beans (*Phaseolus vulgaris*), feeding on developing corn kernels or beans. Infestations of WBC larvae can reduce yield 30-40% and cause crop quality to be down graded or rejected by processors. Corn and bean production is vital to the diversified agricultural economy of the Northeast, including dairies and vegetable farms, and accounts for more than 7 million acres of cropland in the region. Our collaborative research proposal seeks to understand the spread of this pest species and the threat it poses, across a significant portion of the Northeast Region, where it has the potential to cause significant damage and prompt widespread increases in insecticide use, and begins the work of developing an IPM plan to manage WBC. Our objectives include: 1) Develop a regional western bean cutworm monitoring network; 2) Integrate existing Great Lakes regional trap capture data into the PestWatch system to understand the spread of WBC and develop a smartphone/web app to report larval infestations into the PestWatch system; 3) Evaluate the relevance for the Northeast of the Midwestern degree day model for predicting various activity periods; 4) Evaluate and improve the pheromone blend used to monitor WBC. These objectives combine practical efforts to understand the distribution of the WBC in the Northeast with promising applied efforts to manage this invasive pest species.

Title: Developing an IPM program for western bean cutworm, a new corn and dry bean pest in the Northeast Region

Problem

Invasive species continually plague the United States, threatening crops and forest resources; consider soybean aphid and emerald ash borer as just two recently examples (Ragsdale et al. 2004, Poland and McCullough 2006). Unfortunately, many farmers in the eastern United States and Canada will soon be facing a new pest species: western bean cutworm (WBC; Lepidoptera: Noctuidae: *Striacosta albicosta* [Smith]; Smith 1887). This pest attacks corn (*Zea mays* L.; including field, sweet and popcorn) and both dry beans and snap beans (*Phaseolus vulgaris* L.), feeding on developing kernels or beans inside husks and pods, respectively. In corn, infestations of one larva per plant over an acre can lead to a yield loss of four bushels per acre (Appel et al. 1993). Unfortunately, infestations typically involve multiple larvae per ear, so yield losses can reach 30-40% in heavy infestations (Michel et al. 2010). In beans, feeding causes direct loss of beans, but also decreases bean quality; two percent damaged beans can cause the quality of a batch of beans to be down-graded and heavier levels of infestation will lead to batches being rejected by processors (Blinkenstaff 1979), seriously influencing growers' bottom lines. In both crops, WBC infestations facilitate colonization by pathogens, furthering damage and yield reduction and posing risk to domestic animal and human health.

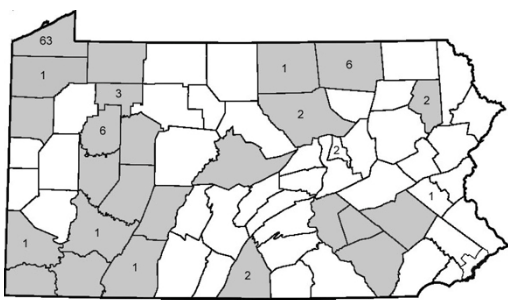

Fig. 1. Distribution of male western bean cutworm moths captured in Pennsylvania in 2009 . Digits indicate the number of moths captured in each county. Absence of a number in a shaded county indicates zero capture in that county). Numbers in unshaded counties indicate moths that were captured outside our trapping network

Unlike many recent invasive pests, WBC is native to North America, but has historically been restricted to the Great Plains and westward (Michel et al. 2010). For some unidentified reason, this occasionally serious pest of corn and dry and snap beans has been expanding its range eastward (Blickenstaff 1979, O'Rourke and Hutchison 2000, Dorhout and Rice 2004, DiFonzo and Hammond 2008, Tooker and Fleischer 2010). From 1998 to 2004, it was reported invading Minnesota, Illinois, and Missouri (O'Rourke and Hutchison 2000, Dorhout and Rice 2004, DiFonzo and Hammond 2008). Moths were first reported from Indiana in 2005, Wisconsin, Michigan, and Ohio in 2006 (DiFonzo and Hammond 2008), and in 2008 moths were discovered in Ontario, Canada as well as Wayne County, Ohio, less than 150 km from Pennsylvania.

In 2009, a new statewide, pheromone trap network in Pennsylvania and a small, local monitoring effort in New York discovered WBC in the Northeast Region, and surprisingly widespread. In Pennsylvania, 92 moths were captured between 10 July and 26 Sept and they were distributed across the state (Fig. 1). In New York where funding was not available for a larger trapping effort, an agricultural consultant collected 11 moths across the four western NY counties where he had traps. Additionally, in New York in 2009 larval infestations were found in corn fields in a fifth county, Niagara. As WBC has moved across the Midwestern and into the eastern United States, economically damaging infestations of caterpillars have been discovered in Iowa, Minnesota, Wisconsin, Illinois, Indiana, Michigan, and Ontario, whereas non-economic larval infestations have been found in Ohio and Quebec, in addition to New York.

In 2010, both PA and NY had more widespread trapping networks in place. New York found 739 moths from 15 June to 6 September in 28 of 29 counties sampled statewide, including Long Island, whereas Pennsylvania found 366 moths from 21 June to 13 Sept in 26 counties, covering the west-to-east length of the state (Fig. 2). In 2011, in NY the number of moths captured doubled to 1533 moths found in 37 counties. Moreover, significant larval infestations were found in several counties, although economic losses have yet to be reported. Moth captures were generally higher in western NY although relatively high numbers were also captured in Essex and Clinton counties bordering Lake Champlain in north eastern NY (Fig. 3). In PA, populations did not increase from 2010 and totaled 350 moths were captured from 13 counties (Fig. 3). Oddly the majority of moths were captured in central PA, not northwestern PA were the majority of moths had been found in the previous two years--indicating that the annual population is dynamic and still shifting within the state. In addition in 2011, we found the first larvae of western bean cutworm in PA; these caterpillars were not causing economic damage but confirm that the species has established reproductive applications in PA. In coming years, we only expect the overall population to grow, and larval infestations will be more common and become economically damaging as moths spread to other states in the Northeastern Region.

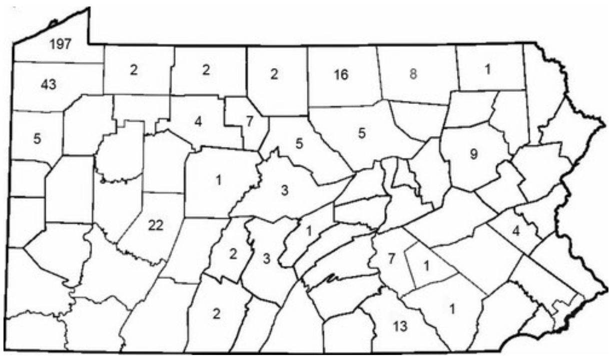

Fig. 2. Distribution of male western bean cutworm moths captured in Pennsylvania in 2010 . Digits indicate the number of moths captured in each county.

We, therefore, propose a research effort that will lead to the development of a Northeastern regional IPM program for this new pest species. Some conventional management tactics (i.e., insecticides and transgenic corn) are available to combat WBC, but the timing of this pest (mid-to late summer), the developmental stage of crops attacked (reproductive stage corn, vegetative and reproductive beans), and the length of its flight season (nearly three months) pose some unique challenges that will necessitate some novel research. Our efforts, spanning Pennsylvania, New York, and Vermont will lay the base for developing an IPM to protect production systems in the Northeast. Northeastern dairy-based cropping systems are quite different and more complex than those grain-production based systems of the Midwest that are currently combating this pest species. Moreover, we propose to accumulate, database, and visualize data illustrating the spread of this pest across the Great Lakes Region, and test its

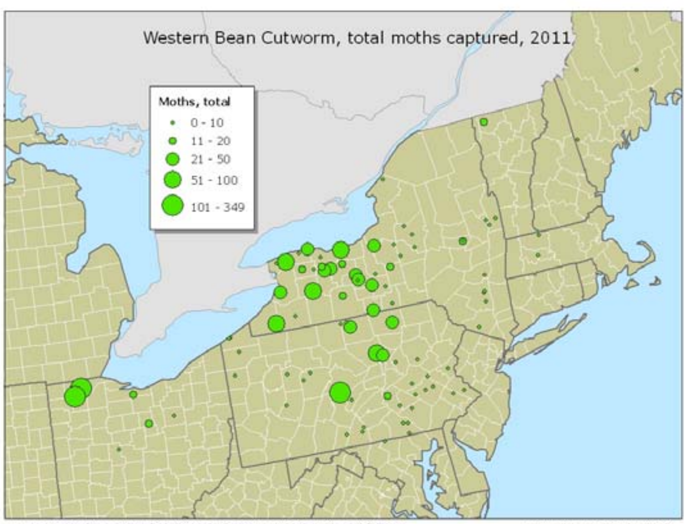

Fig. 3. Distribution of male western bean cutworm moths captured in the Northeastern US in 2011. Data compiled from PestWatch reports

activity against the degree-day model developed for the Midwest, so that we can advise growers on the risks posed by this pest. From our three years of experience with WBC in the first states in the Northeast Region to be invaded by this pest, it is clear that this pest is here to stay. Now is the time to develop a plan to protect against potentially significant damage to field corn, sweet corn, snap bean and dry bean crops in the Northeast.

Background

Our proposed work will track population growth of this new pest species, assess its spread across the Great Lakes and into the Northeast, test, validate and/or refine a Midwestern phenology model in its newly invaded range, and better develop a population monitoring tool that will help in establishing an IPM program against WBC. This information, particularly assessing WBC populations, is critical to informing growers of the risk this pest poses to their crops. For example, in Michigan WBC populations ballooned very quickly, surprising scientists and the agricultural community. (The following information was shared with us by Dr. Chris Difonzo, Michigan State University, and some of it was gleaned from her extension reports and newsletter articles). In 2006, three WBC moths were discovered in southwestern Michigan. In 2007, 54 moths were trapped and these individuals were distributed across the southern part of the state. Also in 2007 economic damage was discovered in corn and dry bean fields, but this damage happened to occur in seven counties where moths were not being trapped. In 2008, a wider monitoring program yielded 1,727 moths and eight counties experienced economically damaging larval infestations. In 2009, 28,344 moths were found, as were more widespread larval infestations and economic damage. As a result of these unprecedented populations, extension personnel issued blanket spray recommendations for growers to protect their corn and dry bean fields. In 2010, 38,009 of moths were captured and larval infestations and associated economic losses were quite widespread, prompting another blanket spray recommendation. In some counties, it was not difficult to find fields where 90% of corn ears were infested. In 2011, the number of moths captured reached 42,783 and larval infestations warranted another blanket spray recommendation. Of course, the expectation is for 2012 to be even worse, and the population growth and damage is likely to continue on this upward trajectory until natural enemies or pathogens switch to the new resource and manage to significantly depress the population. Indiana, Ohio and Ontario also appear to be developing similarly large populations.

Our concern for the Northeast is that Pennsylvania and New York could develop similarly large populations in the coming years and populations in these states will serve as sources for other states in the region. This concern is particularly valid for New York, which, like Michigan, has substantial acreage (42,100 acres) of snap and dry bean production (NYS Ag Statistics 2010) that provides a second host-plant crop and may allow WBC populations to build particularly quickly. And this concern in New York was supported by the 100% increase in moths captured from 2010 to 2011. Pennsylvania and Vermont do not support much dry bean production, and like New York, these two dairy-based states have the majority of their production acreage dedicated to corn to support the needs of local dairies. It only makes sense that we begin understanding this new pest in the two states that already have confirmed populations of moths and Vermont which has just seen a hand full of moths thus far.

The broad goal of our project is to begin developing a range of IPM tactics that can be used to help manage WBC and avoid relying on broadcast insecticide sprays to control the caterpillar.

By focusing on many aspects of an IPM program for this new invading pest of field crops (i.e., corn) and vegetables (sweet corn, snap beans, and dry beans), our project has broad support from regional priorities developed by a range of stakeholders. For example, the IPM RoadMap (2004) set as a priority "Minimize adverse environmental effects from pests and related management strategies" and identified as a research needs 1) "Clarify pest biology and host/pest…interactions to identify vulnerable cropping systems and vulnerable stages in the pest life cycle" and 2) "Develop economical high-resolution environmental and biological monitoring systems to enhance our capabilities to predict pest incidence, estimate damage, and identify valid action thresholds. Our efforts clearly satisfy these priorities and research needs because we seek to avoid the environmental repercussions associated with blanket insecticide sprays, and our efforts seek to understand the biology of this pest in the northeast region. Other relevant priorities include those based on invasive species that threaten crop production as cited by the North Central IPM Center Priorities 2009-2010 (i.e., "invasive species education and mitigation"), the Entomological Society of America (Entomology 2007; "Invasive Species – Issues and Opportunities"), Experiment Station Plant and Pest Biology (2007; Plant Biology Priority: "Develop the knowledge base for rapid detection of threat agents, risk assessment for emerging and new threats, and food safety and security), and the Pest Management Alternative Program for the Northeast (2009; "Develop IPM tactics for critical or emerging agricultural/forestry pests of regional or national magnitude"). Our efforts also fulfill regional Sweet Corn Research High Priorities for "Mid and Late Season Insect Control - Worm management, including cultural and biological methods (NYSIPM Program 2009)" and "High Priority Issues for New York Dry Bean Industry for 2011-Western bean cutworm." Lastly, in addition to these regional priorities, we have heard from local commodity groups, such as the NY and PA Corn Growers Associations, industry consultants, and Pioneer Hi-Bred (see attached letters of support), who all support our research because this pest has a substantial chance to seriously influence their production success.

Life Cycle of Western Bean Cutworm

Western bean cutworm poses a serious challenge to growers because of the time of season larvae are active and the duration of this activity. While called a cutworm, WBC is not a traditional cutworm, like black cutworm (*Agrotis ipsilon* Hufnagel), which tends to be active in spring cutting down seedlings. Western bean cutworm is a univoltine, mid- to late-season pest, attacking corn and beans July-September. Adult moths emerge from their overwintering sites in the soil in mid-summer. Females attract males using a sex pheromone (Klun et al. 1983) and then females lay eggs on the upper surfaces of corn leaves or underside of bean leaves. In corn, WBC larvae hatch from these eggs and seek reproductive tissue, typically feeding upon pollen gathered in the whorl, tassel or silk tissue. As these tissues senesce, larvae move into the ear where they feed upon developing kernels (Michel et al. 2010). In dry and snap beans, young larvae feed on leaf and flower tissue and then progress to pods, which they chew into and feed upon developing seeds. In both crops, WBC damage to ears and pods facilitates establishment of fungal pathogens that can contribute to yield loss and produce toxins that can poison consumers. While WBC larvae can survive for short periods on other crops and weedy plant species, available evidence suggests corn and various species of beans (*Phaseolus vulgaris, P. lunatus, P. coccineus,* and *P. acutifolius*) are the original and current hosts (Blickenstaff and Jolley 1982, Michel et al. 2010).

Developing an IPM Approach to Control of Western Bean Cutworm
To contend with this emerging pest, it is imperative to proactively identify the current range and timing of WBC activity to time and target field scouting for eggs and larvae and develop a suitable IPM approach. As a *first objective*, we propose to establish a regional, pheromone-trap monitoring network to document the current and spreading geographic distribution and seasonal timing of adult WBC activity in New York, Pennsylvania and Vermont. Our work thus far has been poorly funded, limited, and uncoordinated, so a larger effort would be valuable to demonstrate the benefits of our approach. And we are confident that funding beyond any NE-IPM award could be derived from Industry once we are able to demonstrate value. Supporting this contention is the regional effort of Pioneer representatives, who in 2011 deployed and monitored pheromone traps in New York, Massachusetts, Connecticut, New Hampshire, and Maine, discovering moths in NY, MA and ME. Pioneer sees value in understanding the spread and establishment of WBC as evidenced by the accompanying letter of support.

Adult WBC monitoring is recommended by Midwestern IPM practitioners to time and target field scouting for eggs and larvae. Unfortunately, the degree-day-based phenology model used in the Midwest was developed in Nebraska, and we have little idea if it is appropriate in the Northeast—it has not been tested. Therefore, as a *second objective*, we propose to gather trap data for recent years from Indiana, Ohio (see accompanying letters of support from Indiana and Ohio), Michigan and Ontario and integrated them into PestWatch (www.pestwatch.psu.edu), which was developed in its current form by the Center for Environmental Informatics (CEI) at Penn State. This national database has interactive maps displaying trap capture data for a suite of lepidopteran crop pests and already houses data from Pennsylvania, New York, and New England, including a handful of traps in Maine Massachusetts, and Vermont. We also propose to develop a smartphone/web-ready feature of PestWatch to accept field reports and track larval infestations. Accumulating in one database new reports of larval infestations and all the Great Lakes trap capture data for this pest will be of value in its own right for understanding its regional spread and areas at highest risk for damage, but the trap captures and their timing will also allow us to address a *third objective* of testing the predictive power of the Nebraska-generated degree-day accumulation models. It may be that our heavier soil types (relative to western Nebraska) and significantly different landscapes may cause moth activity levels to be significantly altered from expected. Our *fourth objective* aims to improve efficiency of trapping because currently available pheromone lures attract significant by-catch of other moth species. Decreasing these non-target captures will improve the information provided by trapping by increasing the efficiency of our cooperators because they will not struggle to discriminate WBC from other species. Moreover, with less by-catch we can be more certain that non-targets are not influencing the WBC moths that we want to capture.

Ultimately, the goal of the WBC monitoring network is to provide a better estimation of the extent and immediacy of WBC on both local and regional scales. Confirmation of actual WBC presence and/or larval infestations and communication of these detections via PestWatch will help inform growers of the risk to their crops. Improved western bean cutworm monitoring via a better pheromone and regional view of population growth over time will help identify hot spots and areas that would be suitable for complementary research to address upcoming IPM needs, such as collecting specimens for assessment of natural biological control, potential for augmentative biological control, efforts seeking to improve trapping efficiency, insecticide toxicity studies, developmental studies, efficacy of insecticidal sprays, etc.

Justification

Our research efforts will directly benefit field-corn (i.e., grain and silage) growers, sweet-corn growers, and snap and dry bean growers in Pennsylvania, New York, and Vermont. In 2011, these three states grew approximately 6.9 million acres of field corn, nearly 40,000 acres of fresh market sweet corn, more than 16,000 acres of dry beans, and 35,000 acres of snap beans (USDA NASS 2011). Without efforts to understand local population dynamics and develop IPM approaches, it is conceivable that WBC could cause upwards of 30-40% yield losses as has been seen in some counties in Michigan where many growers were caught off-guard. In addition to helping manage a pest that could infest many acres of northeastern crop fields, our efforts in these three states will be relevant and easily translated into efforts in other states in the Northeast Region, and potentially in the North Central region. It is clear that conventional wisdom about this pest gained from historic research conducted in Nebraska (the center of its 'native' range) is not holding true in Midwestern states. We expect even less information will translate to the Northeast, which differs in many ways, including weather, soil types, prevailing cropping systems, and crop species and landscape diversity to mention just a few. Further, our efforts seek to avoid or reduce pesticide use that could easily result if growers are not educated about the risk posed by WBC, when it is active, and the damage it can cause. Chemical inputs, including insecticide use, on conventional farms have associated environmental and health costs of approximately $12 billion annually (Pimentel 2005). In addition to these societal costs, expenditures by farmers on these chemical products and their application, which use fossil fuels, have increased with the cost of oil over recent years. Therefore, the development of farming practices that are less reliant on pesticides has the potential to enhance the profitability of farming while concomitantly reducing environmental and human health risks associated with these products.

Due to the life cycle of WBC, growers face challenges in trying to control larval infestations. First, our experience trapping for moths indicates they can be active from mid-June to mid-September, an extremely large window of flight activity. In PA and NY, adult populations tend to peak in late July or early August, but the duration of the flight period suggests that adults may deposit eggs for nearly three months, a very large window of time to cover with expensive scouting efforts. Second, because larvae often tend to be hidden in ears or pods, they are not as vulnerable to insecticides as many exposed-feeding pests; therefore, timing of chemical applications is critical. Third, because larvae attack corn later in the season when plants are tall or nearly fully sized, applying insecticides to fields requires specialized equipment (e.g., a highboy sprayer) to which some growers may not have access. Fourth, many WBC larvae can develop in each corn ear. Corn earworm (*Helicoverpa zea* [Boddie]), which is a common corn-ear pest, is typically found at densities of one larva per ear because it is cannibalistic, limiting the amount of damage an infested ear can receive. In contrast, WBC is not cannibalistic and upwards of ten larvae have been found in an ear. Such densities obviously can cause major damage, almost cleaning ears of all their kernels, indicating that WBC has potential to be quite a bit more damaging than current ear pests, including corn earworm, fall armyworm, and European corn borer. In addition, insect feeding damage provides opportunities for infection by ear mold fungi, including those capable of producing mycotoxins. Fifth, larvae are more mobile than other ear pests. Western bean cutworm larvae readily move between and within rows, feeding upon multiple plants (Michel et al. 2010). While this movement would make larvae more susceptible to natural enemies and insecticides, it also causes larvae to be more damaging, accessing more ears and damaging more bean pods. Sixth and finally, while there are some transgenic varieties of field corn that are effective against WBC, they do not offer complete control. Varieties of transgenic corn containing the *Bacillus thuringiensis* [Bt] proteins Cry1A, Cry1Ab or Cry2Ab have no activity against WBC. Only lines that contain Cry1F have activity against WBC, but even these lines do not provide 100% control as growers using Cry1A, Cry1Ab or Cry2Ab lines against European corn borer have come to expect (Eichenseer et al. 2008). One study revealed that damage to ears of allegedly resistant Cry1F lines by WBC can still reach fairly high levels (24%; NC-IPM Center 2005). In sweet corn and dry and snap beans, transgenic varieties that could potentially control WBC are not yet available, so biological or chemical control are the only term alternatives—and only the former option is viable for organic growers. We think it is clear from this list of challenges to achieving control of WBC that this pest poses a significant new threat to corn and bean production in the northeast. Our research efforts will help develop an IPM base for Northeastern growers, but our research will also contribute to improved monitoring and control of WBC in Midwestern states that were invaded by this new pest species in recent years.

Objectives and Anticipated Impacts.

1. Develop a regional western bean cutworm monitoring network in NY, PA and VT to determine the magnitude, timing and potential impact of the emerging western bean cutworm problem;
2. Integrate existing Great Lakes regional trap capture data into the PestWatch system to understand the spread of WBC and develop a smartphone/web app to report larval infestations and trap capture data into the PestWatch system to understand the regional threat to production in the Northeast;
3. With regional data, evaluate via PestWatch the relevance for the Northeast of the Midwestern degree day model for predicting various activity periods;
4. Optimize the WBC pheromone blend to improve trap capture and decrease non-target catches.

Anticipated impacts:

1. Characterize the continued spread of this invasive species from New York and Pennsylvania into more central portion of the Northeast Region, including Vermont. Identify areas of New York, Pennsylvania, and Vermont that are at greater risk for larval infestations and warn growers of the threat.
2. Better understand the timing and spread of WBC moths and larval infestations across New York, Pennsylvania and Vermont. Communicate these risks to growers so they understand the threat posed to their own farms.
3. Establish a firm understanding of the phenology and risk periods associated with WBC in the Northeast
4. Develop a better western bean cutworm pheromone blend. The current blend attracts a large amount of by-catch, which increases processing time and may be reducing the efficacy of our pheromone traps.

Approach and Procedures

Objective 1: Develop a regional western bean cutworm monitoring network in NY, PA and VT to determine the magnitude, timing and potential impact of the emerging western bean cutworm problem

The goal of this objective is to trap male WBC moths at numerous locations throughout New York, Pennsylvania and Vermont to determine the geographic distribution and seasonal activity and magnitude of adult WBC populations. Trapping efforts will also track the species spread and help predict likelihood of this pest species causing economic damage.

Pheromone Trapping Network

Pheromone trapping networks first detected WBC in Pennsylvania and New York in 2009. More extensive pheromone trap monitoring efforts were conducted in these two states during the summers of 2010 and 2011. The research proposed herein would continue to implement, but expand, WBC monitoring in NY and PA and initiate pheromone trap monitoring in VT. Monitoring will employ commercial bucket traps (also known as universal moth traps or unitraps) using Trécé's Scenturion western bean cutworm lure to trap male moths. This pheromone blend is the best option available even though it has some limitations (see Objective 4). Pheromone lures will be replaced every 14-21 days to ensure traps remain operative. The methods used would follow the protocol developed by the Pennsylvania State University and the Pennsylvania Department of Agriculture WBC survey (Appendix 1: Western bean cutworm trapping protocol). Monitoring sites would be established in collaboration with county-based Cooperative Extension (CCE) field staff, field corn, sweet corn, snap bean and dry bean growers and agribusiness cooperators. More extensive monitoring would be established in production regions with the higher acreage of corn and beans.

In 2012, we would have at least 40 traps in PA and 65 in NY, where corn production spans the states, and 11 traps in the three counties in VT where corn and dry bean production is concentrated. In 2013, the same trap sites will be maintained, but we also may add additional sites to monitor the continued spread of WBC. Traps will be placed in strategic locations beginning early June and maintained through the first week in September. Traps will be hung approximately 4 feet from the ground the along the edges of corn fields, and beans fields where possible. Traps will be checked weekly and the quantity of captured WBC moths for each location will recorded and evaluated to determine where, when and how many WBC moths were detected and to identify potential sites of egg laying and local risk for damage. Trap capture counts will be posted on PestWatch. Depositing our trap captures with PestWatch allows project managers, data collectors, IPM staff, farmers, and other agricultural professionals to visualize pest activity levels in their area. The trap data we collect will also be used to determine whether the timing of captures and potential egg laying coincides with standard worm sprays for other late season worm pests (e.g., European corn borer, fall armyworm, and corn earworm) or whether additional sprays will be necessary to control WBC. Unfortunately, while pheromone traps are good predictors of WBC presence, they are poor predictors of potential damage to corn (Mahrt et al. 1987) – this is true for many caterpillar pest species. Therefore, it is important to scout for egg masses and feeding damage when moth flight is detected and increasing in the pheromone traps.

<u>Objective 2: Integrate existing Great Lakes regional trap capture data into the PestWatch system to understand the spread of WBC and develop a smartphone/web app to report larval infestations and trap capture data into the PestWatch system to understand the regional threat to production in the Northeast</u>

Western bean cutworm invaded the Great Lakes region when it was captured in Illinois for the first time in 2004 (Dorhout and Rice 2004). The next year it was found in Indiana, and then in 2006, it was found in Wisconsin, Michigan, and Ohio (DiFonzo and Hammond 2008). In 2008, moths were discovered in Ontario, Canada. The invasions of these moths in IN, MI, OH, WI, and ON were tracked by pheromone traps, providing an excellent record of their activity, but these data remain isolated with researchers in each state/province. For this objective, we will collect data from cooperators in the four states/provinces (IN, OH, MI, and Ontario) that had sizable trapping networks, but have unable to assemble their data and enter them into PestWatch due to limitations of money and time.

The limitations of the current Pestwatch tool for fully serving the needs of IPM specialists are evident in the missing information from IN, OH, MI, and Ontario. This challenge, with historic WBC data, provides an opportunity modernize Pestwatch (first placed on line in its current form in 2003) to allow for increased flexibility in data contribution and analysis, while at the same time bringing the power and capability of a full content management system environment to the challenge of recording and reporting insect populations. Similar to the portal that the Center for Environmental Informatics (CEI) developed with PD Tooker for brown marmorated stinkbug (www.stinkbug-info.org), we will create a new data contribution interface for Pestwatch as well as improved data access and analysis tools to study the spatial and temporal distribution of WBC. The new data contribution interface will include the capability for entomology/extension specialists to submit their observations via a tab- or space-delimited file upload that will then be parsed and integrated into the full Pestwatch database. For each state/province, we have sought and obtained permission from the entomology specialist (see letters of support from IN and OH; letter from the others did not arrive in time). After we gather the trapping data in the proper format, the PestWatch system will accurately map and animate the spread of moths across the states, which will allow us to see where the moths are most numerous and problematic. Combined with Objective 3, this effort will allow us to develop, assess and refine predictive models of flight activity for moths in the Northeast.

In addition to this effort gathering together capture data from existing trapping networks, we will also develop capacity within PestWatch to remotely report trap captures, as well as larval infestations. Thus far, larval infestations have been ignored in online reporting, creating a gap in our understanding of where larval infestations are occurring and whether there is any relationship between moth capture and in-field infestations. Remote reporting of trap captures will be accomplished via a mobile ("smartphone") application to be developed specifically for PestWatch. Building on CEI's experience in creating other mobile applications (these include mobile applications for the Commonwealth of PA PAMAP LiDar (http://www.pasda.psu.edu/) and a mobile application for the US Wheat and Barley Scab Initiative (www.wheatscab.psu.edu), the Pestwatch app will allow field personnel to securely login and contribute trap captures, larval infestations and severity levels directly from the field. The app to be created will be functional across Android and IOS 5 (iPhone and iPad) devices. When integrated with the current PestWatch mapping system and the new CMS-based PestWatch portal (which will take advantage of RSS and SMS news and messaging technology), these captures and infestations would then be rapidly reported by extension specialists and educators, farmers, agricultural consultants, industry representatives, and other professionals, and the data will used to notify others of local trouble spots, characterize areas of infestation, and identify areas of concerns that are worthy of more in-depth scouting efforts.

Objective 3: With regional data, evaluate the relevance for the Northeast of the Midwestern degree-day model for predicting flight activity of western bean cutworm moth.

Midwestern states currently base timing of trapping and scouting efforts on degree-day accumulations identified as critical by researchers at the University of Nebraska. However, it is well recognized that habitat and its influence on behavior of individual insects can strongly affect the accuracy of phenology models (e.g., Kührt et al. 2006). Certainly the landscape and dominant soil types of the Northeastern region differ from those in western Nebraska, the heart of the historic range of this pest (Michel et al. 2010); therefore, there is ample reason to believe that western bean cutworm adult phenology might be different in the newly invaded region. Having improved phenology models for adult activity will allow us to better focus trapping and scouting efforts. Moreover, we will be able to assess at any point of the summer the percentage of moths that have emerged from the pupal stage and still pose a risk to sweet corn, field corn, and dry and snap beans.

Using the dataset accumulated in Objective 2, we will work with our colleagues at the CEI to assess phenology of WBC moths via trap captures. Our database will contain trap captures for at least the past three years from Indiana, Michigan, New York, Ohio, Ontario, Pennsylvania, and Wisconsin. For each location in each state (hundreds of locations), we will generate phenology models based on relative activity of the total number of moths captured at each trap. Growing degree-days (GDD) will be accumulated from January 1st (50° F base). Models will be average across states and then compare to the currently available model. Results and associated recommendations will be distributed in the Northeast as well as the Midwest, particularly to those states that contributed data. Weather stations throughout the region will be used to determine GDD's. Hourly reporting weather stations maintained by the NWS, as well as independent weather networks of weather stations from Agricultural Weather Networks (Agnets) in at least 17 states are available to PestWatch for this work via CEI's long-term collaboration with Dr. Paul Knight, PA State Climatologist on our highly successful wheat scab forecasting system. The expanded PestWatch tool will allow users to "click-on" their station(s) of interest to view current and season GDD information. As growing seasons accumulate in the PestWatch system, future users will be able to compare the current growing season to historic conditions.

To reporting our findings for Objectives 1-3, we will use traditional extension networks, including in-person meetings, conference calls, and newsletter as well online resources, such as PestWatch and IPM websites of the three Universities involved and the NE-IPM Center. These resources will help growers gauge for themselves the threat that WBC poses to their fields or areas.

Objective 4: Optimize the pheromone blend to improve trap capture and decrease non-target catches.

Objective 4 has two complementary components (4a & 4b) to improve the pheromone blend used to monitor WBC.

- *Objective 4a: Test a blend without the minor component of the WBC pheromone ([Z]-7-dodecenyl acetate) to determine if it attracts WBC at rates comparable to commercial lures and decreases non-target catch.*
- *Objective 4b: Sample the headspace of calling WBC females and analyze the samples with gas chromatography-mass spectrometry to more accurately identify the true sex pheromone released by WBC*

To improve WBC monitoring efforts, we will conduct research to improve the pheromone blend used to monitor WBC. Currently available commercial pheromone blends are good tools and appear to be effective and attract WBC male moths, but they are imperfect, also pulling in high numbers of males of two other noctuid species, yellowstriped armyworm (*Spodoptera ornithogalli* [Guenée]) and dingy cutworm (*Feltia jaculifera* [Guenée]). This by-catch complicates monitoring programs and decreases trapping efficiency, and strongly suggests that the pheromone blend has not been optimized. A review of the pheromone literature reveals a potential cause, a potential solution, and two promising lines of inquiry. The cause of the by-catch appears to be explained by (*Z*)-7-dodecenyl acetate, which is the minor component of the four compound WBC pheromone, but either the dominant compound or second most abundant compound for yellow striped armyworm and dingy cutworm, respectively (Table 1). Surprisingly, research seeking to optimize the pheromone blend for WBC did not test the effectiveness of the blend without this minor component of the WBC pheromone (Klun et al. 1983), a logical choice and potential solution given that many pheromone blends work as well in the absence of some of the minor components (Tumlinson et al. 1986). Therefore, we propose to test various combinations of the blend in Centre County in Pennsylvania and Wyoming and Ontario Counties in New York, the highest density counties in the two states.

Table 1. Published pheromone blends (µg/septum) of western bean cutworm (WBC), yellow striped armyworm (YSA) and two sibling species of dingy cutworm (DC)

WBC[1]		YSA[2]		DC[3]		
Compounds	µg/sept	Compounds	µg/sept	Compounds	Sp. A- µg/sept	Sp. B- µg/sept
z5-12Ac	5	z9-12Ac	1	z9-14Ac	100	100
z7-12Ac	**1**	**z7-12Ac**	**56**	**z7-12Ac**	**13**	**0.5**
delta 11-12Ac	5	diunsaturated 12Ac	16	z11-16Ac	3	0.3
12Ac	5	16 Ac	< 1			
		z11-16Ac	9			
		z7-12OH	1			
		z11-16OH	1			

[1]From Klun et al. 1983; [2]From http://www.nysaes.cornell.edu/pheronet/phlist/spodoptera.html; [3]From Byers and Struble 1990

In addition to testing blends of known pheromone components, we also propose to seek novel, perhaps overlooked components. Our review of the methods used to first identify the WBC sex pheromone revealed that the pheromone is only based on solvent extracts of pheromone glands dissected from four female moths (Klun et al. 1983). Work with other noctuid moths has demonstrated that solvent extracts can yield pheromone blends that in fact are different than those emitted by calling females (Tumlinson et al. 1986). Therefore, we also propose to sample the headspace of calling females and analyze the samples with gas chromatography-mass spectrometry to more accurately identify the true sex pheromone released by WBC. If we identify alternative components, we will formulate new blends and field-test their effectiveness.

For the two proposed lines of inquiry, Trécé Incorporated will provide us with the synthetic blends that we will test, whereas we will conduct field tests, laboratory collections and analyses.

Objective 4a: we will field test the following treatments at three sites, one in PA and two in NY:

- Treatment 1: The Trécé western bean cutworm pheromone lure, a four component blend comprising: (Z)-5-dodecenyl acetate (62 µg/septum), (Z)-7-dodecenyl acetate (12 µg/septum), 11-dodecenyl acetate (62 µg/septum), and dodecyl acetate (62 µg/septum).
- Treatment 2: Our alternative western bean cutworm pheromone lure, which would lack the minor component, (Z)-7-dodecenyl acetate, but the other three components would remain in the same abundances
- Treatment 3: A blank solvent control

In PA, our research sites will include Penn State's Russell E. Larson Agricultural Research farm (Centre County). Traps at this site in 2011 yielded 124 moths (35% of the moths we collected in Pennsylvania in 2011). In NY, our research sites will be based on farms that yielded significant trap captures in 2011. The Wyoming county (Attica) site collected 165 moths in 2011, 65 more than the next highest location. A second field site will be located at the NYS Agricultural Research farm in Ontario county (Geneva) NY. Farmers in these locations grow substantial acres of corn and welcome collaborations with Cornell Cooperative Extension personnel.

At each of the study sites (PA and NY), pheromone lures (treatments) will be placed in green unitraps, and traps spaced at least 50 meters apart. We will use a randomized complete-block design, with four-to-five replications of all treatments at each study site. Data will be taken weekly throughout the flight period of WBC. Treatments locations within each of the replications will be re-randomized for each week that data are taken. Vapona insecticide strips will be placed in the trap bucket to kill entering moths. We will analyze the number of moths of each species trapped by each treatment by analysis of variance (PROC GLM in SAS) using treatment, block, week, and their various interactions as fixed effects in the model.

Objective 4b: This objective will be more exploratory and the experimental design will not involve treatments until new potential pheromone blends emitted by female moths are identified. We have a commitment from Dr. Jeffery Bradshaw at the University of Nebraska at Lincoln to provide us with live female moths, which are very common in his area and we have already obtained a USDA permit to ship live pupae or moths to PA. To sample the pheromone blend, we will sample the "headspace" of calling females using an automated volatile collection system (Volatile Assay Systems, Rensselaer, NY). Using this system, we will draw purified air through specialized glass chambers containing calling females, collecting the pheromone emitted into the headspace of these chambers on an adsorbant polymer called SuperQ. We will sample at least twenty females and organic-solvent washes of SuperQ filters will be analyzed using an Agilent 7890 Gas Chromatograph with a flame ionization detector and gas chromatography and coupled gas chromatography-mass spectrometry (Aglient 7890 Gas Chromatograph interfaced with an Aglient 5975N Mass Spectrometer) to identify the components. We will compare our volatile-based analyses with the published results derived from solvent washes of four female glands, and aerations of commercially available pheromone lures that we purchase (these latter two blends should be the same). Given typical differences between solvent washes of glands and aerations of calling (i.e., pheromone emitting) individuals (Tumlinson et al. 1986), we expect results to be different. Based on our results, Trécé Incorporated, our industry partner, will synthesize appropriate pheromone blends to test. The tests will proceed similarly to the field protocol described for Objective 4a.

Timetable

Objectives	2012 Sum	Aut	Win	2013 Spr	Sum	Aut	Win	2014 Spr
1-Monitoring	XX	XX			XX	XX		
2-Database building	XX	XX	XX	XX				
3-Model testing				XX	XX	XX	XX	
4-Pheromone work	XX	XX		XX	XX	XX		XX
Extension presentations/pubs			XX	XX			XX	XX

Evaluation Plan

Objective 1. To evaluate the anticipated impacts of our WBC monitoring network, we will assess the number of WBC moths we capture, the geographic range where we trap moths, and the duration of moth flight activity. In 2010 and 2011, we had success independently coordinating monitoring programs in PA and NY, and captured moths across both states. Guided by lessons learned from our past efforts, we are confident we will be able to characterize local WBC populations in 2012 and 2013 in PA and NY and we do not see any trouble sharing our expertise and extending our efforts to VT. In addition, because we will be posting our data to PestWatch, hits and WBC queries on this website will provide an unbiased measure of the appeal of the information we generate.

Objective 2. To evaluate the anticipated impacts of our effort to accumulate data across the Great Lakes region and add a remote reporting capability to PestWatch, we will assess the impact of the aggregate dataset for generating useful information for the region. Given the expertise of the Center for Environmental Informatics, we feel our chances for success are very good. To determine if we are successful in communicating our findings to growers, we will conduct surveys of our extension audiences to measure pre- and post-presentation levels of knowledge.

Objective 3. To evaluate our effort to use the accumulated data to generate phenology models, we will compare our results with established extension recommendations for initiating trapping and estimating peak flight. Moreover, our trapping efforts for 2012 and 2013 will provide a test and sort of ground trothing of our revised model.

Objective 4. To evaluate the anticipated impacts of our effort to improve the WBC pheromone blend, we will rely on number of WBC moths in traps emitting the pheromone blends we develop. If we are successful, our new or refined blends will capture significantly more WBC moths, or maintain levels of WBC capture, while decreasing non-target by-catch.

Due to the two-year duration of this project, we will have excellent opportunities to obtain cooperator feedback on effectiveness of proposed efforts and their value in contributing to the development of an IPM program for use in commercial production systems. A true understanding of the value of these efforts will unfurl over several years and is beyond the scope of this current proposal

Logic Model for Developing an IPM program for western bean cutworm in the Northeast Region

Situation

Western bean cutworm (WBC) is invading the Northeast Region, threatening production of field corn (grain and silage), sweet corn, and dry beans.

Inputs

- Inputs
- Personnel
  - University faculty and staff
  - Penn State
  - Cornell
  - University of Vermont
- Research money
- In-kind contributions of time
- Logistical and administrative costs

Objectives and Anticipated Impacts.

1. Track the range expansion of WBC using pheromone traps;
2. Integrate existing Great Lakes regional trap capture data into PestWatch to understand the spread of WBC and develop a smartphone/web app ;
3. With regional data, evaluate the relevance for the Northeast of the Midwestern degree day model for predicting various activity periods;
4. Optimize the WBC pheromone blend to improve trap capture

Outputs

1. WBC monitoring network
2. Improve timely access to regional WBC activity info
3. Enhance timing of WBC IPM activities
4. Improved pheromone blends to improve trapping efficiency

Assumptions:
Effective and economical WBC control tactics will emerge from an understanding of local pest dynamics and collaborative research

External factors:
Agricultural industry will promote transgenic- and chemical-based control based on a general risk of pest damage without ground truthing

Outcomes of research efforts

- Begin to develop a regional approach for managing invasive species that threaten large crop acreages
- Solid understanding of regional phenology and population dynamics of WBC in PA, NY, and VT that will be applicable to other states in Region/country.
- Increased trap capture efficiency to better detect local populations of moths in corn and dry bean fields.
- Presentation of findings to county, state and regional stakeholders to refine development of research, extension and education needs for WBC

Expected knowledge gain among collaborators, stakeholders:

-Better understanding of WBC biology, population size and spatio-temporal distribution of adults and larval infestations

Expected actions from stakeholders:

-Seek current information generated by research program about WBC phenology and status
-Scout fields based on risk factors we develop
-React to actual pest levels, not perceived risks
-Adopt effective, economical, environmentally aware management options for WBC

Expected changes in condition:

-Invasion of WBC is not as damaging
-Risk of WBC is known and predictable
-WBC distribution is known, populations dynamics are understood
-Overuse of insecticides do not threaten environmental quality or pest-control services provided by natural enemies

Key Personnel.
Dr. John F. Tooker, Dept. of Entomology, Penn State University, is the project director and will oversee and coordinate the project. Tooker will also coordinate the WBC monitoring effort (Objective 1) and field characterization (Objective 2) in PA, as well as conduct research to improve the pheromone blend used to trap WBC (Objective 3). Tooker will also present and coordinate extension programming for WBC in PA and the region.

Keith Waldron, New York State Integrated Pest Management Program, Cornell University, is the Co-PD and will help oversee and coordinate the project. Waldron will also coordinate the WBC monitoring effort (Objective 1) and field characterization (Objective 2), and field testing of pheromone blends (Objective 4) in NY. Waldron will also present and coordinate extension programming for WBC in NY.

Dr. Margaret Skinner, Dept. of Entomology, University of Vermont will coordinate the WBC monitoring effort (Objective 1), field characterization (Objective 2), and extension programming in VT.

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