BIOLOGY AND MANAGEMENT OF WESTERN BEAN CUTWORM (*STRIACOSTA ALBICOSTA* SMITH)
IN MICHIGAN DRY BEANS (*PHASEOLUS VULGARIS* L.)

By

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ABSTRACT

BIOLOGY AND MANAGEMENT OF WESTERN BEAN CUTWORM (*STRIACOSTA ALBICOSTA,* SMITH) IN MICHIGAN DRY BEANS (*PHASEOLUS VULGARIS,* L.)

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The western bean cutworm (*Striacosta albicosta*, Smith) is a native pest of dry beans and corn in western North America, and since 2000, has expanded its range eastward to include Michigan. It was discovered in the state in 2006, and has been reported as a pest of Michigan dry beans and corn since then. Michigan is the second largest producer of dry beans in the United States, and western bean cutworm was a new threat to this industry. Our overall objective was to study western bean cutworm biology and control to develop management recommendations for Michigan dry bean growers. Moth flight was monitored, and range expansion was tracked, through a pheromone trap network from 2006 – 2012. In central Michigan, pheromone traps near dry beans caught significantly more moths than traps near corn. Health of egg masses decreased due to possible predation, fungal pathogens, and proved parasitism. Western bean cutworm larvae have the potential survive on alternate host plants, many of which are produced in Michigan's diverse agriculture. Larvae are difficult to scout for in dry beans because they remain on the ground during the day. Prepupae are found overwintering as deep as 38 cm in the soil. Significant damage to dry bean quality and marketable yield was observed with 1 egg mass per 1.5 m of row or 2 larvae per 0.3 m of row. A spray application of λ-cyhalothrin 1 to 2 weeks after local peak flight offers the most effective control of western bean cutworm in Michigan dry beans.

ACKNOWLEDGEMENTS

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CHAPTER 1:

LITERATURE REVIEW

History of western bean cutworm

The western bean cutworm, *Striacosta albicosta* (Smith) (formerly *Loxagrotis albicosta* and *Richia albicosta*) (Lepidoptera: Noctuidae), is native to North America. Western bean cutworm was first characterized from an Arizona moth collection in 1887, and found in Colorado light traps in 1896 (Smith 1887, Hoerner 1948). Specimens were caught in light traps in Kansas in 1934 and Nebraska in 1935 and 1936 (Hoerner 1948). Western bean cutworm larvae were first reported to damage dry beans (*Phaseolus vulgaris* L.) in Colorado in 1915 (Hoerner 1948). By the 1940's, it was frequently reported as a pest of dry beans in both Idaho and Colorado (Hoerner 1948, Douglass et al. 1955). By the 1960's, damage in Nebraska resulted in lower market grade beans, as well as rejected bean shipments (Hagen 1962b). The first report of economic injury to corn (*Zea mays* L.) was in 1957 in Idaho (Douglass et al. 1957). By the mid 1950's, the range of western bean cutworm included Arizona, Colorado, Idaho, Iowa, Kansas, Nebraska, New Mexico, Texas, Utah, Alberta Canada, and southern Mexico (Crumb 1956). From 1970 to 1980, its range expanded to include Oklahoma, South Dakota, and Wyoming (Blickenstaff and Jolley 1982). In the western United States, populations of western bean cutworm could be high for several years and then decline for no apparent reason (Hantsbarger 1969).

Between 1980 and 2000, western bean cutworm was sporadically found in corn in western Iowa (Rice 2000). However, beginning in 2000, populations increased and spread

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across Iowa; the range expanded quickly east and adults were collected in 11 additional states and provinces, including Illinois, Indiana, Iowa, Michigan, Minnesota, Wisconsin, and Ontario by 2009 (Michel et al. 2010). This recent eastward range expansion occurred at approximately the same time as the introduction of transgenic Bt corn hybrids used to control European corn borer (*Ostrinia nubilalis*, Hubner) (Miller et al. 2009, Dorhout and Rice 2010). Miller et al. (2009) found that the range expansion of western bean cutworm did not result from a genetic bottleneck, and speculated that the use of Bt corn reduced competition between western bean cutworm and the more dominant European corn borer, allowing western bean cutworm populations to increase and spread (Dorhout and Rice 2010).

Western bean cutworm feeds on dry beans, garden beans, and corn (field and sweet) (Blickenstaff 1979). Dry beans and corn were planted by Native Americans in the southwest United States for centuries, and were speculated to be the original hosts for western bean cutworm (Blickenstaff 1979). In a study where dry beans were not included, sweet corn and garden beans were the only hosts on which larvae survived and reached acceptable larval weights of 0.61 g and 0.63 g, respectively, after 21 days (Blickenstaff and Jolley 1982). In the same study, larval development on scarlet runner bean (*Phaseolus coccineus* L.), adzuki bean (*Vigna angularis* L.), lima bean (*Phaseolus lunatus* L.), horse bean (*Vicia faba* L.), crimson cowpea (*Vigna sinensis* L.), garden pea (*Pisum sativum* L.), and tepary bean (*Phaseolus acutifolius* L.) was moderate to good with larval weights ranging from 0.29 g to 0.57 g after 21 days. However, larval development was poor on soybean (*Glycine max* L.) with either no survival, or larval weights of 0.09 g after 21 days (Blickenstaff and Jolley 1982). Tomato, ground cherry, and nightshade were classified as unsuitable hosts based on low larval weight and poor

survival (Blickenstaff and Jolley 1982). However, Blickenstaff (1979) found that later instars

could finish development on ground cherry and nightshade if they previously fed on corn or

beans.

Biology of western bean cutworm

Moths: Adult western bean cutworms are gray-brown in color and approximately 2 cm long

(Smith 1887, Antonelli 1974). The moth has a wing expanse of 3.81 cm, the wings are brown

with lighter markings, and the costal margin of the front wings is nearly white (Hoerner 1948).

This white stripe, along with a circular spot and a comma-shaped spot of similar color, form the

primary identifying markings of this Noctuid (Michel et al. 2010).

In the western part of its range, moth flight begins in June, peaks towards the end of

July, and typically ends by late August (Blickenstaff 1979, Dorhout and Rice 2008). However,

variability in flight time can occur due to differences in climate and location (Michel et al. 2010).

Oviposition typically occurs 2 to 4 days after emergence (Antonelli 1974, Blickenstaff 1979),

with the majority of eggs laid in July and August (Michel et al. 2010). In its western range,

female moths deposited 84 to 627 total eggs, with an average of 321 to 407 (Blickenstaff 1979,

Douglass et al. 1957). Ovipositing females are initially attracted to late whorl-stage corn that is

about to tassel (Seymour et al. 2004). The deposition of egg masses has a random distribution

throughout the corn field (Moraes 2012). If cornfields have started to pollinate, or if corn is not

available, females may deposit eggs in nearby dry bean fields (Blickenstaff and Jolley 1982).

Eggs: Females typically oviposit on the upper surfaces of newly unfolded corn leaves (Seymour

et al. 2004) or on the underside of dry bean leaves deep within the canopy (Hoerner 1948).

Eggs are dome shaped with a diameter of 0.08 cm, coarsely ribbed, reticulated, and pearly white when fresh (Hoerner 1948). They become pale yellow, then turn purple as they develop (Antonelli 1974). Egg development takes 5 to 7 days (Seymour et al. 2004). Hoerner (1948) reported that eggs were laid in groups from 3 to 79. In Nebraska, Hagen (1962b) reported that oviposition was complete within 10 days of peak flight. In Iowa, however, with peak flight in mid-July, oviposition continued through the end of August (Rice 2006, Dorhout and Rice 2008). Once the eggs hatch, first instars typically consume the egg chorions; this behavior makes it difficult to scout for hatched egg masses (Michel et al. 2010).

Larvae: In corn, freshly-hatched larvae move away from the egg mass to feed on the pollen in the whorl until the tassel emerges (Hagen 1962a). Once the tassel emerges, larvae travel down the plant to feed on pollen that collects in the leaf junctions (Hagen 1962a). If the tassel has already formed prior to hatch, larvae move to the ear zone to feed on silks (Hagen 1962a). Later-instars feed on mature corn ears and a single ear of corn can contain multiple larvae (Seymour et al. 2004).

In Colorado dry beans, young larvae fed on the leaves and buds (Hoerner 1948). Once the larvae reached the third or fourth instar, they fed on developing pods at night and on cloudy days (Antonelli 1974, Hoerner 1948). Hoerner (1948) observed that when larvae were not feeding, they burrowed into the soil around the plants. In pulled beans, larvae that were not mature at harvest congregated in the soil under windrows and continued to feed on pods (Hoerner 1948, Seymour et al. 2004).

Mature larvae are approximately 4 cm in length and pinkish brown in color (Hoerner 1948). There are usually six instars, with a rarely seen seventh instar (Antonelli 1974). In

laboratory studies, larvae reached a non-feeding stage ready to begin prepupation after an average of 31 days (Blickenstaff 1979).

Pupae: In late August to early September, mature larvae drop off plants and burrow into the ground to form overwintering chambers constructed out of soil (Seymour et al. 2004). Burrowing depth was reported to be 12 to 25 cm in Nebraska (Seymour et al. 2004). The larvae remain in a prepupal state throughout the winter, then pupate and complete development in late spring to early summer (Seymour et al. 2004). The pupae are almost 2 cm in length and a dark brown color (Hoerner 1948). An overwintering study done by Hoerner (1948) showed that fewer moths emerged from clay soils than from sandy soils, and Douglass et al. (1957) found that western bean cutworms caused more damage to beans and corn grown in sandy loam, than in heavier, soils. Hantsbarger (1969) found severe western bean cutworm feeding injury in corn grown in sandier and irrigated ground. Hein and Seymour (2000) reported a greater proportion of larvae formed overwintering chambers below 10.2 cm (4 inches) in sandy soils (40%) than in loamy soils (12%). Michel et al. (2010) speculated that it was easier for larvae to burrow deeper into sandier soil, which provided more protection from cold temperatures and increased overwintering survival. Hoerner (1948) found that a precipitation even that moistened the soil at the time of emergence was necessary, in both light textured and heavier soils, before moths were able to emerge.

Western bean cutworm as a pest

On dry beans, the first sign of larval feeding is leaf feeding, which is minimal and does not have an economic effect on the crop (Hagen 1973). Older larvae feed on and inside pods,

decreasing yield and quality, and allowing entry of fungal and bacterial pathogens (Michel et al. 2010). As few as 2% damaged beans (pick) results in increased sorting time, reduced quality, and a lower grade of dry beans. Thus western bean cutworm poses a direct economic impact to dry bean growers. On corn, larvae feed on ears, causing direct loss of kernels, deformed ears, and entry of fungi (Hagen 1962a). Yield losses of 30 to 40% were reported in heavily infested cornfields in Nebraska (Keith et al. 1970).

<u>Monitoring and thresholds for western bean cutworm in the western United States</u>

It is easier to scout for western bean cutworm in corn than in dry beans. In corn in Colorado and Idaho, egg masses are deposited on upper leaves and larval feeding on tassels are often apparent and have been used, along with moth flight, to assess potential damage to the overall crop (Hantsbarger 1969, Blickenstaff 1979). In Idaho, corn growth stage influences egg laying, and therefore the degree of larval infestation and damage to corn; scouting efforts are often focused on late whorl stage corn (Blickenstaff 1979). In Idaho in the 1970's, Blickenstaff (1979) found that ear damage was positively correlated with local moth catches. Corn in the late whorl stage or with tassels just emerging, is attractive to moths for egg laying and has a higher number of larvae and more feeding than younger or older corn (Blickenstaff 1979, Hantsbarger 1969). Western bean cutworm injury to corn was higher in fields that were irrigated and that had sandy soil types in Colorado (Hantsbarger 1969). In the 1970's, Blickenstaff (1979) reported that economic injury to corn started when 6% of plants had western bean cutworm injury. In the 1990s, Appel et al. (1993) recommended an economic threshold of 33 eggs per plant in Nebraska. However, determining the average number of eggs

per mass can be time-consuming, and in general, a threshold of 5 to 8 % of plants with egg masses is currently used in the western and central United States (Wright et al. 1992, Seymour et al. 2004, Rice and Pilcher 2007, Krupke et al. 2009). Scouting for larvae is also important since one larva per corn plant at dent stage will reduce corn yields by 3.7 bu/acre (Dorhout and Rice 2004).

Scouting and timing insecticide applications is more difficult in dry beans than in corn. Moths lay egg masses on the underside of leaves in the mid-canopy, making egg mass scouting impractical (Michel et al 2010). In the western United States, two other strategies have been recommended. One focuses on larval scouting, recommending that an insecticide be sprayed at a threshold of two or more larvae per foot of row (Seymour et al 2004). Like egg masses, however, larvae are difficult to detect in a dense canopy. More commonly, moth traps are recommended to monitor population levels, determine peak flight, and trigger applications (Seymour et al 2004). In Idaho in the 1970s, Blickenstaff et al (1975) correlated light trap catch with bean damage. They found that a catch of 700 or more moths per trap by 25 July correlated to at least 2% damage. This percentage was important to Idaho processors because dry beans coming in from the field with this level of damage required extra time and effort in cleaning (Blickenstaff et al. 1975). Seymour et al (2004) also used a cumulative moth catch of 700 per trap as an action threshold for dry bean damage in Nebraska, except that they applied this number to pheromone traps. They also recommended examining dry bean pods in the field for feeding injury two to three weeks after peak flight, and using the combination of moth catch and feeding as a spray trigger (Seymour et al 2004). Unfortunately, the western threshold of 700 moths per trap did not prove useful in Michigan after western bean cutworm colonized the

state. High percent pick was observed, and dry bean loads were rejected, from fields with pheromone trap counts of as few as 100 moths per trap (Michel et al. 2010).

Management of western bean cutworm

Western bean cutworm egg masses and larvae are killed by many of the same pathogens and predators that attack other Lepidopteran pests of corn. Helms and Wedberg (1976) found that the pathogen, *Nosema*, infected the midgut of dead larvae reared in the laboratory. It has been observed that insects in the family Coccinelidae, Anthocoridae, Nabidae, Lygaeidae, Chrysopidae, as well as spiders fed on western bean cutworm larvae in the laboratory (Blickenstaff 1979). Coccinelid adults fed on eggs and young larvae in the field (Seymour et al. 2004). Predation by birds was also observed in cornfields (Seymour et al. 2004).

There are also cultural methods for managing western bean cutworm. Plowing, disking, or disturbing the soil in other ways may reduce the ability of the prepupae to overwinter (Seymour et al. 2004). There were also dry bean varieties developed for resistance to western bean cutworm, however, these varieties were not suitable for commercial production due to poor coloring and extremely viney growth habits (Antonelli and O'Keeffe 1981, Seymour et al. 2004).

Insecticide management of western bean cutworm in corn can be difficult due to uneven distributions of larvae in the field as well as the larvae being sheltered in the ears (Michel et al. 2010). It is important to monitor for adults through pheromone trapping and to scout for egg masses (Michel et al. 2010). When scouting, a random sampling pattern should be

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used across the field since egg masses are randomly laid (Moraes 2012). Pyrethroids are the most effective insecticide group for control of western bean cutworm in corn (Michel et al. 2010). Another way to use insecticides to control western bean cutworm is to plant Bt corn. There is no difference in the proportion of egg masses deposited in Bt corn or non-Bt corn (Moraes 2012). However, only Bt corn hybrids that contain the Cry1F toxin or the Viptera trait (Vip3A) control western bean cutworm (Seymour et al. 2004, Volenberg 2010). Corn hybrids with other Bt traits are still susceptible to western bean cutworm feeding (Catangui and Berg 2006).

Insecticide management of western bean cutworm in dry beans is not as difficult, because the larvae move around in the dry bean canopy. Trap counts were used to monitor adult population numbers and fields were checked for pod feeding in Nebraska (Seymour et al. 2004). If there was a significant amount of pod feeding, an insecticide application was recommended (Seymour et al. 2004). Prior to 1970, DDT or carbaryl was used in dry beans to control western bean cutworm in the western United States (Hagen 1976, Blickenstaff and Peckenpaugh 1981). Endosulfan effectively controlled western bean cutworm when a spray application was made during moth flight in Idaho (Blickenstaff and Peckenpaugh 1981). Two pyrethroids, fenvalerate and permethrin, offered nearly 100% control of western bean cutworm when applied up to 29 days after peak flight in Idaho dry beans (Blickenstaff and Peckenpaugh 1981).

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CHAPTER 2:

RELATIONSHIP OF PHEROMONE TRAP CATCH TO
CLIMATOLOGICAL FACTORS, SURROUNDING CROPS, AND TRAP TYPE AS
WESTERN BEAN CUTWORM (*STRIACOSTA ALBICOSTA*, SMITH) COLONIZED MICHIGAN

Abstract

The western bean cutworm (*Striacosta albicosta*, Smith) is a native pest of dry beans

and corn in Western North America, and since 2000, has expanded its range eastward to

include Michigan. The purpose of this study was to determine the range and density of western

bean cutworm in Michigan, and to identify environmental trends that may affect the number of

moths captured in pheromone traps. Range and peak flight were determined through a

cooperative trapping network in 2006 – 2012. Data from this network were used to identify

relationships between trap counts and atmospheric temperature, precipitation, soil

temperature, nearby crop type, and pheromone trap type. This research determined that

western bean cutworm populations steadily increased and established a state-wide range in

2006 – 2012, and a natural fluctuation in population numbers were observed in 2010 – 2012.

No significant relationships between atmospheric temperature, precipitation, or soil

temperature and trap counts were observed. Pheromone traps associated with dry bean fields

caught significantly more moths in Central Michigan than traps only associated with field corn

in 2010 – 2012. Peak flight occurred at different times for dry beans and field corn in 2010 and

2012. Pheromone trap type had no significant affect on the number of moths captured. This

information was important in developing western bean cutworm management

recommendations for Michigan dry beans.

<u>Introduction</u>

The western bean cutworm, *Striacosta albicosta* (Smith), is native to North America and was first described in a moth collection from Arizona in 1887 (Smith 1887). Western bean cutworm was first observed causing damage to dry beans in Colorado in 1915, when a load of pinto beans was rejected due to poor quality (McCampbell 1941). Western bean cutworm larvae feed on and in dry bean pods, causing decreased yield and quality and resulting in lower market grade (Hagen 1962a, Seymour et al. 2004, Michel et al. 2010). Dry bean producers consider 2% damage to beans (pick) to cause an economic impact (Blickenstaff 1979, Mahrt 1987, Michel et al. 2010). The first observations of western bean cutworm causing damage to corn were made Idaho in 1954 (Douglass et al. 1957). Larvae negatively affect corn yield by feeding on and in ears, causing kernel loss, deformed ears, and an entry point for fungal pathogens (Hagen 1962b).

By the mid 1980's, the range of western bean cutworm included Arizona, Colorado, Idaho, Iowa, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, Utah, Wyoming, Alberta Canada, and southern Mexico by the mid 1950's (Crumb 1956, Blickenstaff and Jolley 1982). Starting in 2000, western bean cutworm populations increased and spread across Iowa and then into Illinois, Indiana, Michigan, Minnesota, Wisconsin, and Ontario Canada by 2009 (Michel et al. 2010).

Pheromone traps are used to monitor western bean cutworm, to time field scouting, and to time insecticide applications in Nebraska (Seymour et al. 2004). In the Western United States, a threshold of 700 or more moths per pheromone trap is used time spray for western bean cutworm (Seymour et al. 2004). In Michigan, significant injury to dry beans was observed

with as few as 100 moths per trap (Michel et al. 2010). Trap height and surrounding vegetative habitat does have a significant effect on the number of moths captured (Mahrt et al. 1987, Dorhout 2007). Pheromone traps set at 1.2 m to 1.8 m captured significantly more moths than traps that were set at 0.6 m (Dorhout 2007). This affect could be attributed to the female moth's inclination to oviposit near the top of corn plants (Douglass et al. 1957, Hagen 1962, Dorhout 2007). The most efficient trapping method was to set traps between 1.2 m and 1.8 m above the ground, and to place traps near two corn fields instead of a corn field and a soybean field (Dorhout 2007).

The overall objective of this study was to identify trends in the environment that had a significant effect on western bean cutworm range and density in Michigan for 2006 - 2012. Specific goals were to determine 1. The peak flight of western bean cutworm each year 2. Where western bean cutworm populations were highest each year 3. If atmospheric temperature or precipitation levels in the summer had a significant effect on the number of trapped western bean cutworm moths each year 4. If atmospheric temperature or soil temperature in the winter had a significant effect on the number of trapped western bean cutworm moths each year 5. If nearby crop fields (dry beans or field corn) had a significant effect on the number of trapped western bean cutworm moths each year and 6. If trap type had a significant effect on the number of trapped western bean cutworm moths in 2010.

Materials and Methods

In the years 2006 – 2012, a pheromone trap network was managed each year to monitor population levels, range expansion, distribution, and the timing of peak flight. In 2006

– 2009, cooperators were mailed western bean cutworm pheromone purchased from Great

Lakes IPM (Vestaburg, MI) and trapping instructions. Trap counts were reported and compiled

each week. In 2010 – 2012, the same pheromone and trap instructions were used, and a

website for reporting trap counts was developed and used so cooperators could easily input

weekly counts. Each week started on Sunday and ended on Saturday, and dates reported were

for the last day of the week. It was assumed that individual trap locations were accurately

identified by the nearest crossroad and township, and moth counts were accurately reported.

Data was managed and peak flight was determined for 2008 – 2012 by graphing the counts

each week (Figure 2.1). Individual trap locations were also plotted for 2007 - 2012 using ArcGIS

9.3.1 (Figure 2.2). The average numbers of moths caught per trap for each county were

calculated for 2007 – 2012 to compile western bean cutworm density and distribution maps of

the state ArcGIS 9.3.1 (Figure 2.3).

Weather data on atmospheric temperature, precipitation, and soil temperature was

downloaded from Enviro-weather (Michigan State University, East Lansing, MI). Methods for

compiling weather data were based on a long term climate study on agriculture in Iowa, North

Dakota, and Minnesota (Carlson et al. 1994). Each year, for each trap location, the nearest

weather station with consistent data was selected to download data. A total of 54 weather

stations were used across the state for this study (Figure 2.4). This method was based on a

study that related cabbage seedpod weevil activity and dispersal in Alberta, CA (Tansey et al.

2010). Any missing data from a given weather station was estimated by averaging data from the

next closest weather station. Summer atmospheric temperature data was averaged and

precipitation data was totaled from the timing of first trap catch to last trap catch for each year.

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Winter minimum and maximum atmospheric temperature data and soil temperature data were averaged, from November to March, for each trap location. Summer temperature and precipitation data were used to see if they were correlated to weekly western bean cutworm trap counts. Winter temperature data and soil temperature data were correlated to total western bean cutworm trap counts.

The effect of nearby crop fields on western bean cutworm trap counts was determined for 2010 – 2012 (Figure 2.5). Through the western bean cutworm trap network, cooperators reported whether their traps were nearest to dry beans, field corn, or both dry beans and field corn. The total trap counts for each trapping location were related to the nearest crop type and analyzed to see if there was a significant relationship. Six counties in Central Michigan were used because they are known to produce both dry beans and corn: Clinton, Gratiot, Ionia, Isabella, Mecosta, and Montcalm counties. There were inherent assumptions with this method of data collection. It was assumed that cooperators accurately reported the nearest crop type to each trapping location, and that the western bean cutworm moth numbers were accurately counted and reported.

To determine if the type of pheromone trap used had a significant effect on the number of western bean cutworm moths caught, a comparison study was done in Montcalm County, Michigan, 2010 (Figure 2.6). Eleven trapping locations, with dry beans and field corn adjacent to each other, were selected. At each trapping location, a commercial bucket pheromone trap (green universal moth trap, Great Lakes IPM, Vestaburg, MI) and a "milk-jug" trap were set up at least 60 m apart (n = 22). Commercial bucket traps were treated with one insecticide tape each (1.3 cm x 1.5 cm, 10% DDVP toxicant insecticide PVC tape, Great Lakes IPM, Vestaburg,

MI). Milk-jug traps were constructed based on the design described by Michel et al. (2010).

Each trap type was set with a western bean cutworm pheromone lure (Scentry lure, Great

Lakes IPM, Vestaburg, MI). Traps were put out on 20 June, and pheromone lures and insecticide

tapes were replaced on 12 July and again on 1 August. Traps were checked on the same day

each week, and weekly counts were reported to the western bean cutworm trapping network

website. Traps were taken down on 28 August.

A voucher collection has been deposited in The Michigan State University Albert J. Cook

Arthropod Research Collection as samples of the species that was used in this research.

Voucher recognition labels with the voucher number (2013-1) have been attached or included

in fluid preserved specimens.

Statistics

The total number of moths caught per week was compiled and compared for 2006-2012

trap counts. A Shapiro-Wilk test was done to determine if the data was distributed normally.

None of the data had a normal distribution so a data transformation of log (x + 1) was done and

resulted in data without a normal distribution. A Kruskal-Wallis analysis of variance (ANOVA)

was used to compare the number of moths caught for each year. Pairwise comparisons were

done with Fisher's least significant difference, and significant differences between means were

separated (α=0.05).

The correlation of summer and winter weather data to western bean cutworm trap

counts was analyzed for each trap site. Total trap counts were correlated with the average

atmospheric temperature and the total amount of precipitation with individual linear

regressions (Tansey et al. 2010). Total trap counts were correlated with average winter atmospheric temperature data and average winter soil temperature data with individual linear regressions.

To determine if nearby crop fields had an impact on the number of western bean cutworms trapped, a one-way ANOVA was done to relate the crop type to the total trap counts for each year. To determine if trap type had a significant effect on the number of moths caught, a one-way ANOVA was done to relate trap type to the total trap counts in 2010. Statistical analysis of the data was performed using Statistix (version 9.0).

Results

By facilitating a western bean cutworm pheromone trap network, peak flight was determined each year for 2008 – 2012 (Figure 2.1). In 2006 and 2007, a total of 3 moths and 54 moths were caught, respectively. In 2008 and 2011, peak flight occurred during the fourth week of July. In 2009, peak flight occurred during the first week of August. In 2010, peak flight occurred during the third week of July. In 2012, peak flight occurred during the second week of July. At peak flight in 2008, there was an average of 9 moths caught per trap and a total of 755 moths caught per trap. In 2009, an average of 50 moths per trap was caught and a total of 9,571 moths per trap were caught at peak flight. In 2010, an average of 97 moths per trap was caught and a total of 14,855 moths per trap were caught at peak flight. In 2011, an average of 98 moths per trap was caught and a total of 17,724 moths per trap were caught at peak flight. In 2012, an average of 21 moths was caught per trap and a total of 3,096 moths per trap were caught at peak flight (DF = 42, F = 16.56, P = 0.00).

Western bean cutworm range expansion within the state of Michigan was monitored with a pheromone trap network each year for 2007-2012 (Figure 2.3). In 2006, a total of 3 moths were caught in Kalamazoo and Van Buren Counties, and this data was used to signify that western bean cutworm were present in Michigan. In 2007, traps were set up in 16 counties, and western bean cutworm moths were caught in 6 counties across Southern Michigan. In 2008, traps were set up in 33 counties, and moths were caught in 25 counties in the Lower Peninsula. In 2009, traps were set up in 46 counties, and moths were caught in 42 counties in the Lower Peninsula. In 2010, traps were set up, and moths were caught, in 47 counties (including 2 counties in the Upper Peninsula). In 2011, traps were set up, and moths were caught, in 37 counties. In 2010, traps were set up in 43 counties, and moths were caught in 31 counties.

There were significant differences between the total numbers of moths caught each year. A total of 3 moths were caught in 2006 and a total of 54 moths were caught in 2007, with an average of 2 moths/trap and 20 moths/trap, respectively.   In 2008, a total of 1,730 moths were caught in 78 traps. In 2009, 277 traps were set up and a total of 28,339 moths were caught. In 2010, a total of 78,361 moths were caught in 346 traps. In 2011, a total of 42,779 moths were caught in 208 traps. In 2012, a total of 12,636 moths were caught in 200 traps (DF = 42, F = 16.56, P = 0.00).

No significant relationships between total western bean cutworm pheromone trap counts and average winter atmospheric temperatures or average soil temperatures were observed in 2007 – 2012 (R^2 <0.7). No significant relationships between weekly western bean

cutworm trap counts and average weekly atmospheric temperature or total weekly precipitation were observed in 2007 – 2012 (R^2 <0.7).

Nearby crop types of dry beans, field corn, or dry beans and field corn, had a significant effect on total western bean cutworm trap counts in 2010, 2011, and 2012 (Figure 2.5). In 2010, the average number of moths per trap was 399 in traps that were near dry beans, 268 in traps that were near field corn, and 393 in traps that were near both dry beans and field corn (DF = 128, F = 7.14, P = 0.00). In 2011, the average number of moths per trap was 265 in traps near dry beans, 215 in traps near field corn, and 362 in traps near both dry beans and field corn (DF = 114, F = 7.88, P = 0.00). In 2012, the average number of moths per trap was 164 in traps near dry beans, 74 in traps near corn, and 86 in traps near both dry beans and field corn (DF = 83, F = 3.55, P = 0.03).

Commercial bucket pheromone traps and milk-jug traps were correlated to total western bean cutworm trap counts in 2010 (Figure 2.6). Trap type was not significantly related to the number of moths caught (DF = 21, F = 0.03, P = 0.87).

Discussion

By monitoring western bean cutworm moth numbers through a network of pheromone traps in Michigan, peak flight was determined for 2008-2012 (Figure 2.1). Peak flight could not be determined in 2006 and 2007 because those years had significantly lower moth counts. Although the average and total number of moths caught per trap varies for each year, the counts were not significantly different in 2008-2012. The highest total numbers of moths were caught in 2010, and the highest average number of moths per trap was in 2011. In 2012, moth

emergence was detected earlier than before with moths being collected as early as 19 May. Also in 2012, the number of moths caught from May through the beginning of September was lower than in 2008-2011, but not significantly lower.

The range of western bean cutworms spread across Michigan from 2007-2012 (Figure 2.3). Nearly half of the Lower Peninsula was trapping western bean cutworm moths in 2008, and the average number of moths per trap was 50 or higher in 4 counties. In 2009, more than half of the counties in the Lower Peninsula were trapping moths, and 16 counties had an average number of moths per trap greater than 100. In 2010, the highest numbers of moths were caught than in any other year. This was due to record high temperatures and growing degree day accumulations. All traps caught at least one moth, and an average number of moths per trap greater than 200 was caught in 19 counties. The counties with the highest western bean cutworm trap catches in Central and Western Michigan were also areas that were known to have lighter soil textures. In 2011, Central and Western Michigan still had the highest trap counts. In 2012, no counties had an average number of moths per trap greater than 200. This year had record high temperatures in March and April, which may have caused overwintering western bean cutworms to pupate early and use up their energy stores. After this warm spell, there was a period of cold temperatures that may have had a negative impact on western bean cutworm survival. In addition to these temperature fluctuations, Michigan was affected by a severe drought. Drought conditions caused field corn to mature at variable rates and dry beans to delay pod set in some areas. This may have affected western bean cutworm survival, which could be attributed to the lower trap counts in 2012. The difference in the number of moths trapped between 2010, 2011, and 2012 may also be attributed to normal fluctuations in

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population that were also seen in the Western United States (Hagen 1976, Blickenstaff 1979, Rice et al. 2004, Dorhout 2007).

No significant relationships between atmospheric temperature, precipitation, or soil temperature and trap counts were observed. When pheromone traps were used to monitor western bean cutworm numbers in Central Michigan, the nearest crop type of dry beans or field corn had a significant effect on trap counts (Figure 2.5). In 2010, significantly fewer moths were caught in traps that were closest to field corn, and significantly more moths were caught in traps that were closest to just dry beans or both dry beans and field corn. In 2011, significantly more moths were caught in traps that were closest to both dry beans and field corn than in traps that were only near field corn. In 2012, significantly more moths were caught in traps near dry beans, and significantly fewer moths were caught in traps near field corn or near both dry beans and field corn. In Iowa, Dorhout (2007) found that more moths were caught in pheromone traps that were placed near two corn fields than in traps that were near a corn field and a soybean field; he speculated that the corn on corn environment provided more cover and a suitable habitat for western bean cutworm. In an environment that includes field corn and dry beans, it is important to note that when traps were near dry bean fields, there were more moths captured. Increased western bean cutworm trap numbers appear to be closely related to a suitable host, and not to the amount of cover offered by field corn.

The timing of peak flight of western bean cutworm moths was also affected by the nearest crop type in 2010 and 2012 (Figure 2.5). In 2010, peak flight occurred the third week of July in traps that were closest to only dry beans or only field corn. In traps that were near both

dry beans and field corn, the timing of peak flight was one week later. In 2012, peak flight occurred the second week of July for traps that were near both dry beans and field corn, the third week of July for traps that were near only field corn, and the fourth week of July for traps that were near only dry beans. In 2010, the separation in peak flights between crop types could have been a result of corn maturing ahead of schedule due to record high temperatures and degree day accumulation, making the field corn less attractive to female moths that were looking for pre-tassel staged fields. In 2012, the separation in peak flights may have been a result of variation in field corn maturity, or delay in dry bean pod set, due to drought conditions.

The number of western bean cutworm moths trapped was not significantly affected by the type of pheromone trap used. Since commercial bucket traps caught the same number of moths, they were recommended for use in place of the milk-jug traps, if desired.

These findings allowed dry bean growers in Michigan to effectively monitor their local western bean cutworm populations and determine peak flight. Based on this research, it is now known that more moths may be caught near dry beans than field corn, and peak flight may occur at different times for dry beans and field corn. It is now possible to say that commercial bucket pheromone traps are equally as effective at capturing western bean cutworm moths as milk-jug pheromone traps. Additional research should be done to determine the effect of non-host crops, and other land cover, on western bean cutworm trap counts. Future research should also address the effect of soil texture on western bean cutworm trap counts. This

research could potentially identify areas with suitable western bean cutworm habitat, and that

are at higher risk for crop damage, in Michigan.

Figures and Tables:

Figure 2.1: Western bean cutworm milk jug pheromone trap (A) and bucket pheromone trap (B).

Figure 2.2: Average number of western bean cutworm moths caught per trap in Michigan, 2008 – 2012.
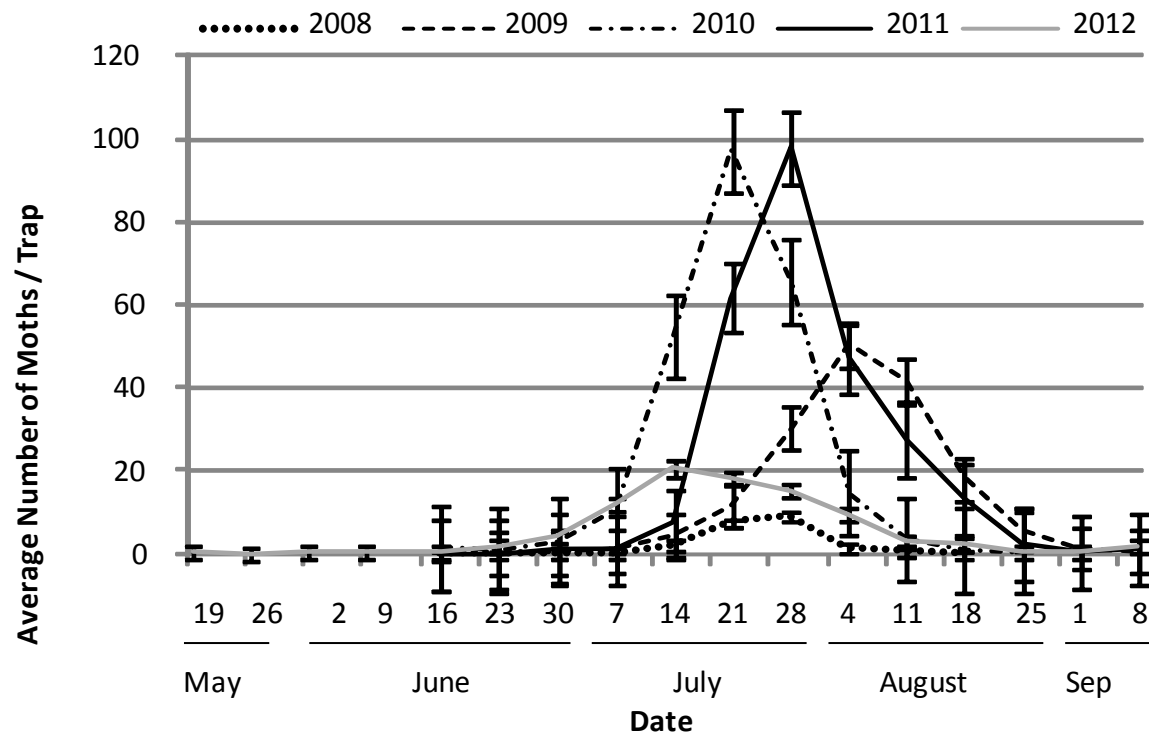
Figure 2.3: Western bean cutworm pheromone trap locations by year in Michigan, 2007 – 2012.
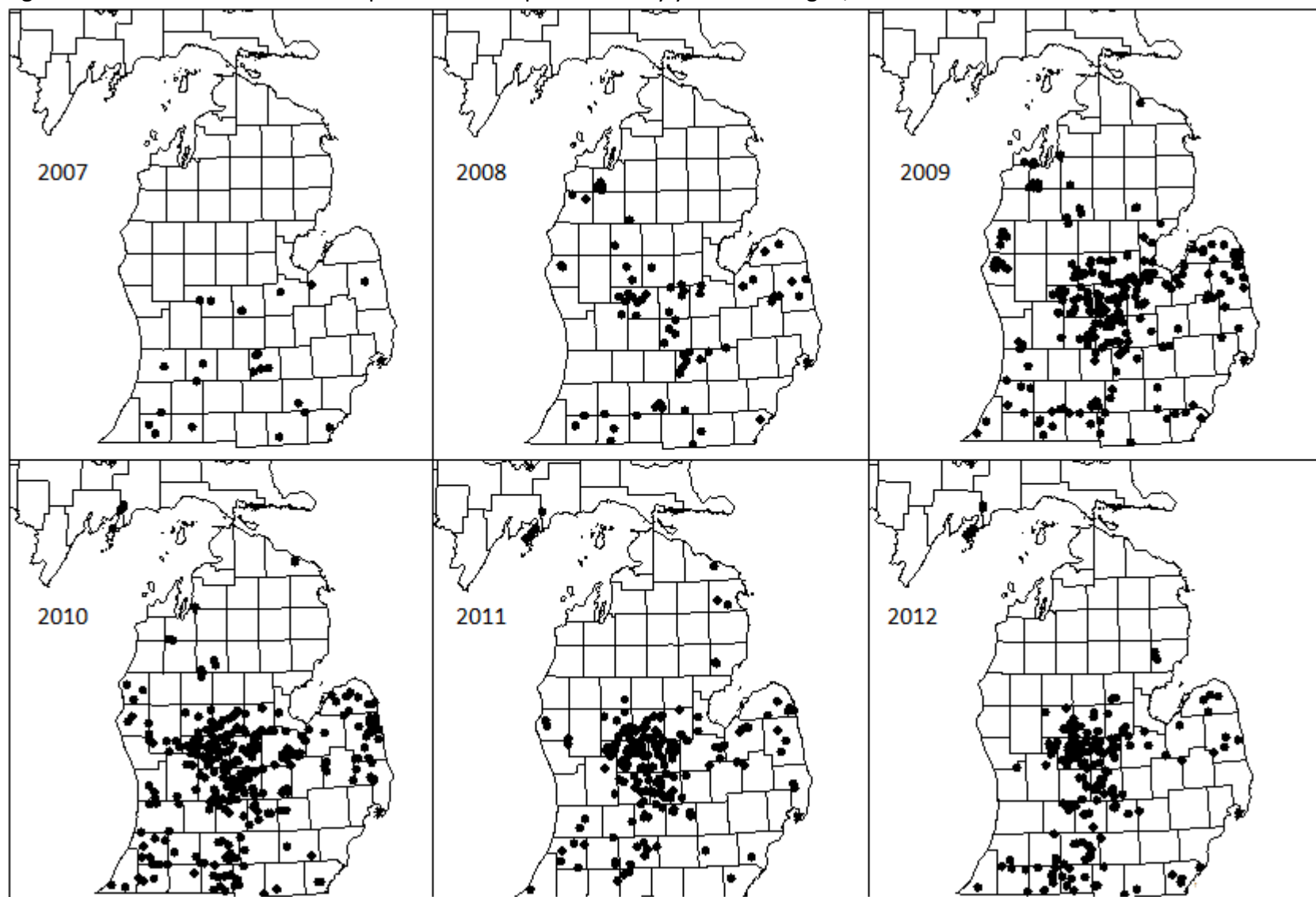
Figure 2.4: Average number of western bean cutworm moths caught per trap by county in Michigan, 2007-2012.
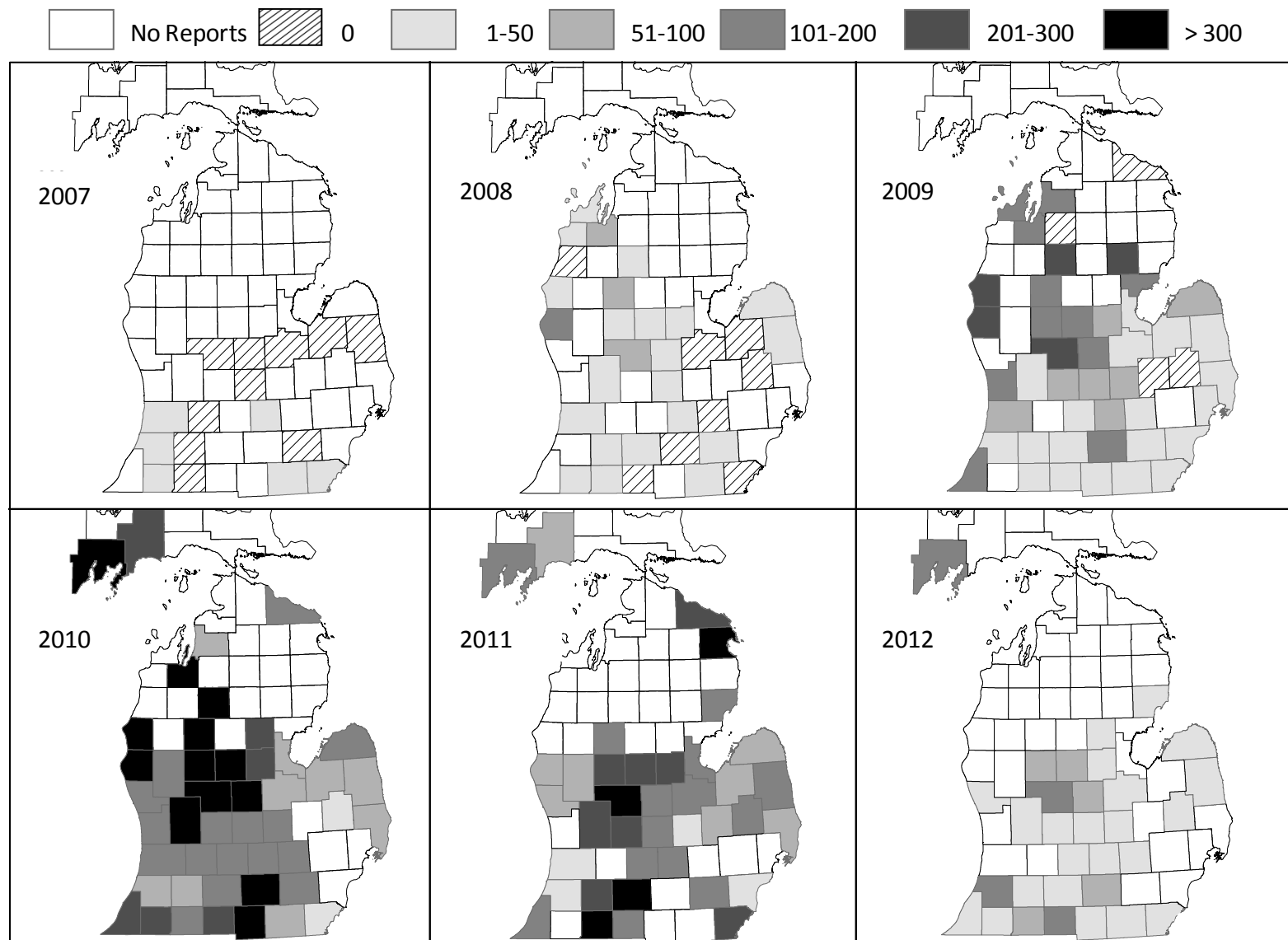
Figure 2.5: Locations of western bean cutworm pheromone traps overall (2007 – 2012) and weather stations.
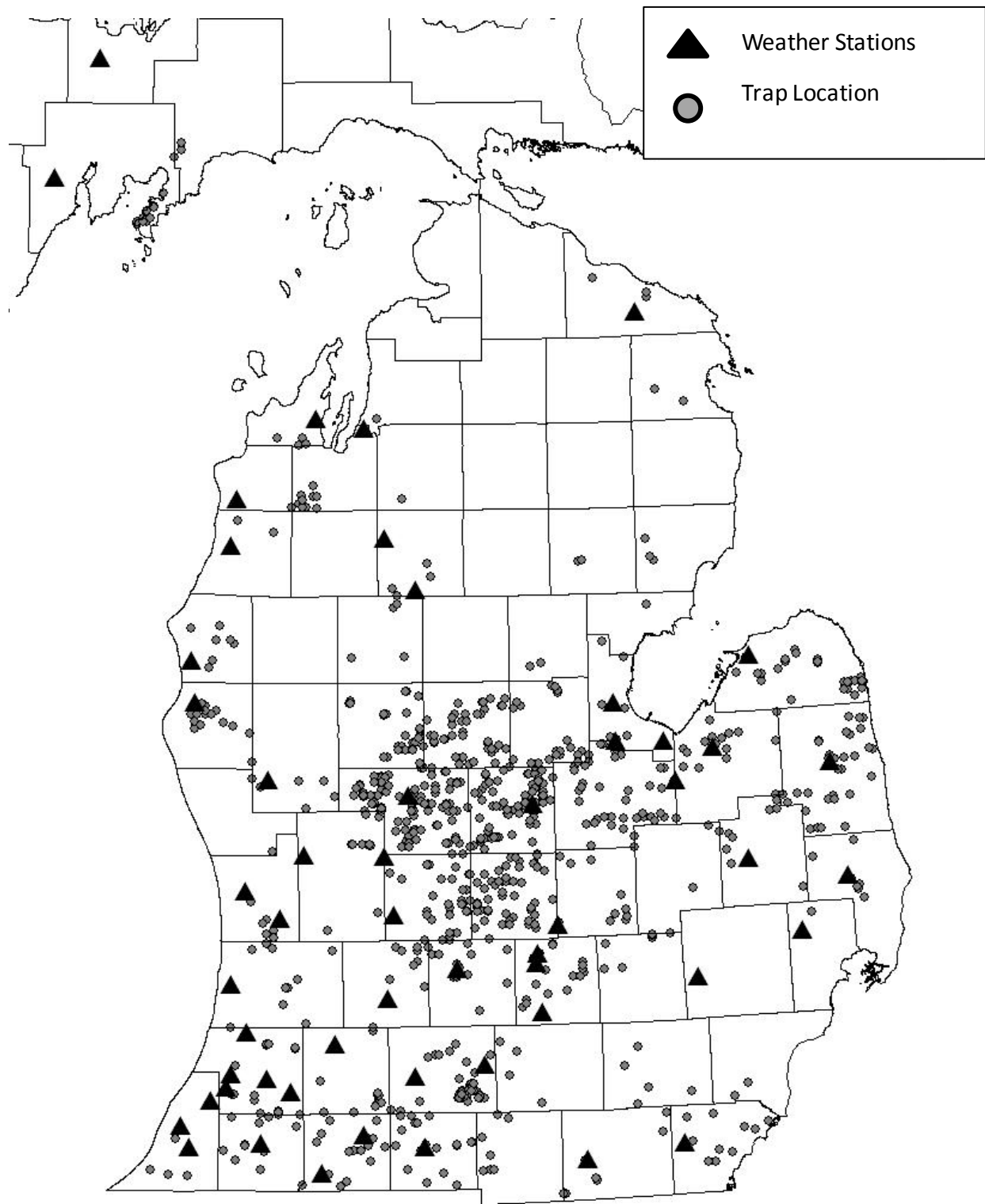
Figure 2.6: Average number of western bean cutworm moths caught in pheromone traps near dry beans, field corn, or dry beans and field corn, in Central Michigan, 2010-2012.
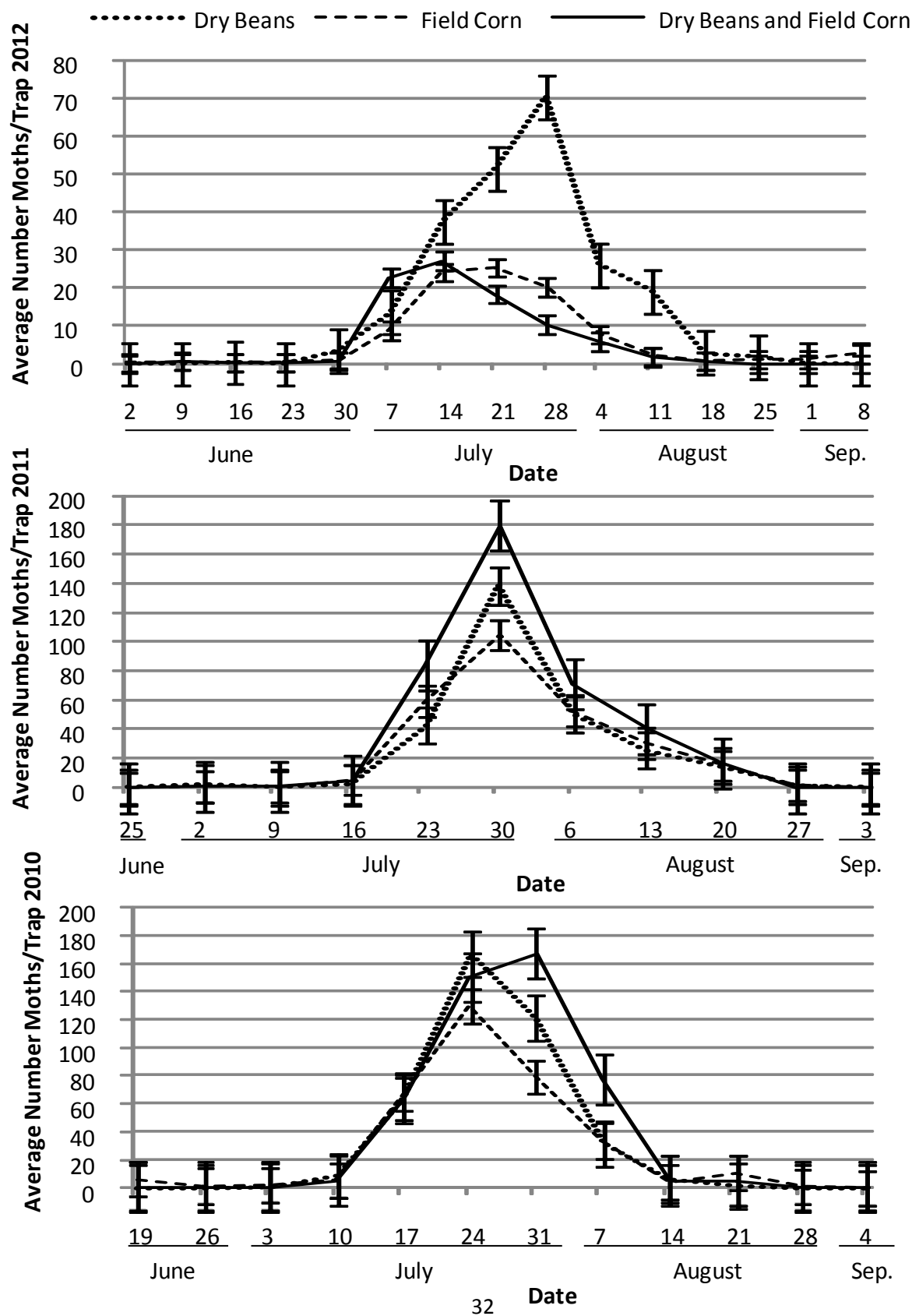
Figure 2.7: The average number of western bean cutworm moths per trap in commercial bucket pheromone traps and in milk-jug pheromone traps in Montcalm County, Michigan, 2010.
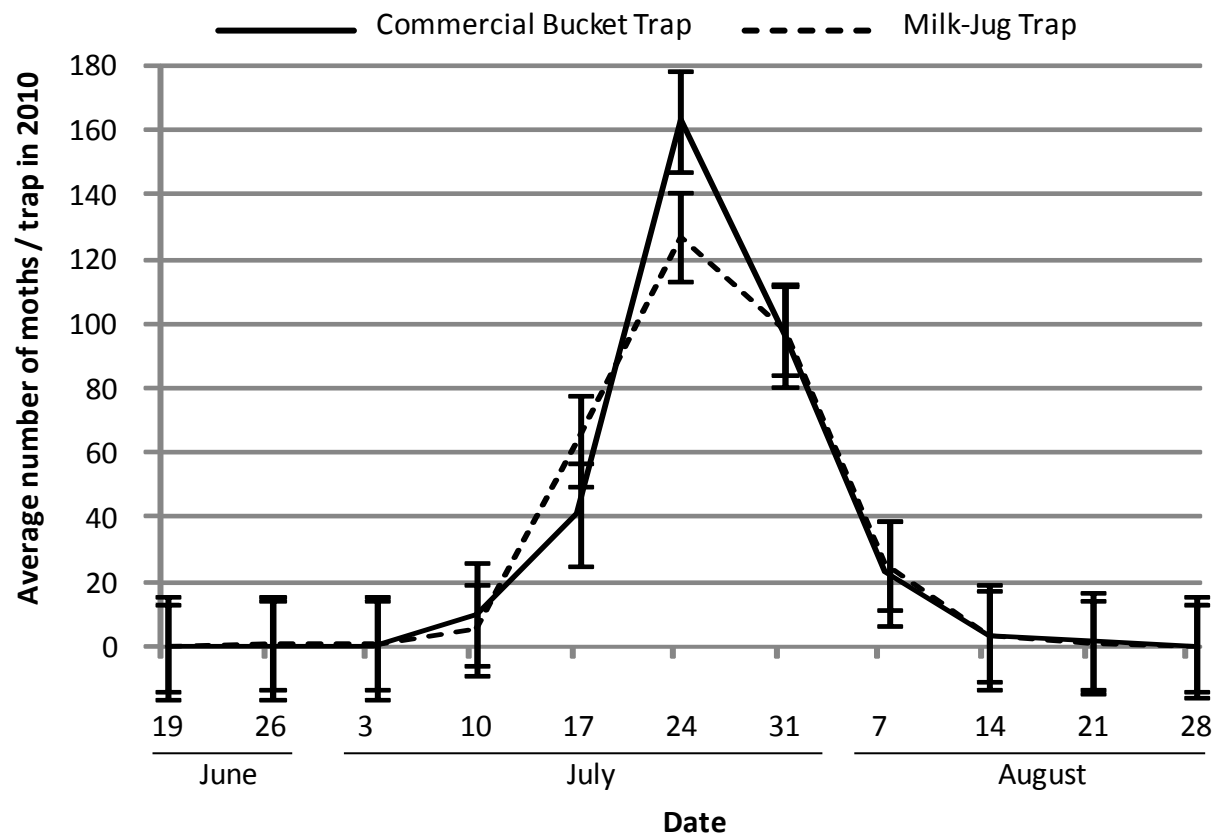
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CHAPTER 3:

BIOLOGY OF WESTERN BEAN CUTWORM (*STRIACOSTA ALBICOSTA* SMITH)
IN MICHIGAN DRY BEANS (*PHASEOLUS VULGARIS* L.)

Abstract

Western bean cutworm (*Striacosta albicosta*, Smith) is native to the western United
States and since 2006 it has become a pest of Michigan dry beans. Since Michigan's climate and
host of vegetation differs from those in the western United States, it became apparent that
research on western bean cutworm's behavior and biology needed to be done to understand
the affect of this pest on local dry bean growers. The objectives of these studies were percent
hatch, potential alternate hosts, distribution and feeding of larvae, and overwintering potential
of western bean cutworm. The percent hatch of western bean cutworm egg masses has
decreased since 2010 due to predators, pathogens, and parasitoids. There is a potential for
larvae to survive on garden peas, gladiolus, gourds, green beans, and squash . Larvae cause
noticeable damage to dry bean blossoms and pods, and as they mature they remain on the
ground during the day and actively feed at night from 22:00 to 5:00 (10:00 pm to 5:00 am).
Prepupae overwinter in at lower depths in sandier soils, and can burrow as deep as 38 cm into
the soil. These findings aided in development of western bean cutworm scouting and control
recommendations for Michigan dry bean growers.

Introduction

The western bean cutworm, *Striacosta albicosta* (Smith), formerly *Loxagrotis albicosta* (Smith) (Lepidoptera: Noctuidae), is native to North America. It was first identified from an Arizona moth collection in 1887 (Smith 1887). By the mid 1950's, the range of western bean cutworm included Arizona, Colorado, Idaho, Iowa, Kansas, Nebraska, New Mexico, Texas, Utah, Alberta Canada, and southern Mexico (Crumb 1956). Beginning in 2000, populations increased and spread across Iowa; the range expanded quickly east to include Illinois, Indiana, Michigan, Minnesota, Wisconsin, and Ontario by 2009 (Michel et al. 2010). Prior to its eastward range expansion in 2000, western bean cutworm was an occasional, but serious, pest of corn and dry beans in the western Great Plains, and this range expansion put many new areas of corn and dry bean production at risk (Michel et al. 2010). Western bean cutworm moths were first trapped in Michigan in 2006 (Chapter 2). The first reports of western bean cutworm damage to Michigan dry beans were received in 2008.

Ovipositing females are initially attracted to late whorl stage field corn (*Zea mays* L.) that is in pre-tassel stage (Seymour et al. 2004). If corn fields have pollinated, or corn is not available, females deposit eggs in dry bean (*Phaseolus vulgaris* L.) (Blickenstaff and Jolley 1982). Female western bean cutworm moths typically oviposit on the underside of dry bean leaves deep within the canopy (Hoerner 1948). Eggs are pearly white when fresh (Hoerner 1948) and turn pale yellow, then purple as they develop (Antonelli 1974). Egg development takes 5 to 7 days (Seymour et al. 2004). Once the eggs hatch, first instars typically consume the egg chorions; this behavior makes it difficult to scout for hatched egg masses (Michel et al. 2010). Hoerner (1948) made preliminary observations that young larvae fed on leaves and buds in dry

beans, and fed on developing pods at night and on cloudy days. He also observed that larvae

burrowed into the soil around the plants when they were not feeding. In late August to early

September, mature larvae drop off the plant and burrow into the soil to form overwintering

chambers constructed out of soil (Seymour et al. 2004). Larvae took approximately 31 days to

reach prepupal stage in laboratory studies (Blickenstaff 1979).

The larvae remain in a prepupal state throughout the winter, then pupate and complete

development in late spring to early summer (Seymour et al. 2004). An overwintering study done

by Hoerner (1948) showed that fewer moths emerged from clay soils than from sandy soils, and

Douglass et al. (1957) found that western bean cutworms caused more damage to beans and

corn grown in sandy loam, than in heavier, soils. Hein and Seymour (2000) reported a greater

proportion of larvae formed overwintering chambers below 10.2 cm (4 inches) in sandy soils

(40%) than in loamy soils (12%). Michel et al. (2010) speculated that it was easier for larvae to

burrow deeper into sandier soil, which provided more protection from cold temperatures and

increased overwintering survival. Hoerner (1948) found that a precipitation even that

moistened the soil at the time of emergence was necessary, in both light textured and heavier

soils, before moths were able to emerge.

Western bean cutworm larvae feed on dry beans, garden beans, and corn (field and

sweet) (Blickenstaff 1979). In a host range study done in Idaho, larvae survived on soybeans

(*Glycine max*, L.) if they originally fed and developed on corn (Blickenstaff and Jolley 1982).

Later-instars could finish development on tomatoes (*Solanum lycopersicum*, L.), ground cherry

(*Physalis pruinosa*, L.), and black nightshade (*Solanum nigrum*, L.) if previously fed on corn or

dry beans (Blickenstaff 1979). Since larvae fed on host plants in the laboratory, there was a potential for western bean cutworm to survive in areas not planted to its known host range and affect other crop industries. This could have a negative impact on Michigan's diverse agricultural production.

The overall objective of this research was to generate up to date, quantifiable, replicated data to better understand aspects of western bean cutworm biology in Michigan. Four specific areas were addressed: percent egg mass survival was followed as western bean cutworm colonized the state to determine if mortality increased over time. Potential larval hosts pertinent to Michigan and Ontario were screened to determine if larvae could feed and survive after 28 to 31 days. The third objective was to determine distribution and activity in dry beans, by instar, to improve scouting for larvae. The last objective was to compare overwintering in a sandy vs. a loamy soil. Identifying where prepupae overwintered successfully has the potential to determine a local range based on soil type. These findings were used to improve management of western bean cutworm in Michigan dry beans.

Materials and Methods

Percent egg hatch

Beginning in 2008, egg masses were hand-collected from naturally infested corn fields in Montcalm County and Oceana County, Michigan. Individual egg masses were cut out of corn leaves on small disks of leaf tissue, kept in a cooler in transit, and used to infest field research trials.   After being pinned to plants, each egg mass was checked daily for hatch, then recovered and examined under a microscope to determine the total number of eggs and percent hatch.

Notes were kept on mortality. The total number of eggs per mass, the number of hatched eggs per mass, and the number of eggs that were discolored and did not hatch was recorded. In 2012, all egg masses were reared individually in small cups (163 mL, SOLO cups, Dart Container Corporation, Mason, MI) to collect larvae for laboratory assays. Egg masses were recovered from cups and examined under a microscope. For each year, the average number and range in eggs per mass was calculated as well as percent hatch and percent parasitism. Parasitized eggs were obvious by the presence of a round emergence hole, but a lack in consuming the chorion.

Potential alternate hosts

In 2010, studies were done in East Lansing, Michigan, United States and Ridgetown, Ontario, Canada to measure survival of western bean cutworm larvae on potential alternate host species tested. At each location, plants were grown in a garden plot, and foliage and reproductive tissues were collected to feed larvae in the laboratory.

In Michigan, 10 different crop species were tested (Table 3.2). Crops included corn, cucumbers, gladiolus, green beans, three varieties of peppers, potatoes, soybeans, squash, and tomatoes. In Ontario, the same crop species, plus two additional species (garden peas and gourds) were tested (Table 3.2). Further, eight dry bean varieties representing eight different dry bean classes and three seed sizes (small, medium, large) were screened (Table 3.3). Corn, peas, and dry beans were positive controls. Other crops were chosen because previous studies (Blickenstaff and Jolley 1982) showed that western bean cutworm developed on legumes as well as weeds in the nightshade family. Gourds and squash were grown with corn and dry beans by Native Americans (aka the 'three sisters'), and it is speculated that this contributed to those crops becoming the original hosts for western bean cutworm (Blickenstaff 1979).

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Gladiolus is an important crop in Southern Michigan, and is attacked by another lepidopteran pest of corn and beans, the European corn borer (Ostrinia nubilalis Hubner). Finally, in Ontario, six weeds that were tested were representative of those species most commonly found in field corn and dry bean cropping systems in the Great Lakes Region.

First instar larvae were hatched from egg masses hand collected from field corn in Montcalm County, Michigan or Bothwell, Ontario, Canada. The larvae were transferred to small cups (150mm x 15 mm , Petri Dish, Fisher Scientific, Waltham, MA) to feed on foliage, with 20 larvae per treatment. Cups were cleaned daily, fresh foliage was added, and filter paper was kept moist to prevent dehydration. Larvae were fed for 28 days in Michigan, or 31 days in Ontario, and percent survival was recorded. The number of dead larvae was recorded, and those larvae were discarded. Larvae that survived were boiled for preservation, and head capsules were measured to determine the average instar per treatment.

Data were subjected to analysis of variance (ANOVA) using Statistix 9.0 (Analytical Software, Tallahassee, FL). Percent survival of larvae on alternate hosts from Michigan and Ontario were combined. Data from the average headcapsule widths were subjected to an ANOVA. A separate ANOVA was performed for dry bean classes. Treatment means were separated using Fisher's LSD ($\alpha \leq 0.05$).

Larval distribution and feeding

To follow western bean cutworm larval distribution and movement in dry beans, a study was done in East Lansing, Ingham County, Michigan in 2010. A 0.81 hectare block of light red kidney bean (cv. California early light red kidney) was planted on 14 June at a rate of 146,491

seeds per hectare with a 76.2 cm (30 inch) row spacing. A fertilizer application of 16-04-08 was

applied at a rate of 224 kg/ha, and the herbicides S-metolachlor (Dual Magnum (1.6 liters/ha),

Syngenta, Greensboro, NC) and halosulfuron methyl (Permit (48 mL/ha), Gowan, Yuma,

Arizona) were applied on 14 June. Fifty individual dry bean plants, in vegetative stage 5 and

reproductive stage 2, were marked and infested with a single egg mass per plant on 19 July.

Plants were spaced 6 m apart within rows, and 8 m apart across rows. In 2011, the experiment

was repeated in Richville, Saginaw County, Michigan. A 0.81 hectare block was planted to black

bean (cv. Zorro black bean) on 10 June at a rate of 41,818 seeds per hectare with 50.8 cm (20

inch) row spacing. A fertilizer application of 17-8-15 plus 1.5% Mn and Zn was applied at a rate

of 336 kg/ha on 10 June. A preplant incorporated herbicide application of S-metolachlor (Dual

Magnum, 2.3 liters/ha, Syngenta, Greensboro, NC) and s S-ethyl dipropylthiocarbamate (Eptam

7E, 4.7 liters/ha, Gowan, Yuma, Arizona) was applied 10 June, while a post emergence herbicide

application of ammonium salt of imazamox (Raptor, 0.2 liters/ha, BASF, Research Triangle Park,

NC), fomesafen sodium salt (Reflex, 0.9 liters/ha, Syngenta, Greensboro, NC), sodium bentazon

(Basagran, 1.2 liters/ha, BASF, Research Triangle Park, NC), crop oil at a rate of 1.8 liters/ha, and

ammonium sulfate at a rate of 7.7 kg / 378 liters was applied prior to infestation. Seventy

individual dry bean plants, in vegetative stage 5 and reproductive stage 1, were marked and

infested with a single egg mass per plant on 20 July or 25 July.

Each year, egg masses were collected from a naturally-infested corn field in Montcalm

County, Michigan. Individual egg masses were cut out of corn leaves on a small disk of leaf

tissue, and kept in a cooler in transit.   That same day, the disks were pinned through the corn

leaf to the lower surface of dry bean leaves in the mid-canopy, where they would typically be

deposited by female moths. Prior to infestation, the blocks of dry beans were scouted before infestation to check for natural infestation; none was found. The masses were checked daily for hatch, and then collected to record the number of eggs per mass and percent hatch using a dissecting microscope. Sets of infested plants were sacrificed and larvae recovered at 1, 3, 5, 10, 14, 21, and 28 days after hatch (DAH). In 2010, the average plant stage was V6-R2 (mid to full flower period) for 1 DAH, V6-R2 for 3 DAH, V7-R3 (early pod set) for 5 DAH, V9-R4 (mid pod set) for 10 DAH, V9-R5 (early seed fill) for 14 DAH, V10-R6 (mid seed fill) for 21 DAH, and V10-R7 (physiological maturity) for 28 DAH. In 2011, the average plant vegetative stage was V9-R1 (one open flower per plant), V8-R1, V10-R2, V10-R2, V10-R2, V11-R3, and V11-R5 for 1, 3, 5, 10, 14, 21, and 28 DAH, respectively. The original infested plant was cut and transferred to a 0.9 x 0.8 m piece of white canvas to prevent any larvae from escaping. The number of larvae recovered and their location on or near the plant (leaves, blossoms, pods, and ground) was recorded. Along the row, 30 cm sections of the row, up to 150 cm from the infested plant in each direction, were cut and transferred to the canvas. These plants were also carefully examined to recover larvae within each 30 cm section. If no larvae were found in one section, further sections were not sampled. To determine if larvae moved across rows, a 30 cm section was cut directly across from the infested plant in both rows, and the number of larvae was recorded. All plants were cut at the base, and the soil was hand sorted for larvae. Larvae were preserved in kerosene-acetic acid-dioxane (KAAD) then transferred to a 70% ethanol solution; larval instar was determined using head capsule width (Antonelli 1974).

The timing of larval activity on dry beans was observed at two locations, East Lansing (cv. CELRK) and Richville, Michigan (cv. Zorro black bean) in 2011 and 2012. At both locations,

barriers were placed around four sets of four dry bean plants. Sets were infested with 5 larvae

each (n=20 for each experiment). Barriers were made by cutting the bottom off of a storage

container (28 liter, Rubbermaid, Atlanta, GA) and placing the container around each plant and

burying the edges with soil to prevent larval escape. Larval location (plant or ground) was

recorded every hour, for 24 hours. A flashlight with a red lens was used for night observations

so larval behavior was not disturbed. After 24 hours, larvae were recovered and preserved in

KAAD and transferred to 70% ethanol; larval instar was determined using head capsule width.

No statistical analysis was performed for the larval distribution studies. For the timing of

larval activity studies, data from each year were subjected to an ANOVA using Statistix 9.0

(Analytical Software, Tallahassee, FL). This was done to determine at what times significantly

more larvae were found on the dry bean plants.

Overwintering study

In 2008 and 2009, western bean cutworm moth catch was higher and reports of dry

bean damage were higher in central Michigan than in the 'Thumb'. Counties in Central

Michigan had a greater tendency towards sandier soil types compared to eastern areas. To

determine if soil type can affect overwintering survival of western bean cutworm pupae, a

study was done in East Lansing in 2010 and in Stanton, Michigan in 2011 and 2012. Two soil

types were compared, a McBride /Isabella sandy loam from Montcalm County, Michigan and a

Tappan Londo loam from Saginaw County, Michigan. Ten nursery pots (23 liter, plastic nursery

pot, 25.4 cm deep x 36 cm diameter) were filled with each soil type. Small holes were drilled in

the bottom for drainage. Each pot was put in the ground, buried to the top edge, and infested

on 20 August with 10 sixth instar larvae. Tomato ring cages (35 cm diameter) with fine netting

(No-See-Um nylon netting, 24 holes/cm^2, Outdoor Wilderness Fabrics Inc., Caldwell, ID) was placed over the pot to prevent larval escape and predation. An ear of field corn was placed in each pot as a source of food, and the larvae were checked daily to make sure they descended into the soil for overwintering. Buckets were hand-pulled on 6 December, 2010 and 11 March, 2011 and the soil was processed by hand on 8 December, 2010 and 14 March, 2011 respectively. The number of larvae found per depth of 2.54 cm was recorded, and the number of larvae found for every 10 cm depth was reported.

In 2011 and 2012, the study was done in Stanton, Montcalm County, Michigan. The same soil types were compared, but the plant pot was replaced with a deeper bucket (50.8 cm deep, 29 cm diameter, 26 liters, Letica Corp., Rochester, MI). To improve drainage, small holes were drilled and a 4 cm layer of pea gravel was included at the bottom of each bucket. In 2011, 20 buckets were filled with soil on 3 June and exposed to weather so natural soil structures could form. A soil auger was used to drill 50.8 cm holes, and the buckets were placed in each hole and buried to the top edge on 6 July. Buckets were infested with western bean cutworm on 16 August and infestation methods were the same as in 2010. The buckets from 2011 were hand-pulled on 1 December, 2011, 19 January, 2012, 14 March, 2012, and 7 May, 2012. In 2012, 10 buckets per soil type were filled with soil on 18 July, put into the ground on 13 August, and infested on 21 August. The buckets from 2012 were hand-pulled on 14 January, 2013. The number of larvae found per depth of 2.54 cm was recorded, and the number of larvae found for every 10 cm depth was reported.

Data were subjected to analysis of variance (ANOVA) using Statistix 9.0 (Analytical Software, Tallahassee, FL). Data from 2011 and 2012 were combined when no significant interactions were present. Treatment means were separated using Fisher's LSD ($\alpha \leq 0.05$).

A voucher collection of western bean cutworm moths and larvae was deposited in The Michigan State University Albert J. Cook Arthropod Research Collection. Voucher recognition labels with the voucher number (2013-1) were attached or included in fluid preserved specimens.

Results

Percent egg hatch

A total of 849 egg masses were collected and counted over a five year period (Table 3.1). Egg masses collected between 2009 and 2012 averaged 57 to 69 eggs per mass, and ranged from a low of 9 eggs to a high of 229 eggs in a single mass. In 2008 and 2009, percent hatch was high, averaging 100% to 98% respectively. In 2010, egg hatch was less, at 84%. For the first time, we observed egg masses with one end 100% emerged (chorions eaten) and the other end had white eggs that did not hatch (eggs appeared not to have been fertilized). In 2011, percent hatch was 90%, and a low rate of parasitism (2%) was observed. Parasitism increased dramatically in 2012, to 19% of eggs. Percent hatch was 42%, 28% of the eggs did not hatch, and 11% of freshly hatched larvae died.

Potential alternate hosts

A total of 29 host plants were fed to western bean cutworm larvae to test their survival on alternate hosts (Table 3.2). Sweet corn and dry beans were used as positive controls because they are known hosts of western bean cutworm. Of the host plants tested in Michigan and

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Ontario, garden peas, hot peppers, squash, cucumber (Eclipse), common lambsquarters, gladiolus, eastern black nightshade, redroot pigweed, green beans, gourds, and soybeans (RR Respond) allowed a statistically similar number of larvae to survive as those that were fed on sweet corn and dry beans (df = 80, F = 5.76, P = 0.0000). Larvae that were fed cucumbers (Straight Eight) had significantly lower percent survival than larvae that were fed sweet corn (df = 80, F = 5.76, P = 0.0000). Larvae that were fed hot peppers (Hot Variety), soybeans (Williams 82), potatoes, tomatoes, peppers, bell peppers, green foxtail, large crabgrass, and velvetleaf had significantly lower percent survival than larvae that were either fed sweet corn or dry beans (df = 80, F = 5.76, P = 0.0000). Eight dry bean classes were tested to see if class or seed size affected larval survival (Table 3.3). No statistical differences in percent larval survival were observed based on dry bean class (df = 15, F = 0.63, P = 0.7246) or dry bean seed size (df = 15, F = 0.47, P = 0.6346).

Larval distribution and feeding

Percent recovery of larvae in the distribution studies in 2010 and 2011 was low (Table 3.4). In both years combined, 22% of larvae were recovered at 1 day after hatch (DAH), 10% at 3 DAH, 1% at 5 to 14 DAH, and 0% at 21 DAH. Average head capsule width increased with each recovery (DAH). The majority of larvae were recovered from dry bean leaves at 1 DAH and 3 DAH, with 57% and 74%, respectively. From 1 to 5 DAH, a large proportion of the larvae (25% to 57%) were recovered from the blossoms. At this time, larvae were first to second instar. After 5 DAH, larvae started to be recovered from the dry bean pods (12.5%) and from the ground

(12.5%). At 14 DAH, all of the recovered larvae were found on the pods (20%) or ground (80%).

At this time, larvae were in their fourth instar.

In the 24 hour larval feeding studies in 2011 and 2012, time of day had a significant effect on larval feeding activity (Figure 3.1). At the Richville site in 2011, significantly more larvae were observed on the dry bean plants from 22:00 to 5:00 than at any other time (df = 95, F = 12.05, P = 0.0000). At the East Lansing site in 2012, significantly more larvae were observed on the plants from 22:00 to 5:00 as well (df = 95, F = 35.20, P = 0.0000). At the Richville site in 2012, significantly more larvae were observed on the plants from 23:00 to 5:00 than at any other time (df = 95, F = 52.79, P = 0.0000). At the East Lansing site in 2011, larval observations were more variable due to a storm and significantly more larvae were observed on the plants from 1:00 to 2:00 and at 6:00 than at any other times (df = 91, F = 3.82, P = 0.0000).

Overwintering study

The overwintering study was done in 2010, 2011, and 2012 to determine how well western bean cutworm overwinter in Michigan soils (Table 3.5). In 2010, more prepupae were recovered at a depth of 15 to 25 cm in sandy soil than at a depth of 3 to 13 cm. Depth of prepupal recovery had no significant effect in the loamy soil. In the shallow depth (3 to 13 cm), more prepupae were recovered in the loamy soil than in the sandy soil. In the lower depth (15 to 25 cm), more prepupae were recovered in the sandy soil than in the loamy soil.

In 2011 and 2012, more prepupae were recovered at a depth of 28 to 38 cm than at any other depth in the sandy soil. More prepupae were recovered at a depth of 15 to 25 cm than at

any other depth in the loamy soil. At a depth of 15 to 25 cm, more prepupae were recovered in the loamy soil than in the sandy soil.

Discussion

Percent survival of western bean cutworm egg masses decreased from 100 % in 2008 to 42% in 2012 (Table 3.1). This decrease in survival was also seen in Nebraska in 2011, when a small proportion of eggs hatched (5%) due to high temperatures, drought, and lack of irrigation (Moraes 2012). Fungal pathogens affecting western bean cutworm eggs and larvae were first observed in 2010. In 2011, the first observations of *Trichogramma* parasitism on egg masses were made. In 2012, rearing every egg mass separately, and tracking percent hatch and larval survival allowed for more reliable observations on western bean cutworm survival. Since 2010, observations of predators such as minute pirate bug (*Amphiareus obscuriceps*, Poppius), lacewing larvae (Chrysopidae), and lady beetle larvae (Coccinellidae) eating western bean cutworm eggs and larvae, have been made in the field. Blickenstaff (1979) found that insects in the families' coccinelidae, anthocoridae, nabidae, lygaedae, and chrysopidae often fed on western bean cutworm larvae. Other observations of western bean cutworm predation by pirate bugs, lady beetles, lacewings, and predacious ground beetles have been made as well (Seymour et al. 2004, Krupke et al. 2009, Cullen and Jyotika 2008). In 2012, it was obvious that many egg masses did not hatch, some due to parasitism. Western bean cutworm is susceptible to infections caused by *Nosema* spp. (a parasitic microspridium) (Blickenstaff 1979, Seymour et al. 2004, Cullen and Jyotika 2008, Michel et al. 2010). An in depth study, replicating individual egg mass rearing, and assessing egg and premature larval mortality, would be beneficial. It is

important to note that all egg masses were collected from corn fields, and additional research should be done to determine if egg masses in dry bean fields are affected by the same factors.

The alternate host studies tell us western bean cutworm larvae have the potential to complete development on other hosts besides dry beans and corn. There is a possibility for larvae to survive on certain weed species such as eastern black nightshade, lambsquarters, and redroot pigweed. If that is the case, western bean cutworm could survive in areas not planted to corn or dry beans or these weeds could offer a refuge in treated areas. In both locations, larvae had high percent survival in gladiolus, which is produced in Southern Michigan. Western bean cutworm has the potential to negatively affect this industry. Additional studies should be done to replicate these findings. Further study should be done to compare larval survival in different dry bean cultivars and varieties. It is possible certain varieties within dry bean classes that were tested are more resistant to feeding, and host plant resistance could be another method of controlling western bean cutworm.

More first and second instar larvae were found on leaves and blossoms of dry beans than on pods or the ground in the larval distribution studies. As larvae matured (third to fourth instar), more were found on pods and the ground. It was easier to find first instar larvae at 1 DAH to 5 DAH, when percent recovery was 1% to 22%. It is important to note that recovered larvae were very small and mostly found within plant tissue. Larval recovery was also low in other studies where it ranged from 2% to 16% in Nebraska from 2009 to 2011 (Moraes 2012).

From these findings we can assume first instar larvae look for cover on dry bean plants and do not move to the ground. As larvae mature, they begin to seek cover on the ground and

move along rows to feed on reproductive tissues. Hoerner (1948) had similar findings of larvae burrowing into the soil around the plants when they were not feeding. Larvae were able to disperse long distances within dry bean rows, and were less likely to disperse across rows. When larvae were on the ground, it was extremely difficult to find them, and only feeding injury was noticeable. Feeding injury to blossoms and/or pods are reliable signs of western bean cutworm larvae in dry bean fields. In blossoms, a pin-hole was observed and larvae were found inside the blossom. Once pods developed, larvae were difficult to find on plants. Small holes were seen on young pods, and older pods had large holes with half-eaten and missing beans. Frass from western bean cutworm larvae was observed in older pods. Michel et al. (2010) stated that older larvae feed on and inside pods, decreasing yield and quality, and allowing entry of fungal and bacterial pathogens. Based on these results, it is obvious scouting for western bean cutworm larvae in dry beans is extremely difficult and should not be used for western bean cutworm management. It raises the question, when are western bean cutworm larvae actively feeding in dry beans?

In the larval feeding activity study, findings show that western bean cutworm larvae are most active from 22:00 to 5:00 (10:00 pm to 5:00 am). This is most likely due to larvae seeking cover on the ground from the sun and predators during the day (Antonelli 1974, Hoerner 1948). Because of this, scouting for western bean cutworm larvae is nearly impossible and unreliable in dry beans and should not be used.

In the overwintering studies, it is obvious that prepupae are able to overwinter at lower depths in sandy soil than in loamy soil. It is also important to note that prepupae were found

deeper (28 to 38 cm) than the 12 – 25 cm burrowing depth reported for Nebraska (Seymour et al. 2004). It is also interesting to note that significantly fewer prepupae were recovered at 41 to 51 cm, which suggests that western bean cutworm do not prefer to overwinter in soil deeper than 38 cm. Western bean cutworm overwintering success due to soil type in Michigan is likely similar to its success in the western United States, where significantly more prepupae survive in sandy soils than loam soils (Hein and Seymour 2000, Seymour et al. 2004).

These findings give dry bean growers in Michigan a better understanding of how western bean cutworm behaves and affects their crop. Natural enemies such as fungal pathogens, predators, and parasitoids may be adding to the efforts to manage western bean cutworm in Michigan. It is now known that larvae may survive on other hosts, and it would be beneficial to monitor those hosts for potential western bean cutworm feeding injury. Through the larval feeding behavior studies, it is now known that larvae cause noticeable injury to dry bean blossoms and pods, but are difficult to scout because they actively feed at night and spend the day on the ground and in the soil. It is still plausible that western bean cutworm larvae have better overwintering success in sandy soils with adequate drainage, and additional studies should be done to quantify this. This research has been used in developing scouting methods, management recommendations, and control methods for western bean cutworm in Michigan dry beans.

Figures and Tables:

Table 3.1: Average number of western bean cutworm eggs per mass and percent hatch in Michigan, 2008 – 2012.

Year	N	Average # eggs/mass	Range # eggs/mass	% eggs hatched	% eggs unhatched	% larvae died[2]	% parasitized[3]
2008[1]	48	-	-	100	-	-	-
2009	64	57 ± 3	16-127	98	2	-	-
2010	226	68 ± 2	9-183	84	16	-	-
2011	174	77 ± 2	16-229	90	10	-	-
2012	337	69 ± 3	18-211	42	28	11	19

[1] Egg masses not counted in 2008, but all had 100% hatch

[2] Neonates died within 24 hours after hatch

[3] *Trichogramma* sp.

Table 3.2: Percent survival and development of western bean cutworm larvae after 28 days (Michigan - MI) and 31 days (Ontario - ON) on potential alternate hosts in a laboratory study, 2010.

| Species tested | Site | Cultivar | % Survival[1] | Head capsule measurement[2] | |
				# Measured[3]	Avg. width mm (Instar)[4]
garden peas (*Pisum sativum* L.)	ON	Spring	100	-	-
pepper (*Capsicum annuum* L.)	ON	Hot Hungarian	100	-	-
squash (*Cucurbita moschata* L.)	ON	Mesa Queen	100	-	-
sweet corn (*Zea mays* L.)	MI	unknown	90	19	3.5 (6)
dry bean (*Phaseolus vulgaris* L.)	ON	OAC Thunder	86	-	-
cucumber (*Cucumis sativus* L.)	ON	Eclipse	80	-	-
common lambsquarters (*Chenopodium album* L.)	ON	n/a	75	-	-
gladiolus (*Gladiolus hyridus* L.)	MI	Firecracker	75	12	2.9 (6)*
gladiolus (*Gladiolus hyridus* L.)	ON	Nova Lux	71	-	-
eastern black nightshade (*Solanum ptycanthum* L.)	ON	n/a	70	-	-
redroot pigweed (*Amaranthus retroflexus* L.)	ON	n/a	65	-	-
squash (*Cucurbita moschata* L.)	MI	Heritage	65	11	2.5 (5)*

Table 3.2 (cont'd)

Species tested	Site	Cultivar	% Survival[1]	Head capsule measurement[2]	
				# Measured[3]	Avg. width mm (Instar)[4]
green beans (*Phaseolus vulgaris* L.)	MI	Greencrop	60	7	3.3 (6)
cucumber (*Cucumis sativus* L.)	MI	Straight Eight	55*	5	2.1 (5)*
gourd (*Cucurbita pepo* L.)	ON	Autumn Wings	55	-	-
soybean (*Glycine max* L.)	ON	RR Respond	55	-	-
gladiolus (*Gladiolus hyridus* L.)	ON	Huntingsong	50	-	-
green beans (*Phaseolus vulgaris* L.)	ON	Tendergreens	50	-	-
pepper (*Capsicum annuum* L.)	MI	Hot Variety	40**	5	2.2 (5)*
soybean (*Glycine max* L.)	MI	Williams 82	40**	3	1.9 (5)*
potato (*Solanum tuberosum* L.)	ON	Norland	35**	-	-
tomato (*Solanum lycopersicum* L.)	ON	H9909	35**	-	-
tomato (*Solanum lycopersicum* L.)	MI	Better Boy	10**	2	1.9 (5)*
pepper (*Capsicum annuum* L.)	MI	Carnival	5**	1	1.3 (4)*
bell pepper (*Capsicum annuum* L.)	ON	Aristotle	0**	-	-

Table 3.2 (cont'd)

Species tested	Site	Cultivar	% Survival[1]	Head capsule measurement[2]	
				# Measured[3]	Avg. width mm (Instar)[4]
green foxtail (*Setaria viridis* L.)	ON	n/a	0**	-	-
large crabgrass (*Digitaria sanguinalis* L.)	ON	n/a	0**	-	-
potato (*Solanum tuberosum* L.)	MI	Atlantic	0**	-	-
velvetleaf (*Abutilon theophrasti* L.)	ON	n/a	0**	-	-

[1]Values followed by an asterisk are significantly less than percent survival on known host(s) sweet corn (*)
or sweet corn and dry bean (**), (LSD, P ≤ 0.05)

[2]Methods for determining head capsule width and corresponding instar as in Antonelli 1974

[3]Head capsules were only measured on larvae that survived in Michigan

[4]Values followed by an asterisk had significantly smaller head capsule width than those in known host sweet corn (*), (LSD, P ≤ 0.05)

Table 3.3: Percent survival of western bean cutworm larvae after 31 days (Ontario) on eight dry bean classes in a laboratory study, 2010.

Dry bean class[1]	Seed size	Cultivar	% Survival[2]
white	small	OAC Thunder	86a
adzuki	small	Erimo	85a
cranberry	large	Enta	80a
dark red kidney	large	Majesty	75a
pinto	medium	Lapaz	75a
black	small	Zorro	65a
otebo	medium	Hime	60a
light red kidney	large	Pink Panther	49a

[1] All are *Phaseolus vulgaris* (L.), except for adzuki (*Vigna angularis* Willd)

[2] In column, means followed by the same letters are not significantly different (LSD, P ≥ 0.05)

Table 3.4: Percent recovery 1 to 21 days after hatch (DAH) of western bean cutworm larvae on individual dry bean plants infested with an egg mass, in Michigan, 2010 and 2011.
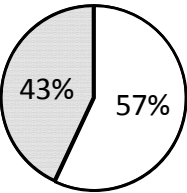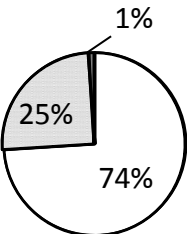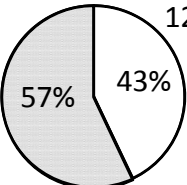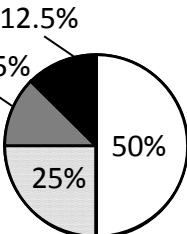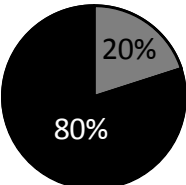
	1 DAH	3 DAH	5 DAH	10 DAH	14 DAH	21 DAH
% recovery overall	22	10	1	1	1	0
average head capsule width, mm (instar)	0.36 (1)	0.47 (1)	0.50 (2)	0.94 (3)	1.63 (4)	-
% recovery by location (of recovered larvae)						-

□ on leaves   ▨ in blossoms   ▨ on pods   ■ on ground

Table 3.5: Total number of western bean cutworm prepupae recovered by depth, and soil type, from buckets filled with two soil types, a sandy loam (McBride/Isabella sandy loam) and a loam (tappan londo loam), Montcalm County, Michigan 2010-2012.

	2010					2011 and 2012				
Depth cm	Sand	Loam	df	F	P	Sand	Loam	df	F	P
3 to 13	22b	43a*	19	9.10	0.0145	6bc	5c	51	0.16	0.6906
15 to 25	78a*	57a	19	9.10	0.0145	31b	65a*	51	12.32	0.0010
28 to 38	-	-	-	-	-	61a	30b	51	2.53	0.1177
41 to 51	-	-	-	-	-	3c	0c	51	1.00	0.3221
df	19	19	-	-	-	103	103			
F	16.96	0.11	-	-	-	8.11	23.71			
P	0.0026	0.7446	-	-	-	0.0001	0.0000			
% larvae recovered	23	46	-	-	-	14	17			

[1] In columns, means followed by different lower case letters are significantly different (LSD, $p < 0.05$)

[2] In rows, means followed by different upper case letters are significantly different (LSD, $p < 0.05$)

Figure 3.1: Percentage of western bean cutworm larvae recovered on dry bean plants over 24 hours in East Lansing and Richville, Michigan, 2011 and 2012
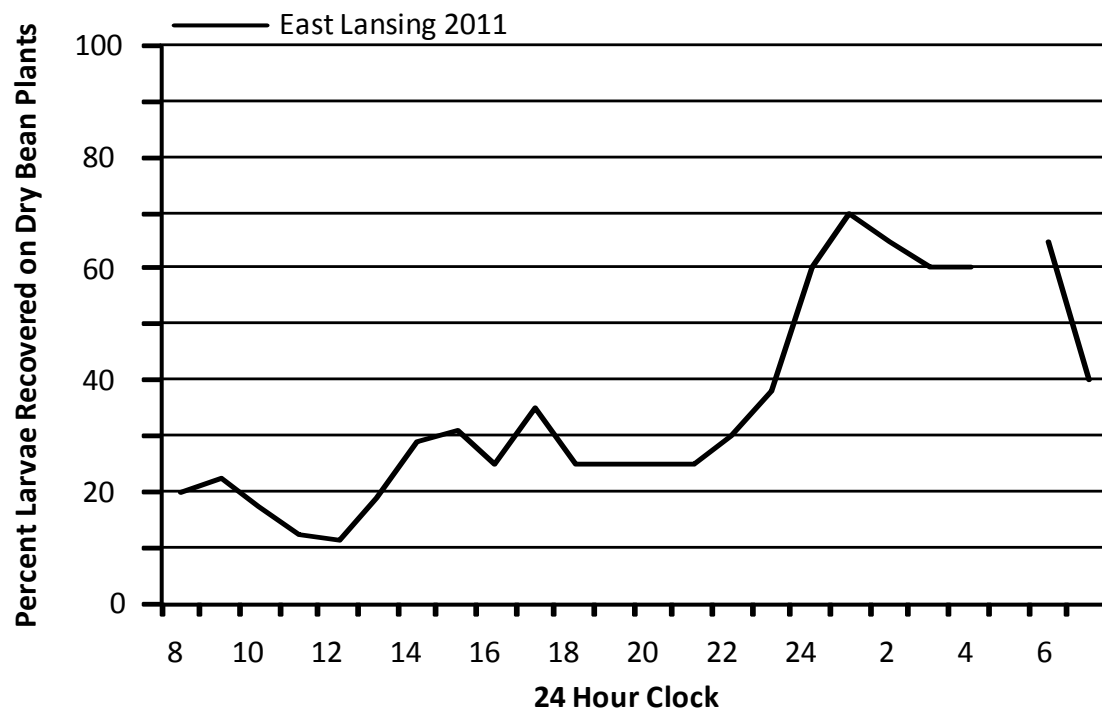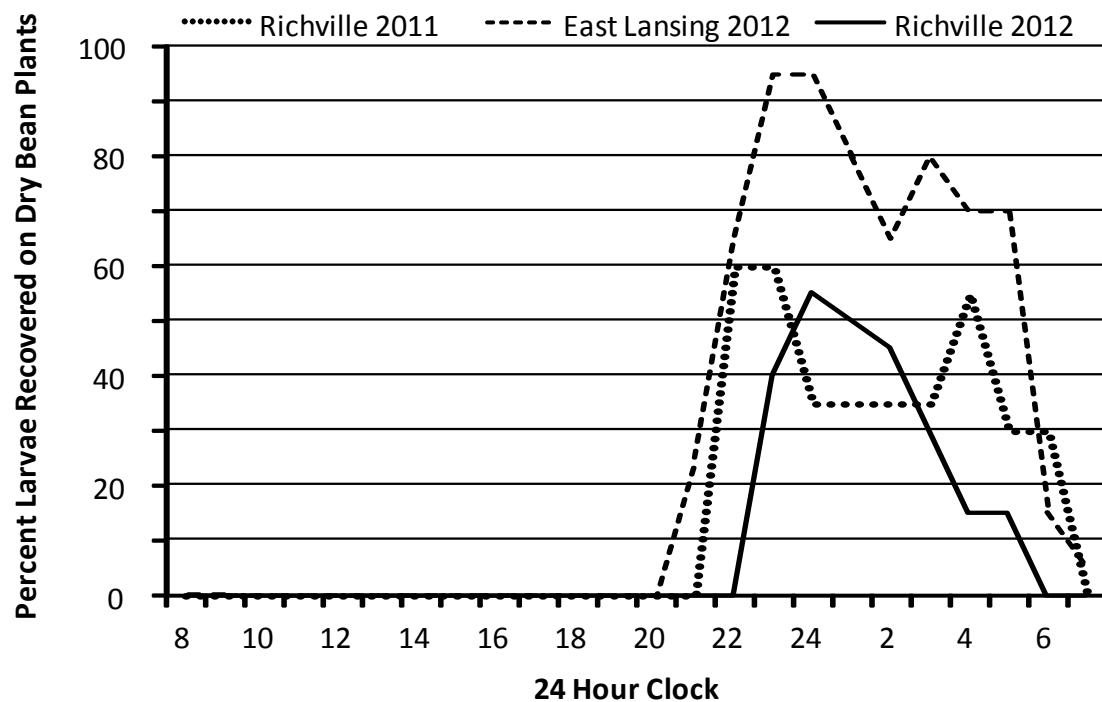
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CHAPTER 4:

IMPACT OF WESTERN BEAN CUTWORM (*STRIACOSTA ALBICOSTA* SMITH) INFESTATION LEVEL
AND INSECTICIDE TREATMENT ON SEED DAMAGE AND MARKETABLE YIELD
OF MICHIGAN DRY BEANS (*PHASEOLUS VULGARIS* L.)

Abstract

The western bean cutworm, *Striacosta albicosta* (Smith), is a pest of corn and dry beans and native to the western United States. Since then, its range expanded to include the Great Lakes Region of the United States and Canada. Objectives were to correlate egg mass and larval populations with dry bean damage, determine the optimal method and timing of insecticide application, and determine how long pyrethroid residues provided larval control on dry bean foliage. As few as 1 egg mass per 1.5 m of row, or 2 or more larvae per 0.3 m of row, caused 0.8% to 2.7% pick (damage to beans) in dry beans. This can reduce quality of dry beans, resulting in additional processing and costs. After testing application methods of thiamethoxam, phorate, aldicarb, and λ-cyhalothrin, the best insecticide application method to control western bean cutworm was a foliar application of λ-cyhalothrin. Pyrethroids offer the most reliable management of western bean cutworm in dry beans. The best time to apply λ-cyhalothrin to control western bean cutworm was 1-2 weeks after peak flight. One well-timed spray was equally as effective as multiple spray applications. Insecticide residues from λ-cyhalothrin effectively controlled western bean cutworm larvae for a minimum of 14 days. These findings were used to develop western bean cutworm management recommendations for Michigan dry bean growers.

Introduction:

The western bean cutworm, *Striacosta albicosta* (Smith) (Lepidoptera: Noctuidae), is a dry bean (*Phaseolus vulgaris* L.) and corn (*Zea mays* L.) pest native to the western United States. It was first described from a moth collection in 1887 in Arizona (Smith 1887). Feeding by western bean cutworm larvae on dry beans was first observed in 1915 in Colorado (Hoerner 1948). By the 1950's, western bean cutworm was recorded as a pest of dry beans in Colorado, Idaho, Kansas, and Nebraska (Hoerner 1948, Douglass et al. 1957). In the 1990's, its range expanded first into Iowa, where it attacked field corn (Rice 2000), then into the Great Lakes region in the early 2000s. Western bean cutworm moths were first detected in Michigan and Ohio in 2006 (DiFonzo and Hammond 2008). By 2010, there were larval infestations in corn in Indiana, Illinois, Michigan, Minnesota, Ohio, Wisconsin, and Ontario (Michel et al. 2010), and damage to dry beans in Michigan in 2008.

Western bean cutworms overwinter as prepupae in the previous years' infested fields. Pupation occurs in the spring, and moths begin to emerge in June (Chapter 2). In Idaho and Iowa, peak flight occurred at the end of July (Blickenstaff 1979, Dorhout and Rice 2008). In Michigan, peak flight occurred as early as mid-July to early August, depending on the season (Chapter 2). In dry beans, females lay egg masses on the undersides of the leaves in the middle of the canopy (Hoerner 1948, Blickenstaff 1983). Hoerner (1948) observed that first instar larvae fed on blossoms or small pods; more mature larvae fed on dry bean pods at night or on cloudy days. When not feeding, larvae were found in the soil around dry bean plants (Hoerner 1948). Pod feeding can result in damaged beans, which not only reduces yield, but contributes

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to 'pick', the percentage on a weight basis of defects (split, shriveled, discolored, and damaged beans plus foreign material) from any cause, in a sample (USDA-FCIC 2010). Dry bean processors expect 1% to 2% pick in a dry bean load, but just 0.5% to 1% additional pick – for instance, from insect feeding - can result in extra handling time and cleaning costs to sort damage from whole beans (Fred Springborn, Michigan State University Extension, personal communication). More importantly, western bean cutworm feeding in particular can impact dry bean quality, as beans with minimal chewing may be difficult to sort and can end up in finished product.

In the western United States, insecticides have been used since the 1940's to manage western bean cutworm in dry beans (Blickenstaff and Peckenpaugh 1981). Prior to 1970, organochlorines including DDT significantly reduced pick when applied after moth flight (Blickenstaff and Peckenpaugh 1981). After 1980, pyrethroids replaced older chemistry and provided effective control, again when applied after peak moth flight (Blickenstaff and Peckenpaugh). To correlate moth flight to dry bean damage, Blickenstaff (1979) found that a total catch of 700 or more moths per light trap by 25 July correlated to at least 2% pick in nearby fields. Others later applied this correlation to pheromone traps, categorizing averages of 700-1000 and > 1000 moths per trap as 'moderate' and 'high risk', respectively, of dry bean damage in neighboring fields (Seymour et al. 2004, Peairs 2008). Management guidelines were also developed based on larval sampling. In Nebraska and Colorado, a threshold of two or more larvae per foot (0.3 m) of row was used to time sprays (Seymour et al. 2004, Peairs 2008). Another strategy was to look for pod feeding; if a significant amount was observed, an insecticide application was recommended in Nebraska (Seymour et al 2004).

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Michigan is the second largest dry bean producer in the United States with 79,723 hectares produced in 2012 (USDA-NASS 2012). The state leads in production of black, small red, and cranberry beans (USDA-NASS 2012). The establishment of western bean cutworm in Michigan was a significant threat to dry bean production and quality in the state. Most of the observations on its biology and behavior, and management recommendations were made at least 40 to 50 years ago, in the western United States. Some western management guidelines did not fit initial observations in Michigan. For example, significantly more than 2% damage was found in fields with only 120 moths per trap (Michel et al. 2010), many times fewer moths than the 700-1000 per trap categorized as moderate risk in Nebraska (Seymour et al. 2004). Since recommendations from the western United States did not appear to translate well to Michigan, our objectives were to determine the relationship between western bean cutworm infestation and damage in the state, and to investigate methods and timing of insecticide applications to reduce pick.

Materials and Methods:

Egg mass and larval infestation studies

To determine the relationship between infestation and damage, separate field trials were conducted, varying the number of egg masses or larvae, in dry bean plots in 2008 and 2009. Treatments in all studies were replicated four times and arranged in a randomized complete block design. In both years, study sites were scouted weekly after emergence for western bean cutworm egg masses and larvae prior to the experimental infestation; no background population was observed.

In 2008, trials were done in East Lansing, Ingham County, Michigan in a field of black bean (cv. Jaguar). Plots measuring 5 m x 1.5 m (2 rows) were planted on 29 May at a rate of 261,820 seeds per hectare with 76.2 cm row spacing. A standard 12-12-12 fertilizer was applied at a rate of 224 kg/ha at planting. Rototilled borders of 4.6 m were maintained to reduce larval movement among plots. A herbicide application of S-metolachlor (Dual Magnum, 46.2 g/ha, Syngenta, Greensboro, NC) and halosulfuron methyl (Permit, 48 mL/ha, Gowan, Yuma, Arizona) was made at planting. A post-emergence herbicide application of fomesafen (Flexstar, 1.2 liters/ha, Syngenta, Greensboro, NC), clethodim (SelectMax, 0.7 liters/ha, Valent, Dublin, CA), and surfactant (Herbimax COC, 1%, Loveland Products, Loveland, CO) was made on 10 July. No insecticide applications were made. Only 14 moths were trapped at this location, but plots were artificially infested with eggs or larvae during the week of peak pheromone trap catch at other locations in the state.

In 2009, studies were done near Sheridan, Montcalm County, Michigan in a field of kidney bean (cv. California early light red kidney – CELRK). Plots measuring 6 m x 3 m (4 rows) were planted on 15 June at a rate of 146,434 seeds per hectare with 76.2 cm row spacing. A standard 12-12-12 fertilizer was applied at a rate of 224 kg/ha at planting. Rototilled borders of 4.6 m were maintained to reduce larval movement between plots. A pre-plant incorporated herbicide application of S-ethyl dipropylthiocarbamate (Eptam 7E, 2.9 liters/ha, Gowan, Yuma, Arizona), ethalfluralin (Sonalan HFP, 1.2 liters/ha, Dow AgroSciences, Indianapolis, IN), and alachlor (Intrro, 4.7 liters/ha, Monsanto, St. Louis, MO) was made on 15 June. A foliar application of sodium bentazon (Basagran, 0.9 liters/ha, BASF, Research Triangle Park, NC), fomesafen (Reflex, 1.2 liters/ha, Syngenta, Greensboro, NC), and crop oil (1.2 liters/ha) was

done on 7 July. The insecticide dimethoate (Loveland Products, 1.2 liters/ha, Loveland, CO) was

applied on 7 July to control potato leaf hopper, *Empoasca fabae* (Harris). Plots were artificially

infested with cutworm eggs or larvae the week prior to peak moth catch at the site.

Egg mass trial: In 2008, both rows in every plot were infested with 0, 1, 2, or 3 egg

masses per 1.5 m of row. Plots were infested on 25 July, when plants were in the R2 (mid to full

flower) stage. Egg masses were collected earlier that same day from a naturally-infested corn

field in Oceana County, Michigan. Individual egg masses were cut out of corn leaves on a small

disk of leaf tissue, and kept in a cooler in transit.   Egg masses were pinned through the corn

leaf disk onto the lower surface of dry bean leaves in the mid-canopy, where they would

naturally be deposited by moths. Egg masses were recovered after hatch and examined under a

microscope to determine percent hatch. In 2009, all rows in every plot were infested with 0,

0.5, 1, 2, or 3 egg masses per 1.5 m of row. Plots were infested on 28 July, when plants were in

the R4 (mid pod set) stage. Egg masses were collected earlier that same day from a corn field in

Oceana County, and transported and pinned on dry beans as in 2008.

Plots were harvested on 11 September, 2008 and 24 September, 2009. Each year, the

center 3 m of one row per plot was hand-pulled and processed in the field with a stationary

large-plot thresher (Almaco, Nevada, IA). Weight of the sample was recorded, and a 250 g

subsample was saved for hand-sorting to determine the proportion of cutworm-damaged

versus whole beans by weight (pick). This percent pick was used to adjust (i.e. dock) the sample

yield to calculate kg/ha marketable yield in each plot. The center 3 m of the second row in each

plot was hand-pulled, bagged, and processed by hand in the laboratory. All pods were removed

and classified as whole or damaged. The whole-pod sample was run through the Almaco thresher and the beans weighed to determine yield. The damaged-pod sample was much smaller, so it was processed through a table-top thresher (Taylor Manufacturing Co., Moultrie, GA). Damaged and whole beans from these damaged pods were separated, counted, and weighed. The weight of the whole beans from the damaged pods was added to the weight of the whole beans from the whole pods, and this weight was used to directly calculate kg/ha marketable yield in each plot. The damaged beans from the damaged pods were weighed to determine the percent pick in each plot.

Larval Trial: In both 2008 and 2009, all rows in every plot were infested with 0, 2, 4, or 8 larvae per 0.3 m of row. Plots were infested on 26 July, 2008, when plants were in the R2 (mid to full flower) stage, and on 28 July, 2009 when plants were in the R4 (mid pod set) stage. Larvae for infestation were hatched from field-collected egg masses in the laboratory, and fed for two to three days (approximately second instar at infestation). In 2008, larvae were placed on the lower surface of dry bean leaves in the mid-canopy with a small paintbrush. In 2009, the appropriate number of larvae for each row was placed in a small cup for transport to the field. Larvae were distributed along each row on mid-canopy leaves, using a small paintbrush.

In 2008, plots were harvested on 10 September. The center 1.5 m of each row was hand-pulled, combined (total of 3 m harvested), bagged, and processed by hand in the laboratory. All pods were removed and classified as whole or damaged. The whole-pod sample was run through the Almaco thresher and the beans weighed to determine yield. The smaller damaged-pod sample was processed through the table-top thresher, and the yield separated

into damaged or whole beans. As described previously, the weights of the whole beans from damaged and whole pods were added and the total used to directly calculate kg/ha marketable yield in each plot. Damaged beans from the damaged pods were weighed to determine the percent pick in each plot. In 2009, plots were harvested on 24 September. One center-row was hand-pulled and processed in the field with the Almaco thresher. As described for the egg mass studies, percent pick in a 250 g subsample was used to adjust (dock) the sample yield from each plot before calculating kg/ha marketable yield. The second center-row was hand-pulled, bagged, and processed by hand in the laboratory as in 2008 to separate damaged pods and beans. Weight of whole beans was used to directly calculate kg/ha marketable yield, and weight of damaged beans to determine the percent pick, in each plot.

Insecticide application studies

Application method: To compare insecticide application methods for western bean cutworm, a study was done in 2009 in Sheridan, Montcalm County, Michigan in the same field as the egg mass and larval studies. Plot size, variety, planting date, experimental design, borders, and pesticide applications were the same as in the egg mass and larval studies. Again, plots were scouted prior to infestation to determine if a natural population was present; none was observed.

Five treatments were replicated four times in a randomized complete block design. One treatment was a seed-applied insecticide thiamethoxam (Cruiser 5FS, 83.5 mL/100kg of seed, Syngenta Crop Protection, Greensboro, NC). This treatment was expected to have no impact on cutworm damage, but it was included because of the increased use of seed treatments in dry

bean production. Two treatments were soil-applied insecticides, aldicarb (Temik 15G, 5.6 kg/ ha in-furrow, Bayer CropScience, Research Triangle Park, NC) and phorate (Thimet 20G, 11.4 kg/ha t-banded, AMVAC, Los Angeles, CA). Both were used by dry bean growers in central Michigan for early-season leafhopper control. Aldicarb application was previously shown to increase infestation and damage by larvae of two other lepidoperans, *Heliothis zea* and *H. virescens*, in cotton and soybean (Ridgway et al. 1967, Kinzer et al. 1977, Morrison et al 1979). The fourth treatment was a foliar application of the pyrethroid λ-cyhalothrin (Warrior, 234 mL/ha, Syngenta Crop Protection, Greensboro, NC) made on 4 August when plants were in the R4 stage.   The foliar treatment was applied four days after plots were artificially infested with western bean cutworm (see below). The fifth treatment was an untreated check.

On 31 July, as moth catch peaked in pheromone traps at the site, plots were infested with western bean cutworm at a rate of 1 egg mass per 1.5 m of row. Egg mass collection and infestation methods were identical to those used in the egg mass infestation studies. Plots were harvested on 24 September, 2009. Harvest methods to determine percent damaged pods and beans, and marketable yield were the same as those in the egg mass infestation studies.

Spray timing: To determine the optimal number and timing of foliar sprays to control western bean cutworm, a study was done in a portion of a commercial dry bean field in Amble, Montcalm County, Michigan. Plots measuring 6 m by 2.5 m (4 rows) were planted to kidney bean (cv. CELRK) on 11 June, 2010, at a rate of 166,972 seeds per hectare with a 76.2 cm row spacing. A standard 12-12-12 fertilizer was applied at a rate of 224 kg/ha at planting. Rototilled borders of 4.6 m were maintained to reduce larval movement among plots. An application of S-

metolachlor (Dual Magnum, 1.6 liters/ha, Syngenta, Greensboro, NC) and halosulfuron methyl (Permit, 46 g/ha, Gowan, Yuma, Arizona) was done at planting. No insecticide applications were made except for the treatments given below.

Six treatments were replicated four times in a completely randomized design. All rows in all plots were infested with western bean cutworm egg masses on 23 July, at a rate of 1 egg mass per 1.5 m of row. The timing of infestation corresponded to peak moth catch in pheromone traps at the site. After infestation, one treatment was never sprayed. Four treatments were sprayed with single applications of λ-cyhalothrin (234 mL/ ha) at 4, 11, 18, or 25 days after infestation (DAI) (27 July, 3 Aug, 10 Aug, and 17 Aug, respectively). The sixth treatment was sprayed at all of these timings (total of four sprays). Plant stages were R4 (mid pod set) and R5 (early seed fill) for 4 – 11 DAI and 18 – 25 DAI, respectively. Plots were harvested on 10 September, 2010. Harvest methods to determine percent damaged pods and beans and marketable yield among treatments were the same as those described in the egg mass infestation studies.

Insecticide residue: To determine how long λ-cyhalothrin residue lasted in the field, a block of black beans (cv Zorro) was planted on 13 June, 2012 in Richville, Michigan. Four replications of 1.5 m by 2.5 m plots were arranged in a completely randomized design. Before insecticide was applied, exposed trifoliates were marked with flagging tape for later foliage collection. A compressed-air backpack sprayer was used to apply λ-cyhalothrin at a rate of 234 mL/ha to each plot. Five treatments consisted of an untreated control and applications of λ-cyhalothrin 1, 5, 7, or 14 days before feeding (DBF) leaflets to larvae in the residue study. Two

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trials were done in separate parts the field, one week apart for replication. For the first trial, dry bean plant stages at time of application had not reached bloom. One day after the final spray, pre-marked leaves were collected, brought to the laboratory, and leaflets were placed individually into small plastic cups (163 mL, SOLO cup, Dart Container Corporation, Mason, MI). A piece of moist filter paper was placed at the bottom of each cup. One second-to-third instar western bean cutworm larva was placed in each cup and there were four cups per plot and four plots per treatment (n = 16 for each treatment). After 24 and 48 hours, the number of surviving larvae was recorded and percent survival was calculated.

Statistics: Data were subjected to analysis of variance (ANOVA) using Statistix 9.0 (Analytical Software, Tallahassee, FL). For the egg mass and larval infestation studies, data from 2008 and 2009 were combined when no significant interactions were present. Treatment means were separated using Fisher's LSD ($\alpha \leq 0.05$). A voucher collection of western bean cutworm moths and larvae was deposited in The Michigan State University Albert J. Cook Arthropod Research Collection.

Results:

Egg mass and larval infestation studies

One or more western bean cutworm egg masses per 1.5 m of row resulted in a significantly higher percent of pods damaged; nearly 22% of the pods were fed on in plots with this level of infestation (Table 4.1). The treatment of 1 egg mass per 1.5 m resulted in significantly more damage to pods and beans that were processed by hand than in plots that were not infested. Two egg masses per 1.5 m resulted in significantly more damage to beans

that were processed with the Almaco thresher than in plots that were not infested. The treatment of 2 egg masses also resulted in significantly lower marketable yield in rows that were processed by hand than in plots that were not infested. The egg mass treatments had no effect on marketable yield in rows processed with the Almaco thresher. A small amount of damage to pods and beans was found in plots that were not intentionally infested, which may have been caused by plot-to-plot movement of western bean cutworm larvae or a low background infestation at the study site.

As few as 2 larvae per 0.3 m of row resulted in significantly higher percentages of damaged pods and beans (8% and 0.8%, respectively) (Table 4.2). Eight larvae per 0.3 m of row caused nearly as much pod damage (20%) as 1 egg mass per 1.5 m of row (21.6%), and over 1% pick. Two larvae per 0.3 m caused significantly more damage to pods and beans than in plots that were not infested. Larval infestation treatments had no effect on marketable yield. Again, damage to pods and beans was found in plots that were not intentionally infested, which may have been related to larval movement or natural infestation.

Insecticide application studies

Application method: Different insecticide application methods had an effect on percent damaged pods and beans in dry beans in 2009 (Table 4.3). Plots treated with a foliar application of λ-cyhalothrin had significantly lower percent damage to pods and beans than any other insecticide treatment tested.   Plots treated with an in-furrow application of the soil insecticide, aldicarb, had significantly higher percent damage to pods and beans than any other treatment. Insecticide application methods had no effect on marketable yield.

Spray timing: Different foliar application timings of λ-cyhalothrin affected the percent damage to pods and beans in 2010 (Table 4.4). Percent damage to dry bean pods was significantly lower in plots that were treated weekly, 4, 11, or 18 days after infestation (DAI), than in plots that were treated 25 DAI or were not treated. Percent damage to beans that were processed by hand was significantly lower in plots that were treated weekly, 4 DAI, or 11 DAI than in plots that were treated 25 DAI or were not treated. Percent damage to beans that were processed with the Almaco thresher was significantly lower in plots that were treated weekly, 4 DAI, 11 DAI, or 18 DAI than in plots that were treated 25 DAI or were not treated. Treatments had no effect on marketable yield.

Insecticide residue: Percent survival of western bean cutworm larvae decreased when fed dry bean foliage with λ-cyhalothrin residue that was up to 14 days old (Table 4.5). Dry bean foliage treated with λ-cyhalothrin 14 day before feeding (DBF), 5 DBF, or 1 DBF had significantly fewer larvae survive than with foliage that was treated 7 DBF or was not treated (control) after larvae fed on the foliage for 24 hours in the first trial. Foliage that was treated 14 DBF, 7 DBF, 5 DBF, or 1 DBF had significantly fewer larvae survive than in foliage that was not treated after 48 hours in the first trial, and after 24 and 48 hours in the second trial.

Discussion:

Dry beans that were infested with 1 or more western bean cutworm egg masses per 1.5 m of row, or 2 or more larvae per 0.3 m of row, resulted in a greater amount of damage to dry bean pods, and 0.8% to 2.7% pick. This level of pick is significant because dry bean processors and shippers consider 2% pick to cause additional processing of the dry beans, which costs time

and money (Blickenstaff 1979, Fred Springborn, Michigan State University Extension, personal

communication). This corresponds to the larval scouting methods in the western United States,

where thresholds of 2 or more larvae per 0.3 m of row are used to trigger insecticide

applications (Seymour et al. 2004, Peairs 2008). This level of pick results in partially eaten

beans, which can be difficult to sort out of the finished product, and can make it to the

consumer. In 2010, western bean cutworm feeding was found in canned white kidney beans

that were grown and processed in Michigan (Greg Varner, Research Director, MI Dry Bean

Research Board, personal communication). This directly impacts the Michigan dry bean

industry's reputation for producing a high quality product.

The most effective insecticide application method for managing western bean cutworm

in dry beans is a foliar application of the pyrethroid, λ-cyhalothrin. Blickenstaff and

Peckenpaugh (1981) found that two other pyrethroids, fenvalerate and permethrin, offered

nearly 100% control of western bean cutworm. Thiamethoxam seed treatments are effective at

controlling potato leaf hopper, in snap bean, up to 38 days after planting (Nault et al. 2004),

and aphids up to 49 days in soybean (McCornack and Ragsdale 2006). They were not expected

to control late season pests like western bean cutworm. With dry beans being planted in early-

to-mid June, thiamethoxam would lose effectiveness by late July, and western bean cutworm

larvae cause damage to dry beans through harvest (Peairs 2008, Seymour et al. 2004,

Blickenstaff 1979). Thiamethoxam seed treatments also offer no control of European corn

borer, *Ostrinia nubilalis* (Hubner), (Groves et al. 2013) in snap beans, so it is unlikely that they

would have an effect on western bean cutworm in dry beans. Soil insecticides like phorate and

aldicarb also offer poor management of western bean cutworm. Plots treated with aldicarb had

greater damage to dry beans. This effect of greater insect pest damage in plots treated with

aldicarb has also been seen in cotton and soybeans, where aldicarb decreased natural predator

populations and made the plots more attractive for oviposition (Ridgway et al. 1967, Kinzer et

al. 1977, Morrison et al. 1979). Dry bean growers who use aldicarb for leaf hopper may be

increasing their risk of having western bean cutworm affect their fields.

The optimum timing number of foliar applications of λ-cyhalothrin to manage western

bean cutworm in dry beans is one application up to 18 days after peak flight. This application is

equally as effective as applying λ-cyhalothrin weekly, up to 25 days after peak flight. If the

single application is made too late (25 days after peak flight), there will be increased pick, which

may result in reduced quality. Insecticide residue from applying λ-cyhalothrin will effectively

manage western bean cutworm larvae for up to 14 days after application. This 14 day window

does not interfere with the 21 day pre-harvest interval of λ-cyhalothrin since foliar applications

would be made through mid-August and harvest does not begin until mid-September.

Based on these studies, dry bean fields that were infested with 1 or more western bean

cutworm egg masses per 1.5 m of row, or were infested with 2 or more larvae per 0.3 m of row,

could be at risk for damage to dry bean pods and beans, and decreased marketable yield. Dry

bean growers should use a foliar insecticide, such as λ-cyhalothrin, to control western bean

cutworm. At planting, applications that were either in-furrow, t-banded, or as seed treatments

were not effective in controlling western bean cutworm. This is due to the fact that damage

does not occur until flowering or when pods develop, which is late in the season, and those

treatments have lost effectiveness. The best time to apply λ-cyhalothrin was one to two weeks

after local peak flight occured. Insecticide residues from λ-cyhalothrin effectively control western bean cutworm larvae for up to 14 days. Future studies should address how well λ-cyhalothrin controls western bean cutworm in large plot dry bean studies and determine the effect on marketable yield. Additional research should be done to determine when pyrethroid residues no longer control western bean cutworm larvae. These five studies have contributed necessary knowledge used for the management of western bean cutworm in Michigan dry beans.

Figures and Tables:

Table 4.1: Percent damaged pods and beans, and total marketable yield, in dry bean plots infested with varying numbers of western bean cutworm egg masses per 1.5 m of row in Michigan. Data for 2008 and 2009 were combined for percent damaged pods and marketable yield.

# Egg Mass / 1.5m	% Damaged Pods[1]	% Damaged Beans (Pick)				Marketable Yield kg/ha	
		Hand Processed		Machine Processed		Hand Processed	Machine Processed
		2008	2009	2008	2009		
0	5.3c	0.2c	0.5c	0.5b	0.2b	3188a	2953a
0.5	11.8c	n/a[2]	1.1bc	n/a[2]	1.3ab	2924ab	2539a
1	21.6b	2.0b	1.9ab	3.3ab	1.6ab	2994ab	2746a
2	27.0b	2.6ab	2.7a	6.1a	2.7a	2779b	2533a
3	32.9a	3.5a	1.4bc	4.8a	2.6a	2892b	2591a
df	35	15	19	15	19	35	35
F	32.94	14.58	6.49	5.33	4.05	2.85	1.59
P	0.0000	0.0008	0.0051	0.0219	0.0264	0.0423	0.2052

[1] In columns, means followed by different letters are significantly different (LSD, P ≤ 0.05)

[2] Treatment level of 0.5 egg masses was not tested in 2008

Table 4.2: Percent damaged pods and beans, and total marketable yield, in dry bean plots infested with varying numbers of western bean cutworm larvae per 0.3 m of row in Michigan. Data for 2008 and 2009 were combined for all variables.

# Larvae / 0.3m	% Damaged Pods[1]	% Damaged Beans (Pick)	Marketable Yield kg/ha
0	3c	0.3b	2675a
2	8b	0.8a	2974a
4	15a	0.9a	2768a
8	20a	1.2a	2899a
df	27	27	27
F	20.39	8.13	1.39
P	0.0000	0.0014	0.2800

[1]In columns, means followed by different letters are significantly different (LSD, P ≤ 0.05)

Table 4.3: Percent damaged pods and beans, and total marketable yield, in dry bean plots treated with different insecticide application methods for managing western bean cutworm in Michigan, 2009.

Active Ingredient[1]	Application Method	% Damaged Pods[2]	% Damaged Beans by Weight (Pick)		Marketable Yield kg/ha	
			Hand Processed	Machine Processed	Hand Processed	Machine Processed
not treated	n/a	15.5b	1.5c	1.8a	2324a	2401a
thiamethoxam	seed	19.5ab	2.5b	2.3a	2549a	2535a
phorate	t-band	16.5ab	2.2bc	2.4a	2458a	2292a
aldicarb	in-furrow	25.0a	3.5a	2.6a	2294a	2449a
λ-cyhalothrin	foliar	1.6c	0.0d	0.0b	2269a	2760a
df		18	18	18	18	18
F		12.16	22.59	5.71	0.26	0.58
P		0.0005	0.0000	0.0098	0.8947	0.6822

[1]Treatments are listed in order of application timing

[2]In columns, means followed by different letters are significantly different (LSD, $P \leq 0.05$)

Table 4.4: Percent damaged pods and beans, and total marketable yield, in dry bean plots infested with 1 western bean cutworm egg mass per 1.5 m of row, and treated with different timed spray applications of λ-cyhalothrin in Michigan, 2010.

Treated	% Damaged Pods[2]	% Damaged Beans by Weight (Pick)		Marketable Yield kg/ha	
		Hand Processed	Machine Processed	Hand Processed	Machine Processed
Weekly	0.6d	0.00c	0.00c	3514a	3672a
4 DAI[1]	0.8cd	0.00c	0.00c	3637a	3643a
11 DAI	2.8bcd	0.00c	0.10bc	3921a	3945a
18 DAI	3.5abc	0.18bc	0.10bc	3422a	3616a
25 DAI	3.7ab	0.25b	0.60ab	3563a	3784a
No	5.6a	0.73a	0.75a	3590a	3855a
df	23	23	23	23	23
F	4.33	20.20	3.15	1.00	0.73
P	0.0122	0.0000	0.0387	0.4520	0.6133

[1]Days after infestation (DAI)

[2]In columns, means followed by different letters are significantly different (LSD, $P \leq 0.05$)

Table 4.5: Percent survival of western bean cutworm larvae that were fed treated foliage, after 24 and 48 hours, in a λ-cyhalothrin residue study in Michigan, 2012.

Treatment	Trial 1		Trial 2	
	24 hours[2]	48 hours	24 hours	48 hours
Control	94a	94a	88a	88a
14 DBF[1]	50c	0c	50b	0b
7 DBF	81ab	19b	13c	0b
5 DBF	56bc	0c	14b	0b
1 DBF	13d	0c	13c	0b
df	79	79	79	79
F	8.67	57.45	8.69	102.45
P	0.0000	0.0000	0.0000	0.0000

[1] Days before feeding (DBF)

[2] In columns, means followed by different letters are significantly different (LSD, P ≤ 0.05)

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APPENDIX

Record of deposition of voucher specimens

The Specimens listed on this page have been deposited in the named museum as samples of the species that was used in this research. Voucher recognition labels with the voucher number have been attached or included in fluid preserved specimens.

Voucher Number: 2013-01

Title of thesis:

BIOLOGY AND MANAGEMENT OF WESTERN BEAN CUTWORM (*STRIACOSTA ALBICOSTA*, SMITH) IN MICHIGAN DRY BEANS (*PHASEOLUS VULGARIS*, L.)

Museum where deposited:
The Michigan State University (MSU) Albert J. Cook Arthropod Research Collection

Specimens

Family	Genus, Species	Life Stage	Quantity	Preservation
Noctuidae	*Striacosta albicosta*	Larva	4	KAAD → Ethanol
Noctuidae	*Striacosta albicosta*	Adult	17	Pinned