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MANAGEMENT OF STINK BUGS (HEMIPTERA: PENTATOMIDAE) ON SOYBEAN IN KENTUCKY

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MANAGEMENT OF STINK BUGS (HEMIPTERA: PENTATOMIDAE) ON SOYBEAN IN KENTUCKY

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the College of Agriculture, Food and Environment at the University of Kentucky

By

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2020

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ABSTRACT OF THESIS

MANAGEMENT OF STINK BUGS (HEMIPTERA: PENTATOMIDAE) ON SOYBEAN IN KENTUCKY

Phytophagous stink bugs (Hemiptera: Pentatomidae) are pests of significant importance to soybean, *Glycine max* (L.), because they can cause severe losses in seed quality, ultimately affecting yield. Damage to soybean is caused through a process called extra-oral digestion. This occurs when the adults and nymphs of stink bugs pierce plant tissues with their mandibular and maxillary stylets, insert digestive enzymes, break down tissue, and extract the digested plant fluid. Three endemic stink bug species of North America are present in Kentucky: green stink bug (*Chinavia hilaris),* brown stink bugs *(Euschistus species* complex*),* and red-shouldered stink bug *(Thyanta custator)*. In addition, the invasive brown marmorated stink bug, *Halyomorpha halys*, has become a more serious soybean pest in the last two decades in certain regions of the country including Kentucky. Soybean is the most valuable commodity crop in Kentucky, bringing in over $700 million in revenue. Given that stink bugs can be detrimental to yield, understanding the effects that particular integrated pest management tactics have on stink bug densities is crucial. The objectives of this thesis are to 1) compare sampling methods used to assess stink bug population size and distribution, 2) evaluate the effects of stink bug populations between full and double-crop season soybean, and 3) compare control tactics for the management of stink bugs. These studies were conducted in several commercial fields located in western and central Kentucky counties and field plots at the UKREC in Princeton, KY. The results of these studies showed that: 1) beat-bucket sampling method produced similar density estimates of stink bugs compared with sweep net and may be a promising method to assess stink bug densities in the field as a replacement for the beat sheet technique, but an economic threshold needs to be established for this method; 2) stink bug species composition changed from western to central counties, where *H. halys* was the predominant species in the central region 3) seasonal stink bugs densities varied based on the physiological stage of soybean in both full and double-crop soybean in 2018; Similar trends in stink bug densities in 2019 full season soybean was documented, where densities in the field were based on food availability and developmental stage 4) the use of calendar sprays resulted in greater insecticide usage without gains in yield to justify their use when compared to a scout and spray if needed approach. Overall, proper pest management strategies should be incorporated to soybean production to assure sustainable suppression of stink bug insect pests.

Keywords: stink bug, maturity group, soybean, insecticide use, sampling method

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INTRODUCTION

Soybean, *Glycine max* (L.) Merrill, is perhaps the most lucrative crop in the world due to its production value resulting from its versatile uses (NASS, 2018). Soybean production is largely used as the main source of protein in animal feed and ranks second as a source of vegetable oil worldwide because the seed composition is made of 38% protein and 18% oil. (NASS, 2018). The U.S. is the largest global soybean producer and it is a major cash crop in Kentucky (NASS, 2019).

1.1 Phytophagous Stink Bug Pest Status

Phytophagous stink bugs (Hemiptera: Pentatomidae) are a significant pest as they can cause damage to soybean (McPherson and McPherson, 2000). Stink bugs pest are in the subfamily Pentatominae which includes 40 genera and 180 species. (McPherson and McPherson, 2000; Panizzi et al., 2000). Within the north central region of the US, there are 23 stink bug species in soybeans, but only five are of economic importance (McPherson and McPherson, 2000; Koch et al., 2017). Phytophagous stink bugs are known for their shield shaped bodies, five segmented antenna, proboscis which starts from the front, and in the adult form: well developed wings. (McPherson and McPherson, 2000; Panizzi et al., 2000; Koch et al., 2017). Stink bugs can cause direct damage to soybean foliage and beans. Feeding is through a process called extra-oral digestion. This is done by using their piercing sucking mouthparts to inject digestive enzymes into the plant tissue and them taking in the digested fluids. Severity of the direct damage caused by the stink bugs varies with the physiology of the soybean plant. (McPherson and McPherson, 2000). The most susceptible stage of a soybean plant is during the reproductive stages when there are developing pods. This can lead to delays in plant maturity such as the staygreen syndrome and lead to the transmission of plant pathogens (McPherson and McPherson, 2000; Boethel et al. 2000). Reproductive stages 3 to 5 (R_3 to R_5) are sensitive to damage as these stages correspond to early pod development and fill, feeding during this period can cause seed abortion or shriveled seeds (McPherson and McPherson, 2000; Koch et al., 2017). Growth stages from R_6 to harvest are not as affected by feeding (McPherson and McPherson, 2000; Musser et al., 2011). Stink bug damage can cause loss in yield quality by deforming and discoloring the seed. Phytophagous stink bugs are not only a problem in soybean, stink bugs can greatly affect fruit trees, vegetables, and other commodity crops.

1.2 Native Phytophagous Stink Bug Species

In Kentucky's soybean fields, there are three predominant endemic stink bug species affecting soybeans, the green stink bug, *Chinavia hilaris* (Say), the brown stink bug *Euschistus servus* (Say) and the red-shouldered stink bug, *Thyanta custator* (Fabricius). There is also predacious species that found in Kentucky soybean, spined soldier bug, *Podisus maculiventris* (Say).

These three species commonly cause losses to soybean producers in the state:

Green Stink Bug, *Chinavia hilaris*

Chinavia hilaris, previously *Acrosternum hilare*, ranges from the Midwestern United States thru the rest of North America. Green stink bug adults are 13 to 19 mm long (McPherson 1982; Panizzi et al., 2000). They are green in color with a rare orange morph (Kamminga et al., 2012). The nymphs in this species are oval shaped and are 1.6 to 12.7 mm long (DeCoursey and Esselbaugh, 1962). The coloration of the nymph's changes from being primarily black with orange patterns to mostly green with some black and orange patterns as they mature (DeCoursey and Esselbaugh, 1962). This species is often mistaken for the southern green stink bug, *Nezara viridula* (Linnaeus), but can be differentiated by its long ostiolar canal, which extends beyond the middle of the supporting plate. The southern green stink bug has a shorter ostiolar canal (McPherson and McPherson, 2000).

Brown Stink bug*, Euschistus servus complex,*

In this species there are two subspecies, *Euschistus servus euschistoides* and *Euschistus servus servus* (McPherson 1982). *Euschistus servus euschistoides'* range is in the northern US and *E. servus servus* occurs in the southern region of the US. They are known to hybridize where both species meet, roughly from Kansas to Maryland (McPherson 1982). These two species and their hydrid adults are similar in size, from 11.0 to 15.0 mm long (McPherson 1982) and light brown in color. The nymphs are oval-shaped and are 1.6 to 12.7 mm in size. Distinguishing the two species can be done by looking closely at the head, antennae, and edge of the abdomen. In *E. servus euschistoides,* the tip of the head appears notched because the juga are longer than the tylus. The juga and the tylus are equal or nearly equal in length on the tip of the head of *E. servus servus* (Paiero et al., 2013; McPherson and McPherson, 2000).

Red-shouldered Stink Bug*, Thyanta custator*

The red-shouldered stink bug occurs in the midwestern region of the US (McPherson 1982; Rider 2012). Adults size ranges from 9 to 13 mm long (McPherson 1982). There are two color forms that occur which show seasonal variation; the green form appears during the spring and summer, the brown occurs in the fall (McPherson 1982; Paiero et al., 2013). Nymphs range in size from 0.9 to 8.2 mm (DeCoursey and Esselbaugh 1962). Also, it is important to clarify that the red-shouldered stink bug should not be confused with the red-banded stink bug, *Piezodorus guildinii* (Westwood).

1.3 Invasive Stink Bug Species

Additionally, there are two invasive species colonizing new areas across the continental USA. The brown marmorated stink bug, *Halyomorpha halys* (Stål) and the red-banded stink bug, *Piezodorus guildinii*.

Brown Marmorated Stink bug, *Halyomorpha halys*

The brown marmorated stink bug is a species of Asian origin and is well established in the central and eastern part of Kentucky. In these areas brown marmorated stink bug can be found affecting fruits, vegtables, corn, and soybeans; insecticides may be required for control. The brown marmorated stink bug has not completely colonized all counties of Kentucky however, it was found in three counties of western KY (Henderson, Daviess, and Trigg) in 2013 (Johnson, 2013). Adults vary in brown color but are generally 12 to 17 mm long with marbled brown coloration. They have light coloration on the ventral side of the body. The antennae have light colored bands on the base and apex of the fourth antennal segment and the base of the fifth antennal segment (Hoebeke and Carter 2003). Nymphs are 2.4 to 12 mm long and body shape varies (elliptical to pear-shape) (Hoebeke and Carter 2003).

Red-Banded Stink bug, *Piezodorus guildinii*

The red-banded stink bug is of South American origin and has been found in several areas around the Gulf States. The red-banded stink bug is currently considered the main pest problems of soybeans in Louisiana, Mississippi, and Texas, and it is moving northward from the Gulf States; it was reported in southern Missouri in 2009 (Bailey 2009). The red-shouldered stink bug's green color has a flatter finish compared to that of other green stink bug species and had a red or purple stripe across the pronotum (McPherson, 2018). Adults range in size from 8.0 to 11.0 mm in length and 4.6 mm across the pronotum (Zerbino et al., 2014). Adults also have a long diagnostic spine on the ventral side of the abdomen.

Furthermore, these two invasive species have two conditions that need to be considered. First, both species lack effective natural enemies, a condition that is advantageous for them to increase their populations more rapidly compared with the native green stink bug or brown stink bug. Second, brown marmorated stink bug and red-banded stink bug are more tolerant to many insecticides available for stink bug control than native stink species on soybean. Temple et al. (2013) had shown that insecticide efficacy for red shouldered stink bug is lower compared to the Southern green stink bug using pyrethroids, neonicotinoids, and insecticide pre-mixtures or product combinations in Louisiana. Therefore, if new counties are being colonized by the brown marmorated stink bug or red-banded stink bug the number of insecticide applications may significantly increase, and cost of production will surge affecting growers' profits.

1.4 Integrated Pest Management

The management of phytophagous stink bugs is difficult because each species has specific characteristics such as host plant selection, and adaptation to different climates, behavior, and tolerance to insecticides. This may require distinct integrated management tactics but currently each species is controlled with the same practices. The life history of each species is a major contributor to understanding the pest presence in crops (McPherson and McPherson, 2000). Cultural practices such as trap cropping is a popular practice which encompasses the stink bugs' preference for certain plant species, cultivars, or crop stages (McPherson and McPherson, 2000). These stink bug preferences are manipulated using the desired trap crop to intercept phytophagous species before reaching the target crop (McPherson and McPherson, 2000). Timing of planting dates and plant maturation has shown many positive results in reducing stink bugs in crops (McPherson and McPherson, 2000). Later maturing varieties of soybean often have more damage than earlier maturing varieties and earlier plantings tend to have more damage than later plantings (Miner 1960). Planting early maturing varieties can also be used to alter seasonal mean stink bug populations due to plants becoming less favorable to the stink bugs before the highest population levels occur (McPherson and McPherson, 2000).

Chemical control is the most reliable approach for growers in controlling stink bugs. Over 300 million pounds of active ingredients of insecticides have been purchased in the US annually for arthropod control (McPherson, 2018). The main insecticides used for stink bug control are pyrethrins, pyrethroids, and neonicotinoids (McPherson and McPherson, 2000). Ideally, insecticides should only be used when the economic threshold levels have been reached, but they are frequently used without pest monitoring. In Kentucky, recommended economic thresholds are 3 stink bugs per 25 sweeps from bloom of the soybean plant to the reproductive stage one (R1) and 9 stink bugs per 25 sweeps from reproductive stage 4 to 6 (Turnipseed and Kogan, 1976). This is done with sweep net sampling. Another technique used to sample stink bugs is a beat cloth. The economic threshold for the cloth is 2 stink bugs per four 0.3 m row samples (Turnipseed and Kogan, 1976). The regular use of insecticides can negatively impact natural enemies which have led to resurgences of a soybean pests. A case study conducted by Saito (2004), documented a resurgence of leafminers in vegetables after an insecticide treatment. A moderate number of leafminers had survived the treatment and low number of parasitoids survived resulting in an outbreak of the following generation of leafminers.

1.5 Objectives

The broad objectives of this thesis are:

1. Comparison of the current and a new sampling method used to assess stink bug (Hemiptera:Pentatomidae) populations in soybean (*Glycine max*).

2. Comparison of stink bug densities and impact on full and double-crop season soybeans.

3. Comparison of control tactic strategies to manage of stink bugs in soybeans.

Chapter 2 Comparison of the current and a new sampling method used to assess stink bug (Hemiptera: Pentatomidae) populations in soybean (*Glycine max*).

2.1 Introduction

Soybean, *Glycine max*, (L.) Merrill (Fabales: Fabaceae), is the most lucrative field crop of Kentucky. The state's soybean acreage has increased from about 200,000 acres in 1960 to almost 2 million acres in 2019 (USDA-NASS, 2019). Along with changes in acreage, soybean production practices have changed. Many Kentucky growers have increased planting densities and at the same time reduced row width from 76.2 cm between rows to 38.1 cm (Kithcart, 1978). Narrow rows have the ability to yield more than the 76.2 cm rows as canopy closure is reached sooner, intercepting more sunlight (Knott and Lee, 2017). An increase in light interception can increase plant growth, the accumulation of dry matter, and seed yield (Knott and Lee, 2017). An increase in canopy closure can also reduce the incidence of weeds in the field thus reducing the cost associated with herbicide applications (Green et al., 2017). Canopy closure occurs during the reproductive stage three (R3) in soybean when planted in rows separated by 38.1 cm. (Bruin and Pedersen, 2009). Studies in Iowa showed that soybean planted in 38.1 cm rows have canopy closure 15 days before those planted at 76.2 cm and produced an average of 9.15 more bushels per hectare (Bruin and Pedersen, 2009).

Phytophagous stink bug species pose a threat to the yields of soybeans as they can cause direct damage by feeding primarily on pods, thus affecting yields, quality, and germination rates (McPherson and McPherson, 2000; Todd and Herzog, 1980). Adult and nymphal stink bugs cause damage by piercing plant tissue with their mandibular and maxillary stylets (Esquivel, 2019). Digestive enzymes are released into the plant resulting in extra-oral digestion (Esquivel 2019). In Kentucky there are three common native stink bug pests of soybeans, green stink bug (*Chinavia hilaris* (Say)), brown stink bug (*Euschistus servus* (Say)), and red-shouldered stink bug (*Thyanta* *custator* (McAtee)). Within the last 10 years, the brown marmorated stink bug (*Halyomorpha halys* (Stål)), has invaded several regions in the state and has become a serious pest of fruit, vegetable, and field crops (Leskey et al. 2012; Lee et al. 2013) including soybeans. The following species, *C. hilaris,* the complex group of *Euchistus spp.,* and *T. custator,* and *H. halys* all invade soybean fields during pod development and share similar feeding habits and yield loss relationships (McPherson and McPherson, 2000) therefore management strategies are similar and these pests are managed as a pest complex rather than individual pests. Phytophagous stink bug species have been of growing concern in the neighboring North Central states (Koch et al. 2017).

Integrated pest management (IPM) strategies provide a framework to reduce losses to pests using cultural, biological, and chemical controls based on economic and social considerations. The economic threshold is a fundamental concept in IPM as it defines pest densities when management action should be taken to prevent pest populations from reaching economic injury levels. Economic injury level is the lowest pest density that will cause injury or yield losses equal to that of management cost. Sampling crop fields regularly during the season is the main method to determine if and when pest populations have reached the indicated economic threshold. The primary sampling technique used in estimating stink bug densities in soybean is the sweep net, which has shown to be a cost-effective method (Todd and Herzog, 1980; Sane *et al.* 1999). Stink bugs can pose a serious threat to soybean production if an infestation occurs during the reproductive stages of the plant from bloom to maturation of the pod (McPherson and McPherson, 2000).

Currently in Kentucky, the recommended scouting methods for stink bugs is to use a 38 cm wide sweep net and take 25 sweeps on the border of a field or to place a 61 cm long shake cloth between the rows of 76 cm soybean and beat any stink bugs off the soybean plants onto the shake cloth. The border of the field is sampled as stink bugs inhabit this section of the fields before colonizing more central areas. The economic threshold for insecticide application is 3 phytophagous stink bugs per 25 sweeps from beginning bloom (R1) to beginning of pod development (R3) (Kogan, 1976) or 9 stink bugs per 25 sweeps for later stages, or an average of 2 or more stink bugs per 1.2 m of row using a shake cloth (Fehr et al., 1971). As the typical width between rows has been reduced from 76 cm to 38 cm and with canopy closure occurring during R3, the shake cloth method is no longer practical for sampling stink bugs. In surrounding states such as Illinois, Indiana, and Ohio, the use of 38.1 and 76.2 cm rows is practiced and the use of sweep net and shake cloth are recommended for scouting stink bugs. Updates to scouting tactics have not been conducted in any of the listed states. Incorrect estimates of pest densities can lead to mismanagement of crop, thus reductions in profits. The objectives of this study were to evaluate the phytophagous stink bug species composition of commercial soybean fields in Central and Western KY and compare the sweep netting sampling with the 30 cm diameter by 37 cm tall white 5-gallon bucket sampling.

In the second objective we also evaluate the feasibility of these method using inexperienced personnel.

2.2 Material and Methods

The study in 2018 used one commercial soybean field in each western Kentucky county: McLean (37°62’66” N, 87°47’70” W); Lyon (37°03’34” N, 88°21’62” W and 37°03’42” N, 88°21’64” W); and Christian (36°87’ 67” N, 87°64’ 69” W). In 2019, one commercial field was sampled in each of Hardin (37°65’96” N, 85°89’ 12” W); Hickman (36°61’39” N, 88°44’03” W); Daviess (37°76’ 38” N, 87°26’82” W); and McLean (37°61’ 35” N, 87°47’00” W) (Figure 1). These locations were selected as species of stink bugs differ from central to the western region of Kentucky;

Halyomorpha halys has not established in the Western Kentucky. In these locations, two sampling methods were compared to estimate stink bug densities in soybean fields and to determine the stink bug species composition in each county. The first method involved using a 38.1 cm wide sweep net (BioQuip, Rancho Dominguez, CA). The net was used to take 50 samples of 10 sweeps (Total = 500 sweeps) each along the border (with ~5 meters of the field perimeter) and another 50 samples of 10 sweeps each 100 meters into the interior of a field. Border sampling was done to account for edge effects as stink bug densities are often high in the perimeter of fields (Olson *et al* 2011). Each of these samples were at least 5 meters apart. The economic thresholds were modified to 1.2 stink bugs per 10 sweeps from bloom to R3 or 3.6 stink bugs per 10 sweeps from R4 to pod fill (Fehr et al., 1971). The second method used a white five-gallon bucket (diameter of bucket: 30 cm; height: 37 cm) (Uline, Pleasant Prairie, WI). The color of the bucket was chosen as it provided better contrast between specimen and bucket. The bucket was used to take 50 samples of 3.05 m row in the border (~5 meters) and 50 samples 100 meters into the field. To assure the sample is from 3.05 m of a soybean row; a 3.05 m polyvinyl chloride pipe or PVC pipe (LDR Industries Inc, Chicago, IL) was used to identify the sample length. The surveyor would drop the PVC pipe next to a row and hold the bucket with one hand and beat or shake the soybean plants into the bucket with the other. Two beat or shake motions were done for each of the plants in the 3.05 m row. Stink bugs in the white bucket were speciated and recorded. There is not a set economic threshold for the bucket method, economic thresholds were solely based on sweep net thresholds. The soybean season was divided into three dates and maturity stages (Figure 2.8). Vegetative stage 3 (V3) to beginning bloom (R1) was early season. Full bloom (R2) to full pod (R4) was mid-season. Beginning of seed (R5) to full maturity (R8) was late season. Visits to these soybean bean field were conducted on a biweekly basis from mid-June to end of August.

Time management with both methods were also addressed by timing three subjects before (inexperienced) and after (experienced) physical demonstration of each method. Inexperienced people were defined as someone who had not used a sweep net nor a bucket to sample soybeans.

The people were given a set of verbal instructions on how to use both methods. They were asked to complete three sets of 10 sweeps and use the bucket to sample three sets of 3.05 m row of soybean plants. Everyone was individually timed for each set. After the first three sets of sampling, the correct manner of sampling was demonstrated to the individuals. They were then asked to sample again, three sets of 10 sweeps and beat 3.05 m of soybean row into a bucket, making them experienced personnel.

2.2.2 Statistical Analysis

A one-way ANOVA test for the sampling methods and dates were conducted with PROC GLIMMIX (SAS 9.4; SAS Institute Inc. Cary, NC) to compare stink bug numbers located in the interior and exterior of the commercial fields. Sampling method was treated as a fixed effect, while samples were considered random effects. The significance level was specified at 95%.

2.3 Results

2.3.1 Species Composition within each County

In Christian County, the densities recorded for all species on the border and interior of the field did not reach the modified economic thresholds of 1.2 stink bugs per 10 sweeps from bloom to R3 or 3.6 stink bugs per 10 sweeps from R4 to pod fill during any sampling period. Stink bugs were more common in the border during the first sampling date, numerically higher in the interior of the field during the second sampling period, and then higher densities were observed in the border during the third sampling date (Fig. 2.2A). *Chinavia hilaris* was the predominate species observed at the beginning of the season; *Euschistus servus* density increased and was the highest density during the middle period, but *C. hilaris* was most common during the last period *Thyanta custator* remained at low densities throughout the season in this field location in both sweep net and bucket samples. *Chinavia hilaris* accounted for the high numbers of captures throughout the season with 49% of 143 total stink bugs; *E. servus* represented 30%; *T. custator* was 21% (Fig 2.4A). The bucket sampling and sweep net method captured similar numbers of stink bugs in both the border and interior of the field ($F_{1,49} = 0.35$, p = 0.553).

McLean County field did not reach the economic threshold set for stink bugs; however, a calendar spray was applied by the producer to the field July 24, 2018, which resulted in a decrease of pentatomids (Fig. 2.2B). With both sampling methods, 299 stink bugs were recorded. The first sampling date accounted for the majority of the stink bugs captured at this field location. *Chinavia hilaris* and *E. servus* were the most common species, representing 54% and 45%, respectively, of the 299 caught in this location (Fig. 2.4B). Although stink bugs were collected during the next two periods, their numbers remained very low. Throughout the season, stink bugs densities did not differ in the border and interior of the fields nor in the type of sampling method ($F_{2,49} = 0.53$, p = 0.588).

In Lyon County, stink bugs in the long-season soybean field did not reach the economic threshold (Fig. 2.2C). Stink bugs were found to inhabit the border and interior of the field during the first two sampling dates and displayed an edge-effect as the season advanced ($F_{1,49} = 4.35$, p = 0.013) Both bucket and sweep sampling showed similar numbers of stink bugs captured ($F_{1,49} = 0.06$, p = 0.812). The densities of *C. hilaris* and *E. servus* bugs in this field were 70% and 29% respectively, throughout the season (Figure 2.4C). *Thyanta custator* appeared on the last sampling date in the border rows in sweep net samples and was recorded to be 0.6% of the total population documented.

In Lyon county, stink bugs in short season soybeans did not reach the modified economic threshold of 1.2 stink bugs per 10 sweeps from bloom to R3 or 3.6 stink bugs per 10 sweeps from R4 to pod fill (Fig. 2.2D). Stink bugs were found at higher levels on the border during the first sampling date and increased in the interior of the field as the season progressed ($F_{1,49} = 5.26$, $p = 0.027$). The green and brown stink bugs populations in this field were similar throughout the season, 53% *C. hilaris* and 47% *E. servus* (Fig. 2.4D. *Thyanta custator* was not collected in this location. Both bucket and sweep sampling showed similar numbers of stink bugs captured through the growing season ($F_{1,49} = 0.53$, $p = 0.588$).

In 2019, McLean county's stink bug densities did not reach the economic threshold during the season (Fig. 2.3A). Stink bugs more common on the border during the first sampling date but increased in the interior of the field as the season progressed ($F_{2,49} = 1.25$, $p = 0.286$). *Chinavia hilaris'* consisted of 74% and *E. servus* accounted for 26% of the total stink bug populations in this field (Fig. 2.5A). There was no record of *T. custator* in this location. Sampling methods did not show differences in number of stink bugs throughout the three sampling dates ($F_{2,49} = 1.58$ $p = 0.208$).

In Hickman County, stink bug densities did not reach the economic threshold during the season (Fig. 2.3B). An insecticide calendar spray was applied to the field on July 08, 2019, which likely caused the decrease of stink bugs. *Chinavia hilaris* was the most abundant species present in this location, accounting for 70 % of 371 stink bugs recorded (Fig. 2.5B). *Euschistus servus* was 27% of the phytophagous pentatomids collected. *Thyanta custator* densities were low (3% of 371 stink bugs) in this location. Both bucket and sweep sampling captured similar numbers of stink bugs ($F_{1,49} = 0.59$, $p = 0.441$).

In Daviess County, economic thresholds set for stink bugs were not reached (Fig. 2.3C). Initially the interior location of the field had more stink bugs present recorded by both sampling methods, as the season progressed no differences were found between the interior and border areas ($F_{1,49}$ = 0.66, p = 0.146). Stink bugs were found to inhabit the interior and border rows of the field throughout the season (Figure 2.3C). Both bucket and sweep sampling showed similar numbers of stink bugs captured ($F_{1,49}$ = 0.49, p = 0.027). *Euschistus servus* represented the highest percentage of species collected (70%) of the 371 stink bugs (Fig. 2.5C). *Chinavia hilaris* accounted for 17% of the total number of stink bugs. The red-shouldered stink bug was 10% of total stink bugs. *Halyomorpha halys* occurred in lower densities in comparison to the *C. hilaris* and *E. servus*, accounting for 0.3% of 371 stink bugs collected during the three sampling periods.

In Hardin County, stink bugs were more common the border during the first sampling date and increased in the interior of the field as the season progressed (Fig. 2.3D). Both bucket and sweep sampling showed similar numbers of stink bugs captured in the interior and border locations in the field ($F_{1,49}$ = 0.74, p = 0.389). *Halyomorpha halys* was the most abundant species in this location throughout the season with 51% of the total number of collected stink bugs (Fig. 2.5D). *Chinavia hilaris* and *E. servus* followed with 32% and 16% of the total 464 stink bugs recorded in this field.

2.3.2 Evaluation of Sampling Methods

Stink bug densities observed in the interior (100m) and border (5m) of the field for all county locations in 2018 and 2019 were found to be significantly different (Figure 2.6; $F_{1,95}$= 4.51, p= 0.037). Stink bugs occurred at higher densities in the border of the field when compared to the interior of the field. The number of stink bugs collected using the two sampling methods, five-gallon white bucket and 38.1 cm wide sweep net, were similar in all fields for both sampling years

(Figure 2.7; $F_{1,95} = 0.40$, $p = 0.527$). Number of stink bugs within each Location in the field (border or interior) was also similar in both sampling methods ($F_{1,95} = 0.24$, $p = 0.624$).

Total number of stink bugs collected from both sampling methods were combined for the interior and border of the field. There were no differences found between the two locations of the field throughout the early, mid, and late dates of the season ($F_{3,95}=0.67$, $p = 0.515$).

The time recorded for experienced and beginner differed between individuals. The time observed for the experienced individuals was parallel to each other in that bucket and net sampling did not differ in time. Inexperienced individuals showed a longer time spend in the bucket sampling as compared to the sweep net method (Figure 2.9). Once, familiar with the bucket sampling, their time reduced.

2.4 Discussion

In 2018 and 2019, stink bug numbers at All the locations in the six counties did not reach the fixed economic thresholds of 1.2 stink bugs per 10 sweeps from bloom to R3 or 36 stink bugs per 10 sweeps from R4 to pod fill. Despite below threshold stink bugs densities, insecticide sprays were made in McLean county on July 24, 2018 and Hickman county on July 8, 2019, thus lowering the stink bug densities recorded for these two locations. These sprays conducted by soybean farmers are considered preventative or calendar-based sprays as they are made regardless of stink bug density. In the western part of Kentucky, the dominant species throughout the four (Christian, Lyon, Hickman, and McLean counties) counties was the *C. hilaris* followed by the *E. servus* and lastly, the *T. custator*. These species are commonly found inhabiting soybean throughout the southeastern region of the US (Pilkay et al., 2015). Sightings of *H. halys* have been recorded in the western part of KY but it is still increasing in numbers in this region. Daviess and Hardin counties different species composition. In these counties, *E. servus* and *H. halys* were the principal species, respectively. In certain instances, seen in Daviess County, *H. halys* can outnumber the native species in soybean fields, like that observed by Nielsen et al. 2011 in Pennsylvania soybean. The factors influencing the distribution of *H. halys* in Kentucky are not well understood. Several factors can affect their spread and distribution; they can overwinter in variety of habitats (urban dwellings and forested areas), are polyphagous, and are known to have a high rate of dispersal (McPherson, 2018; personal information; Fann, unpublished).

The overall evaluation of the interior (100 m) and border (5 m) areas of soybean fields in the six counties showed there were 3 significant differences in the numbers of stink bugs collected in these two field locations. Stink bugs are known to behaviorally congregate at the edge of fields, also known as an edge effect, of soybean fields adjacent to woodlands and can therefore cause damage to the outermost location of the field (McPherson and McPherson, 2000; Venugopal et al., 2014). Edge effects are defined as the changes in an organisms' density between two different habitat types (Olson et al., 2011). Movement of stink bugs between adjacent wild host and soybean is based on crop phenology and the availability of food sources (Jones and Sullivan, 1982). Phytophagous pentatomids are highly mobile and move to the interior of the soybean field as the season progresses (McPherson and McPherson, 2000). Stink bugs may also remain in the field until the soybean is harvested or move to overwintering sites (Jones and Sullivan, 1981).

The white five-gallon bucket sampling method was evaluated to provide a comparative and substitute sampling method to the shake cloth and may potentially be used as an alternative method to the use of a sweep net. Similar numbers of stink bugs were collected using the sweep net and the five-gallon bucket methods (Fig. 2.7, $F_{1,95} = 0.40$, $p = 0.527$). The diameter and height of the bucket is 29.97 cm and 44.28 cm long, allowing a surveyor to easily maneuver the bucket through the 38.1 cm wide rows. Brown marmorated stink bugs drop to the ground if disturbed, thus the 5-

gallon bucket may increase the recorded number of stink bugs. The sweep net typically samples the top canopy of soybean and length of the bucket may allow a better sample estimate as soybean plants can grow to over 1.0 m tall. Although the area covered by the sweep net is greater than that of the bucket, similar numbers of stink bugs were collected. Given that the bucket sampling covers a smaller area when sampling, this may indicate more stink bugs are present in the field than sweep nets are capturing. Establishing an appropriate sampling method is difficult as it heavily depends on the life stage and density of the insect pest and crop (Reay-Jones et al., 2009). Duncan (1968) compared the ground cloth to the sweep net in their abilities to sample adults and all nymphs of *Nezara viridula* and found 4th, 5th, and adults were equally as captured by both techniques. The ground cloth sampled 2nd and 3rd instars more efficiently compared to the sweep net. An economic threshold must be established for the buckets before recommending of use to growers.

Growers may favor the use of 5-gallon buckets as they are readily available to them. Hodgson et al. (2007) showed that the simplification of sampling may help crop consultants and growers effectively scout for pests. The timing of the inexperienced individuals using the bucket shows growers may be able to easily adapt to this method. Growers may be more inclined to sample their field if the tools needed to do so were at their disposal. Five-gallon buckets may be purchased at local hardware stores or superstores as compared to the 38.1 cm wide sweep net that needs to be ordered from an online catalog. The proper use of scouting may also reduce the cost associated with sprays: fuel, pesticide, use of equipment, and time input.

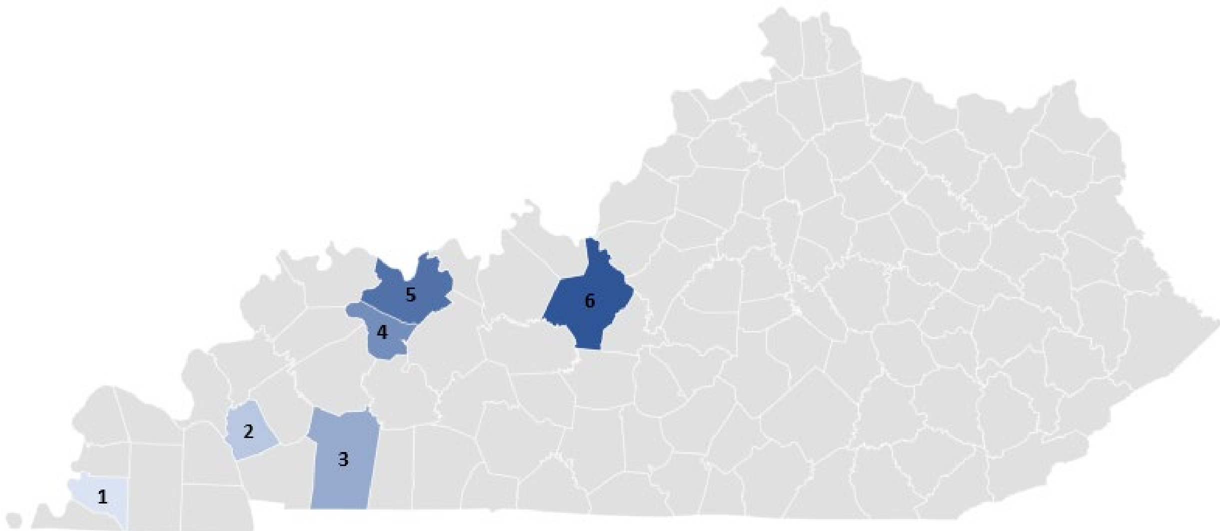

Figure 2.1. Fields in counties in Kentucky that were sampled for stink bugs from left to right: Hickman Co. (1), Lyon Co. (2), Christian Co. (3), McLean Co. (4), Daviess Co. (5), and Hardin Co. (6).

Results

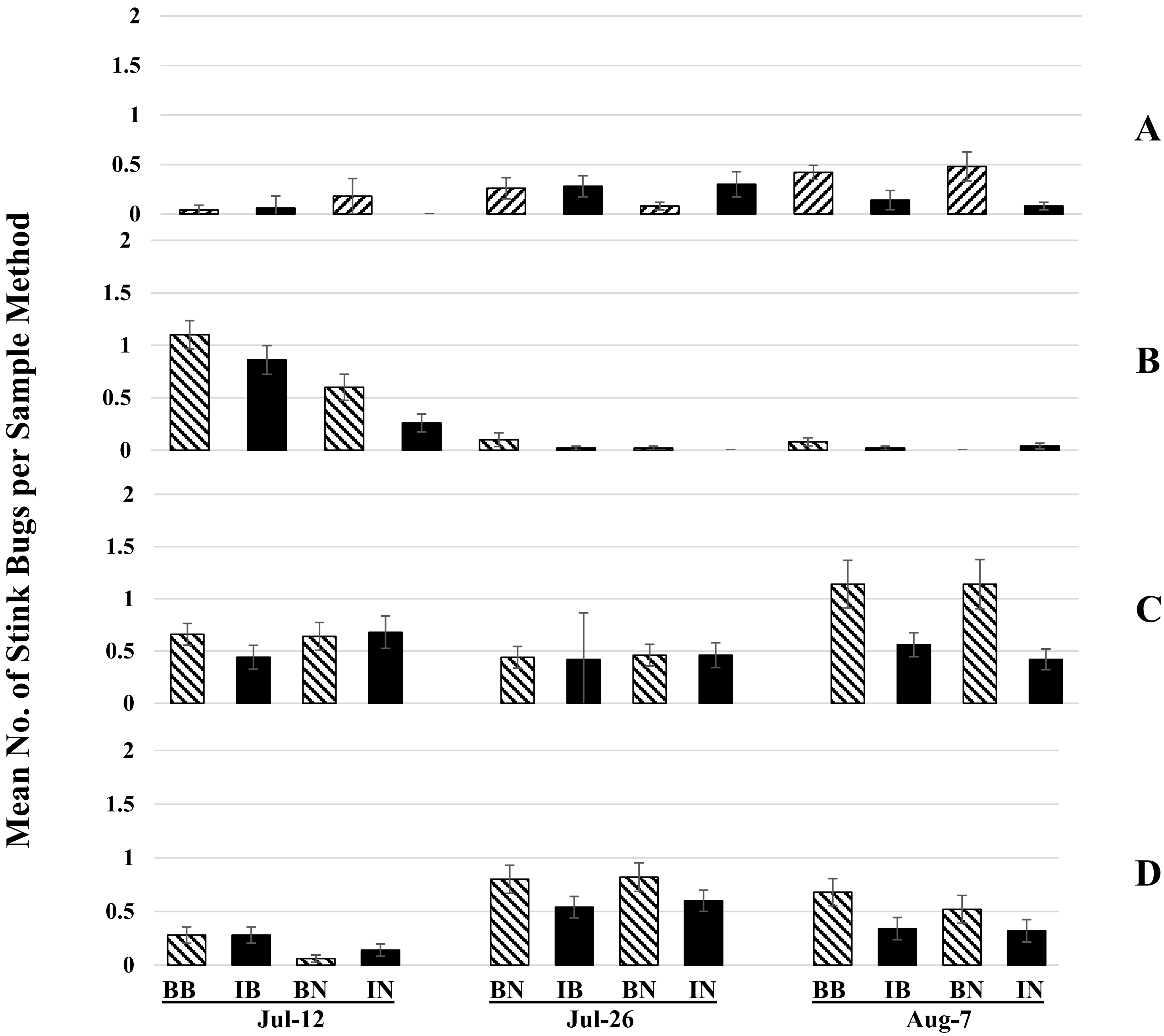

Figure 2.2. Mean number (±SEM) of stink bugs collected at each of 50 samples on the border and interior of a commercial long-season soybean fields with two sampling methods in (a) Christian, (b) McLean, (c) and (d) Lyon counties in, KY, in 2018. Each bucket sample consisted of surveying 3.05 m-length-rows for a total of 152.4 m sample (50 samples); whereas, each sweep net sample consisted of 10 sweeps in 50 different locations (500 sweeps) in each border (5 m from edge) or interior (100 m from edge). BB= Bucket border, IB= interior bucket, BN=Border using sweep net sampling; IN=Interior of field using sweep net sampling).

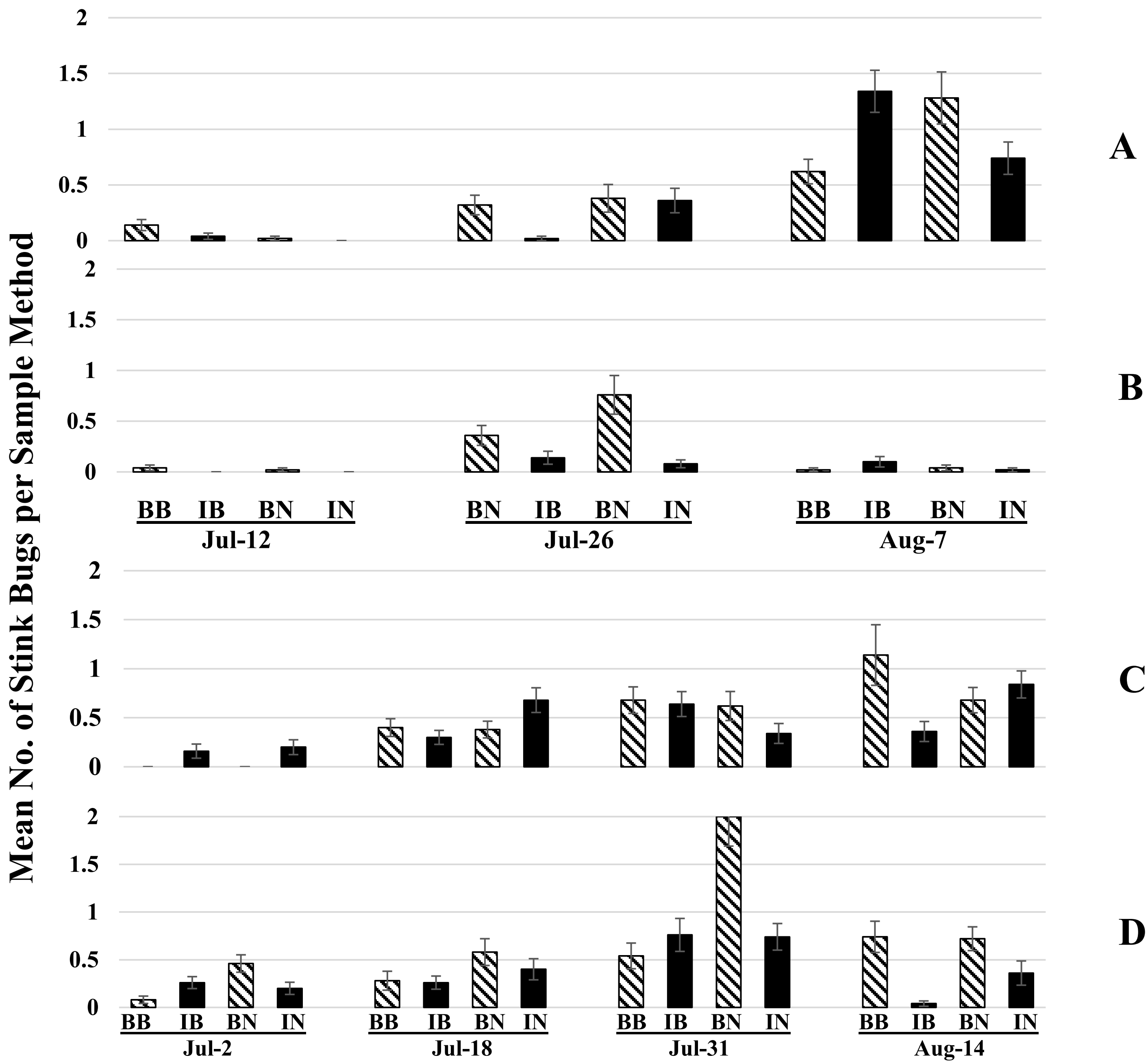

Figure 2.3. Mean number (±SEM) of stink bugs collected at each of 50 samples on the border and interior of a commercial long-season soybean fields with two sampling methods in (a) McLean, (b) Hickman, (c) Daviess (d) Hardin counties in, KY, in 2019. Each bucket sample consisted of surveying 3.05 m-length-rows for a total of 152.4 m sample (50 samples); whereas, each sweep net sample consisted of 10 sweeps in 50 different locations (500 sweeps) in each border (5 m from edge) or interior (100 m from edge). BB= Bucket border, IB= interior bucket, BN=Border using sweep net sampling; IN=Interior of field using sweep net sampling). Daviess and Hardin Co. experienced one more sample date, July 2nd earlier in the season as they were past V_3.

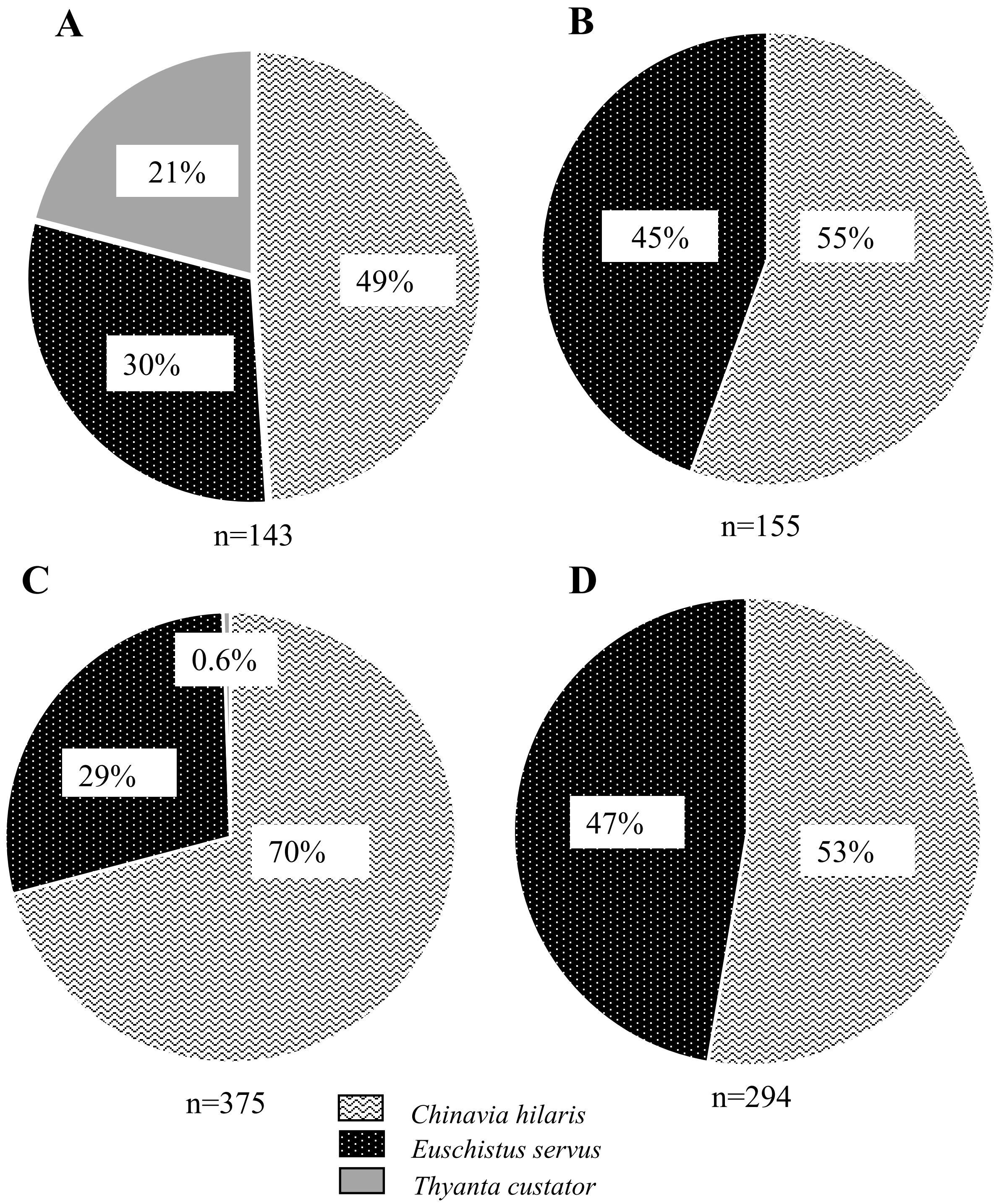

Figure 2.4. Stink bug species composition in (a) Christian, (b) McLean, (c) and (d) Lyon counties in, KY, in 2018 collected by 50-10 sweep net and 50-3.05 m bucket samples on each of 3 sampling dates.

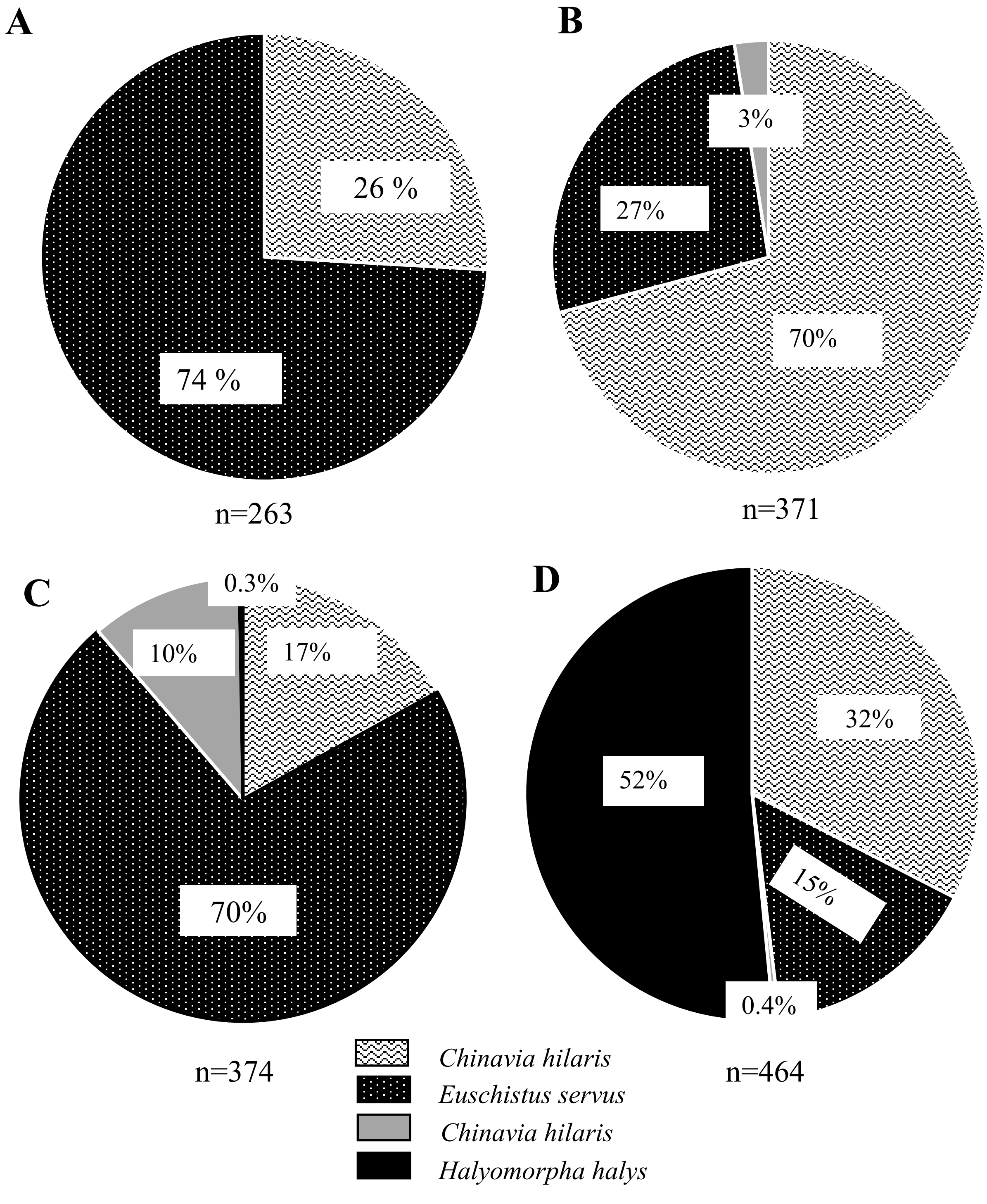

Figure 2.5. Stink bug species composition a) McLean and (b) Hickman in, KY, in 2019 collected by 50-10 sweep net and 50-3.05 m bucket samples on each of 3 sampling dates. Four sampling dates were recorded for (c) Daviess and (d) Hardin counties.

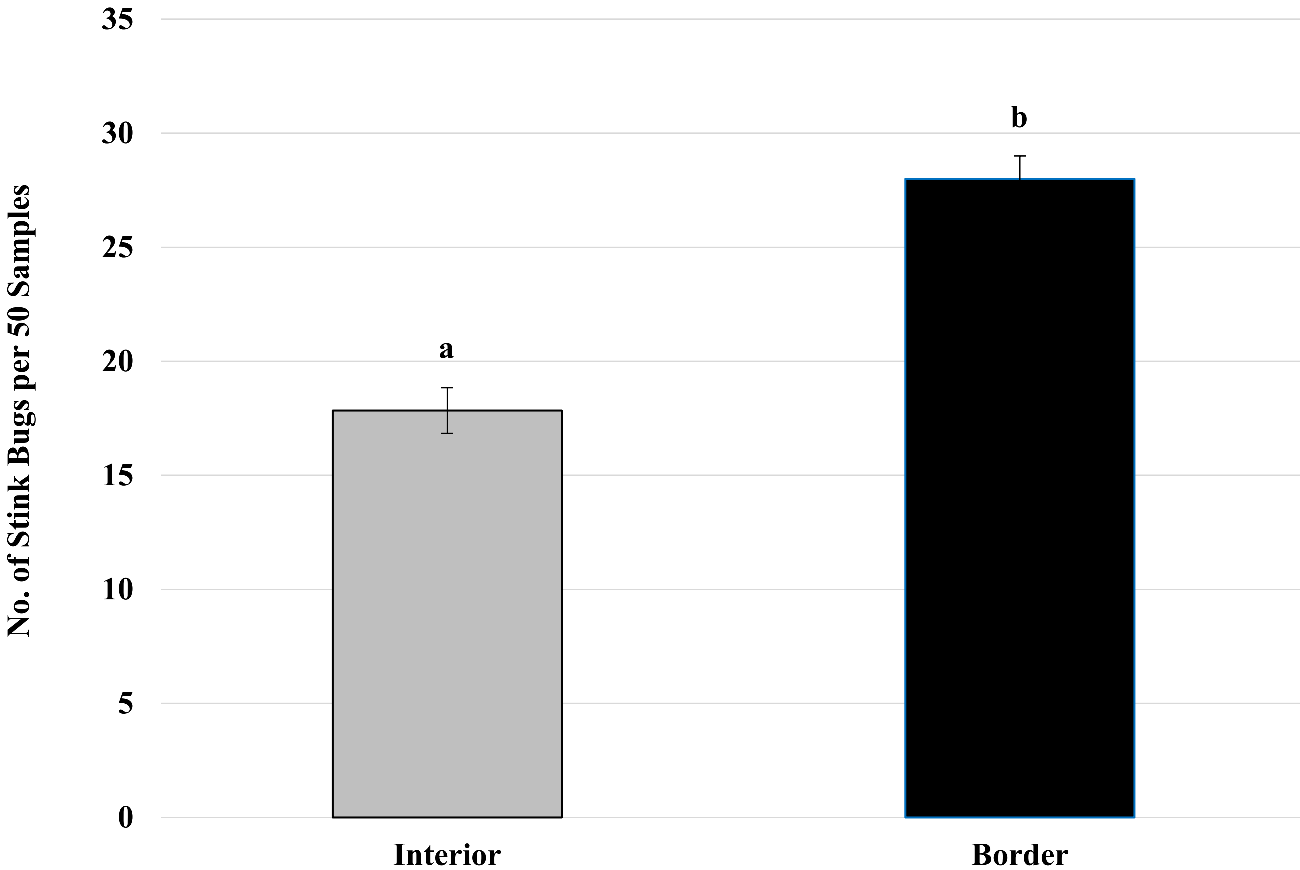

Figure 2.6. Comparison of mean number (+ SE) of stink bugs found per 50 samples throughout all six county field locations in the interior (100 m) and border (5 m) of the field in 2018 and 2019. [a] Means with a different letter are significantly different (Mixed-model ANOVA $P<0.05$)

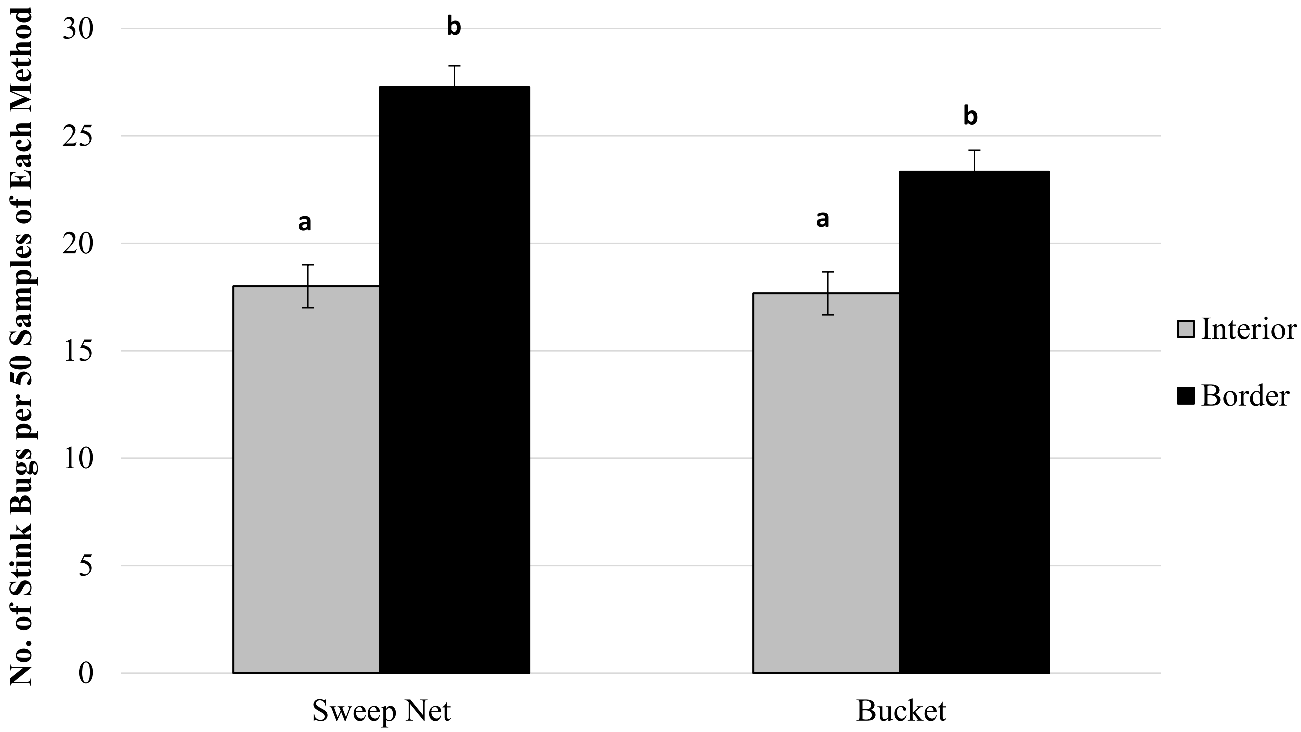

Figure 2.7. Comparison of both sampling methods, sweep net and bucket, based on the mean number (+SE) of stink bugs recorded in the six county field sites. The interior (100 m from border) and border (5 m) were compared for both sweep net and bucket in 2018 and 2019.

[a] means with a different letter are significantly different (Mixed-model ANOVA $P<0.05$)

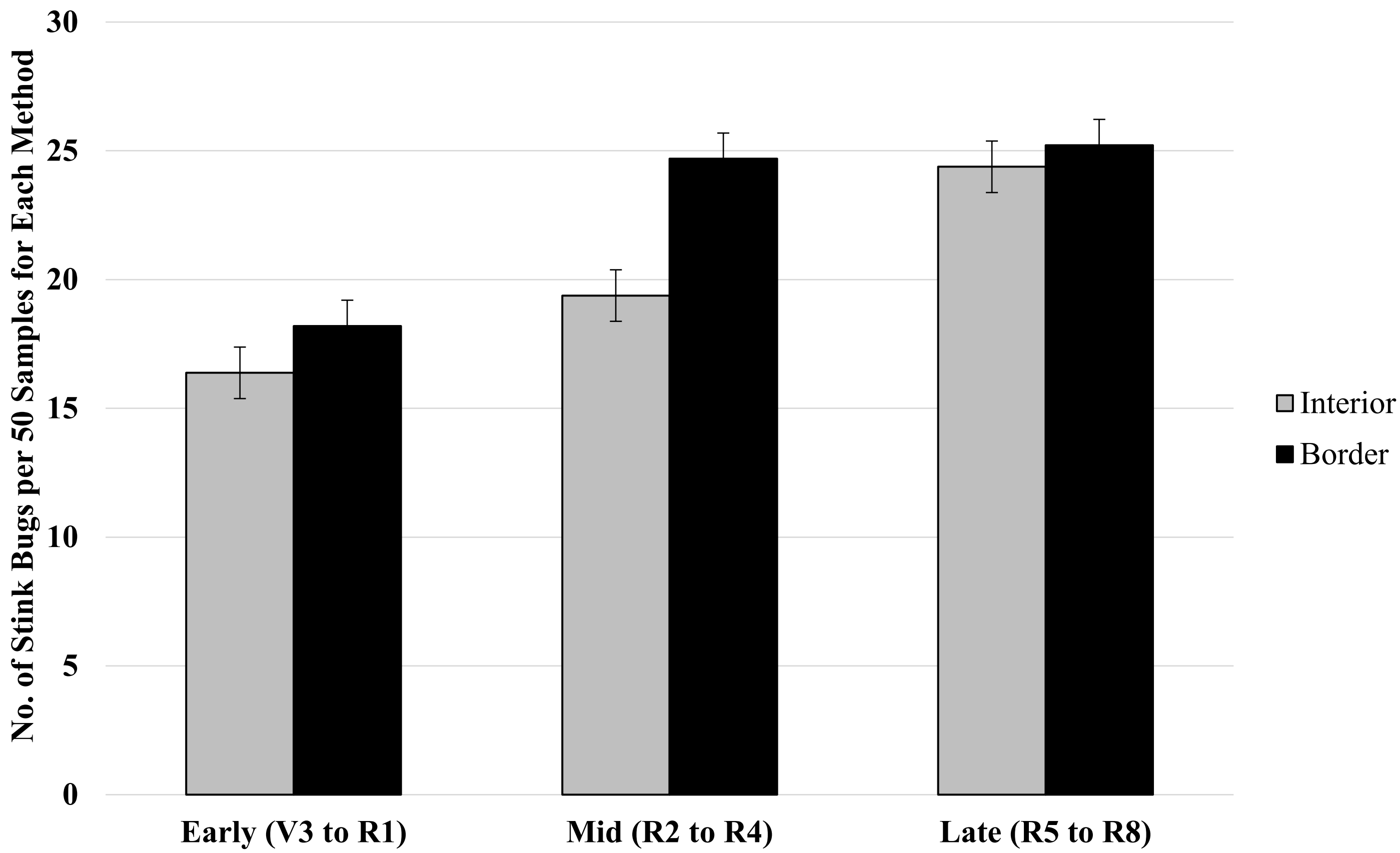

Figure 2.8. Mean number (+ SE) of stink bugs recorded throughout the growing season of all six counties in 2018 and 2019. Early, mid, and late season dates were based on date of sampling and maturity of the soybean. Vegetative stage 3 (V3) to beginning bloom (R1) was considered to be early season. Full bloom (R2) to full pod (R4) was mid-season. Beginning of seed (R5) to full maturity (R8) was late season. Stink bugs recorded for both sampling methods were combined for the interior (100 m) and border (5 m) mean number of stink bugs.

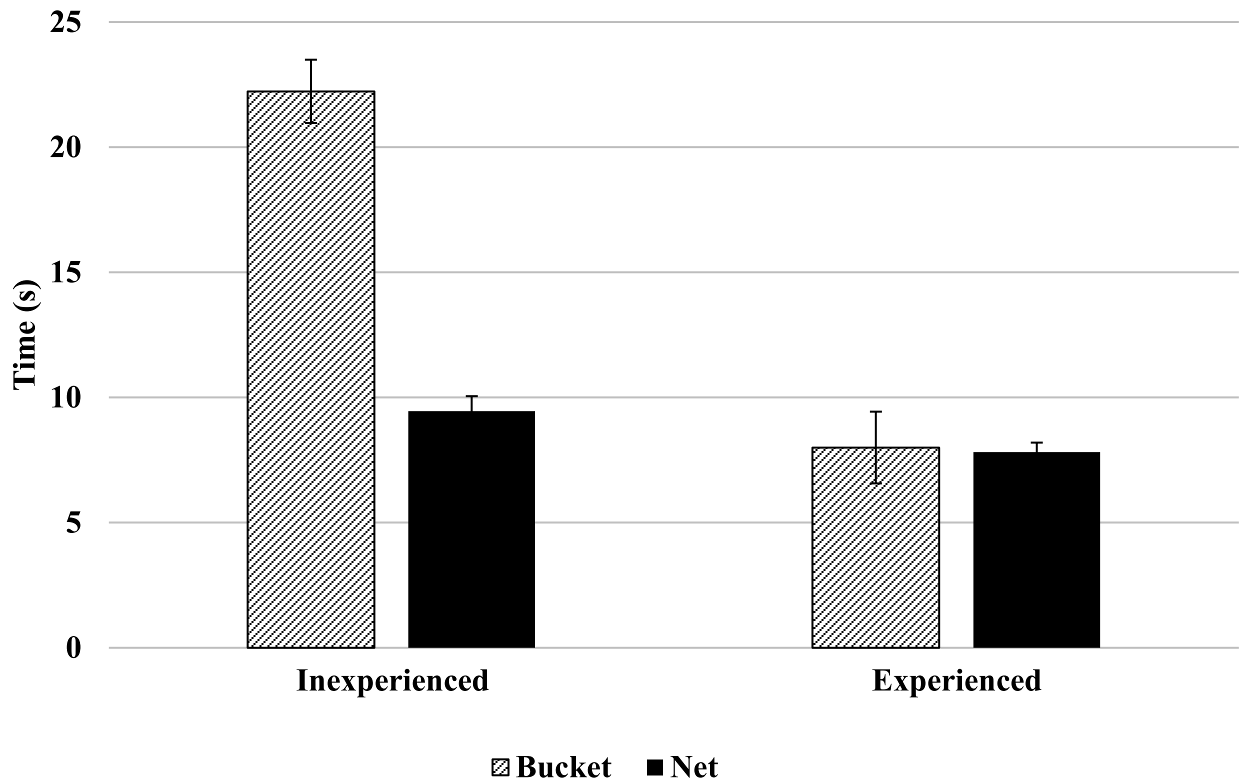

Figure 2.9. Average (+SE) time in seconds recorded for three inexperienced (beginner) and three experienced people surveying stink bugs in R6 soybean. Each subject completed four replicates of 10 sweeps and four replicates of 3.05 m samples for the buckets.

Chapter 3 Comparison of stink bug densities on full and double-crop season soybeans

3.1 Introduction

Cultural practices are critical tactics in any sustainable pest management program. Planting date and maturity groups (MG) are important cultural practices that contribute to pest management by reducing the synchrony of peak pest densities and crop vulnerability. Soybean development is dependent on temperature and day length (Hatfield et al., 2011), so soybeans are categorized by relative MG which are used to determine suitability for season length at different latitudes where they are produced (Summerfield and Wien, 1980). Thirteen maturity groups (000 through X) have been recognized (Singh and Hymowitz, 1999). Maturity groups in the VIII to X are commonly grown in Central and South America (Stowe and Dunphy, 2017). In the mid-southern region in the US, cultivars planted are in maturity groups III to VI. A soybean variety that matures early is sensitive to shorter nights and requires longer days to begin blooming as opposed to late maturing variety which requires more hours of darkness to begin blooming (Hymowitz, 1990). Lower rating groups represent earlier maturing varieties and are more adapted to the shorter growing season in northern parts of the US (Singh and Hymowitz, 1999)

Maturity groups (late) II, III, IV, and V are best suited for Kentucky (Venard et al., 2017). Egli and Cornelius (2009) found that yields started to decrease when planting dates get into late May or early June in Kentucky (Lee and Knott, 2017). The factors that influence the decrease in yields include the possibility of late summer droughts, higher incidence of disease, or buildup of arthropod pest pressure (Salmeron et al., 2014).

Growers in Western Kentucky use double-crop soybean in rotation with corn and winter wheat, which requires a low maturity group (late MG II) as it will be planted after the winter wheat. The central region of the state does not typically use MG II as double-cropping winter wheat and soybeans are practiced less. The central region of Kentucky does not practice double-cropping as wheat is not produced in that region. Planting dates for double-crop soybean are mid to late June with MG II (Lee and Knott, 2017). Double-cropping soybean following wheat harvest often causes delays to the optimum planting dates and may create yield losses of 1.5% each day if the crop is not planted by June 15 (Lee et al., 2017). Late planting along with low MG can decrease the duration of flowering, pod set, and ultimately the seed number (Egli and Bruening, 2000). Despite these disadvantages of late planting, farmers continue to implement double-crop soybean in their practices as it can increase cash flow and profits by having more intensive use of land, equipment, and labor (Holshouser 2015). This tactic also allows for ecological advantages as it can help improve soil quality and reduce the occurrence of erosion (Holshouser 2015).

Many growers in KY also plant full-season soybeans which ranges in MG III to V, with MG IV being the most common maturity group planted (Lee and Knott, 2017). Unlike low MG, maturity groups in full-season soybeans use the complete growing season to fully develop through their vegetative and reproductive stages. Optimal planting dates in western Kentucky for full-season or MG IV are early to mid-May and mid-May in central KY (Lee and Knott, 2017). This is done to avoid late spring frost, which may occur the last weeks of April (Lee and Knott, 2017. About 25% of all soybean production in Kentucky is double-crop (Lee and Knott, 2017).

Insect pest risk in soybean depends on the growth stage and increasing temperatures (Baur et al., 2000). Three properties of soybean physiology are important to understand how it responds to stressors associated with pests; cultivar type, growth stages, and the maturity group (McPherson and McPherson, 2000). Stressors such as low or high temperature, drought, and flooding can stunt soybean growth. Studies conducted in southern states (Arkansas, Georgia, and Louisiana) (Tugwell et al., 1973; McPherson et al., 1996; Boyd et al., 1997) showed that maturity group and planting date affect the abundance of insect pests in soybean. Earlier maturing varieties (low MG) often have less damage when compared to later maturing varieties and earlier plantings are noted to have more damage than compared to late plantings (McPherson and McPherson, 2000). Understanding the physiological growth of soybean is important in managing its pests. Through Decision Support System for Agrotechnology Transfer (DSSAT) soybean simulation growth estimates, soybean in western KY in MG IV planted May 1st reached R5 (beginning seed) on June 22; MG III planted June 1st reached R5 on July 9th (Salmeron and Purcell, 2016). In soybean there are two physiological stages of soybean: vegetative (V_x) and reproductive (R_x). Phytophagous pentatomids can feed on above-ground vegetation but prefer the reproductive stages of soybean due to pod availability: R3 (beginning pod) to R6 (full seed) (Todd and Herzog, 1980; Lee et al., 2013). Stink bugs cause mechanical injury to the seed by inserting mouthparts and releasing digestive enzymes, which break down plant tissue (McPherson and McPherson, 2000). In Kentucky, the green stink bug (*Chinavia hilaris),* brown stink bug *(Euschistus spp),* red-shouldered stink bug *(Thyanta custator)*, and the brown marmorated stink bug (*Halyomorpha halys)* are the pests of great importance as they can directly damage the developing pods and seeds (Koch et al., 2017). Critical stages where soybean is most susceptible to stink bug damage occurs during different periods for each maturity group (McPherson and McPherson, 2000). A two-year study conducted in Mississippi compared three planting dates between two MG (IV, and V) and showed MG IV avoided heavy stink bug densities if planted early (late March- early April) (Gore et al., 2006).

Densities of stink bugs occurring in full season and double crop season soybeans have yet to be directly compared in Kentucky. In this chapter, I determined the influence of each maturity group on stink bug densities and the effects on soybean yield.

3.2 Materials and Methods

These field experiments were conducted at the University of Kentucky Research and Education Center in Princeton, KY (37°05’49.6” N, 87°51’40.9” W) in 2018 and 2019. The climate according to the Köppen Classification is humid subtropical (Cfa) and the predominant soil type is Crider silt loam.

In 2018, soybean fields for both full and double-crop soybean were preceded by a cover crop: winter wheat, *Triticum aestivum* (L.). The wheat was cut down and an application of herbicide dimethenamid-P (Verdict® Powered by Kixor® Herbicide) (0.14 kg/ha $^{-1}$) with glyphosate (Cornerstone® Plus, Agrisolutions™) (rate of 1.24 kg/ha^{-1}) was made. Prior to planting the double-crop soybeans, an application of saflufenacil (Sharpen® Powered by Kixor® Herbicide) at 0.02 kg/ha^{-1} plus glyphosate (Cornerstone® Plus, Agrisolutions™) at 1.24 kg/ha^{-1}, was made on June 15th.

In 2019, full-season soybean was preceded by the 2018 soybean residues and double-crop soybean was planted into wheat residue. A pre-emergence spray of herbicide, with s-metolachlor (Dual II Magnum, Syngenta®) (rate of 0.63 kg/ha^{-1}) was applied to the full season soybean field on May 18th. A second application of herbicide was made June 4th with glyphosate at a dose of 1.24 kg/ha^{-1}. The full season field had a heavy presence of weeds therefore a final application of glyphosate at a dose of 1.24 kg/ha^{-1} was made on July 26th.

In 2018 and 2019 both fields had 20 replicate plots for each maturity group. Seeds used for these two maturity groups were treated with systematic insecticide Gaucho 600 SC (imidacloprid). This was done to replicate growers use of insecticide treated seeds to treat pre- emergence pests including wireworms and seedcorn maggot. The soybeans were planted using 38 cm row spacing with a four-row precision Kincaid Voltra Planter (Kincaid Equipment Manufacturing, Haven, KS).

The plots were 6 m long and 1.5 m wide with 1.5 m wide alleys between each plot. Seeding rates were adjusted to 247,000 seeds/hectare for full season and 345,800 seeds/hectare in double crop based on germination rates (90% in 2018 and 80% in 2019) listed on the bags of seed, 10% assumed stand loss, and 38 cm width row (Table 3.1).

Plant stand counts were conducted 21 days post emergence to ensure the proper establishment of the crop. Due to the low stand count, a second planting of full-season soybean was done in the same field on June 6th, 2019. Environmental conditions (heavy rains) and logistical issues delayed the planting of double-crop soybean in 2019. Post planting, July 7th, temperatures reached 32 ºC, which caused unfavorable conditions for soybean emergence. Stand counts for double-crop soybean were poor; no analysis was conducted.

Visual counts of stink bugs were conducted from V_E to V_3 to ensure no damage was inflicted to the developing soybean plant. Once most soybean plants were past V_3, 10 pendulum sweeps were taken at the top to mid canopy of two rows of soybean in each plot with a sweep net. The numbers of all life stages of stink bugs were recorded.

The established economic thresholds for KY of 3 stink bugs for 25 sweeps for R1-R3 growth stage and 9 stinkbugs per 25 sweeps at R4-R6 growth stage were considered if there was need for chemical control. However, since 10 sweeps were taken per plot, the threshold was modified to 1.2 stink bugs and 3.6 stink bugs per 10 sweeps, with respect to soybean physiology. The insecticide to be used was Warrior II with Zeon Technology (rate 0.01 kg/ha^{-1}) (lambda-cyhalothrin, Syngenta Crop Protection, Greensboro, NC).

3.2.1 Statistical Analysis

Full-season and double-crop soybean were analyzed together to compare densities of stink bugs and separately to look at the weekly recorded densities of stink bugs for each maturity group in 2018. In 2019, the full season soybean was analyzed based on the different densities observed in each sampling date. A student's t-test using SAS 9.3 (SAS Institute, Cary, NC) determined if there were differences between the mean densities recorded for each sampling period for both maturity groups. A confidence interval was set at 95% or $P \leq 0.05$.

3.3 Results

Significant differences were not found in the numbers of stink bug densities among the two maturity groups in 2018 throughout the growing season (Figure 3.1; $F_{2,76} = 1.79$, $p = 0.19$). These numbers were below economic thresholds for both MG and years. Total numbers of all stink bug nymphs and adults per species found infesting full and double-crop soybean during the growing season in 2018 are shown in Figures 3.2 and 3.3 respectively. The highest recorded number for *C. hilaris* for both maturity groups was in mid-July to mid-August (Figures 3.2 and 3.3). Stink bugs densities were documented in the late vegetative and early reproductive stages of these MGs. Similar information for full-season soybeans in 2019 is in shown in Figure 3.4. In 2019, mean numbers of stink bugs in full-season soybeans are shown in figures 3.5. Most plants in full-season and double crop soybeans reached R_4 (pod fill) by July 20th and August 3rd in 2018; and there were not distinctive peaks in stink bug densities in both maturity groups. Whereas in 2019 there was delay on reaching R4 (July 26th). This reproductive stage is important as stink bug infestations generally increase during this period and may significantly impact the quality of the soybean yield. Stink bug densities were observed to increase during the late vegetative and early reproductive stages of both the full and double-crop season soybean.

The total cumulative percentages for species composition in 2018 (full season and double crop) and 2019 (full season) are presented in Figures 3.6, 3.7, and 3.8, respectively. *Chinavia hilaris* was the predominant species collected, accounting for 68.3% (Figure 3.6) for full season and 63.4% (Figure 3.7) for double-crop soybeans in 2018; and 67.3 in full season in 2019.

The average (±SEM) yields recorded for full and double-crop soybean were 2270.31 (±SEM) kg /ha and 2217.83 31 (±SEM) kg /ha, respectively in 2018. The yields for both full and double-crop soybean showed no differences (Figure 3.9; $F_{1,33}$=1.73, p = 0.19). The recorded yield for full season soybean in 2019 was 2139.24 (±SEM) kg per ha. Due to unfavorable planting conditions, double-crop soybean was planted almost four weeks later than the recommended optimal planting date in 2019. This led to poor germination rate and low stand count. Stand counts were on average 2 plants per 0.30 m, which was equivalent to 69,700 plants per acre. Ultimately, 2019 double-crop soybean was dropped from the comparative analysis. No economic thresholds for stink bugs or any other soybean pest was met, therefore no foliar insecticide applications were made.

3.4 Discussion

In 2018, the number of stink bugs recorded in early- and late-maturing cultivars varied throughout the season. The populations of stink bugs found in each maturity group was dependent on the growth stage. Both maturity groups in 2018 had higher stink bug numbers present between V_3 to R_4; full-season soybean had more stink bugs present earlier in the growing season and double-crop soybean had a more stink bugs present in the mid to late growing season. In Midwestern states, overwintering adults colonize soybean during R1 or flowering for maturity groups III and IV (Koch et al., 2017). Stink bugs are known to directly damage the pod/seed and severity is dependent on the stage of soybean (McPherson and McPherson, 2000). Although *Nezara viridula* (L.) (southern green stink bug) is not commonly found in Kentucky, a study showed this stink bug's damage delayed maturity when infestations occurred during pod set and filling (R3 to R5), thus resulting in yield reductions (Beothel et al., 2000).

There are many studies addressing the effects of environmental stressors attributed to each soybean MG (Zhang et al., 2007; Salmeron et al., 2014); however, description of the impact insect pests have on each MG is generally unknown. The results in this study showed that stink bugs colonize soybean based on growth stage due to food availability. Potential future studies include investigating the use of a trap crop for soybean in Kentucky. Trap crops are plants grown to intercept insect pests before they infest a main crop. Sequential trap cropping where the trap crop is planted earlier or later than the major soybean to enhance the attractiveness of the trap crop to the target pest may be used (Shelton et al., 2006). A two-year study conducted in Arkansas showed using MG III and IV as a trap crop for MG V, did not reduce the number in the main crop as the trap crops were only attractive for about 4 to 5 weeks (Smith et al., 2009). Trap crop soybean was treated with lambda-cyhalothrin aerially when economic thresholds of 9 stink bugs per 25 sweeps were met. This study also showed the two to three-month planting period and the adjacent fields with different MG can ultimately affect the success of the trap crop as stink bugs are highly mobile; this can cause new establishment of stink bugs in non-infested fields (Smith et al., 2009). Given the outcome of this study, a trap crop of the same MG may have to be included to the regimen to prevent movement of stink bugs into the major crop.

It is important to note, in this study stink bugs remained below economic threshold densities. Further studies must be conducted to understand the population dynamics occurring in both maturity groups when stink bug densities are above economic thresholds. Densities observed in both years were lower than those reported by growers in Kentucky. Economic thresholds are typically met during R6 in Kentucky soybean.

Table 3.1 Full-season and double-crop soybean planting dates, cultivar, and maturity groups used for field trials in Princeton, KY; 2018 and 2019.

Soybean	Cultivar	Maturity Group	Planting Date	Seeding Rate
Full-Season	470 RR/STSn[1]	4.7	05/18/2018	304,000 seeds ha-^{1}
Full-Season	470 RR/STSn[1]	4.7	05/22/2019	324,000 seeds ha^{-1}
Full-Season	AG41X8 RR2X/SR[2]	4.1	06/06/2019	324,000 seeds ha^{-1}
Double-Crop	286 RR2Y/STSn[1]	2.8	06/19/2018	428,000 seeds ha^{-1}
Double-Crop	AG27X7 RR2X[2]	2.7	07/07/2019	479,000 seeds ha^{-1}

[1] Caverndale Farms Brand Seeds, Danville, KY
[2] Asgrow Seed Co LLC, Bayer Ag, Germany

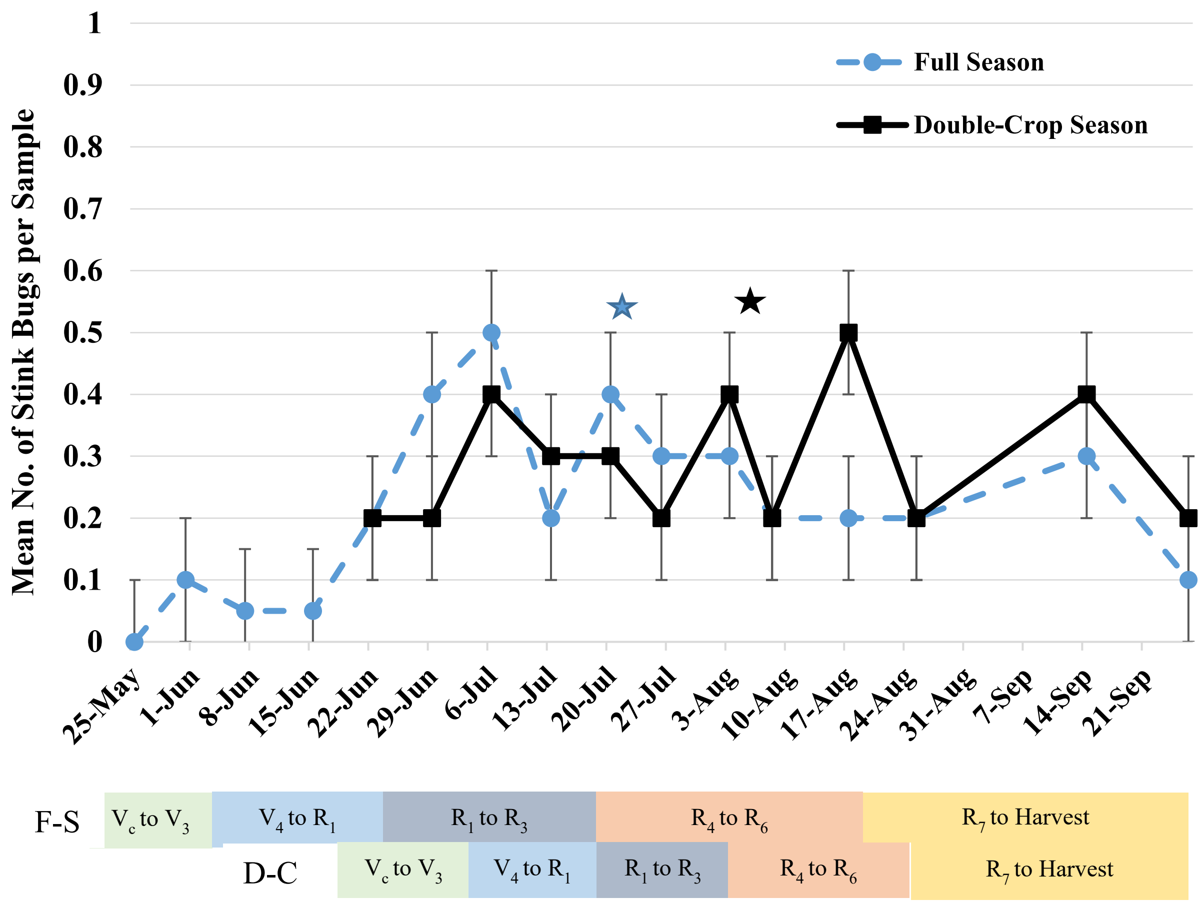

Figure 3.1 Mean (±SEM) number of stink bugs occurring in full and double-crop soybean in 2018. Abbreviations 'FS' is full season soybean and 'D-C' is double-crop soybean. Visual counts for full season soybean was conducted from May 25th to June 7th; visual counts for double crop was conducted from June 22nd to June 29th. Sampling with a sweep net was conducted from June 15th to harvest for full season soybean; sweep net was used from July 6th to harvest for double crop soybean. Blue star indicates where full season soybean reached R_4. Black star indicates where double-crop soybean reached R_4. No differences (P<0.05) were found between maturity groups ($F_{1,76}$= 1.79, p = 0.19).

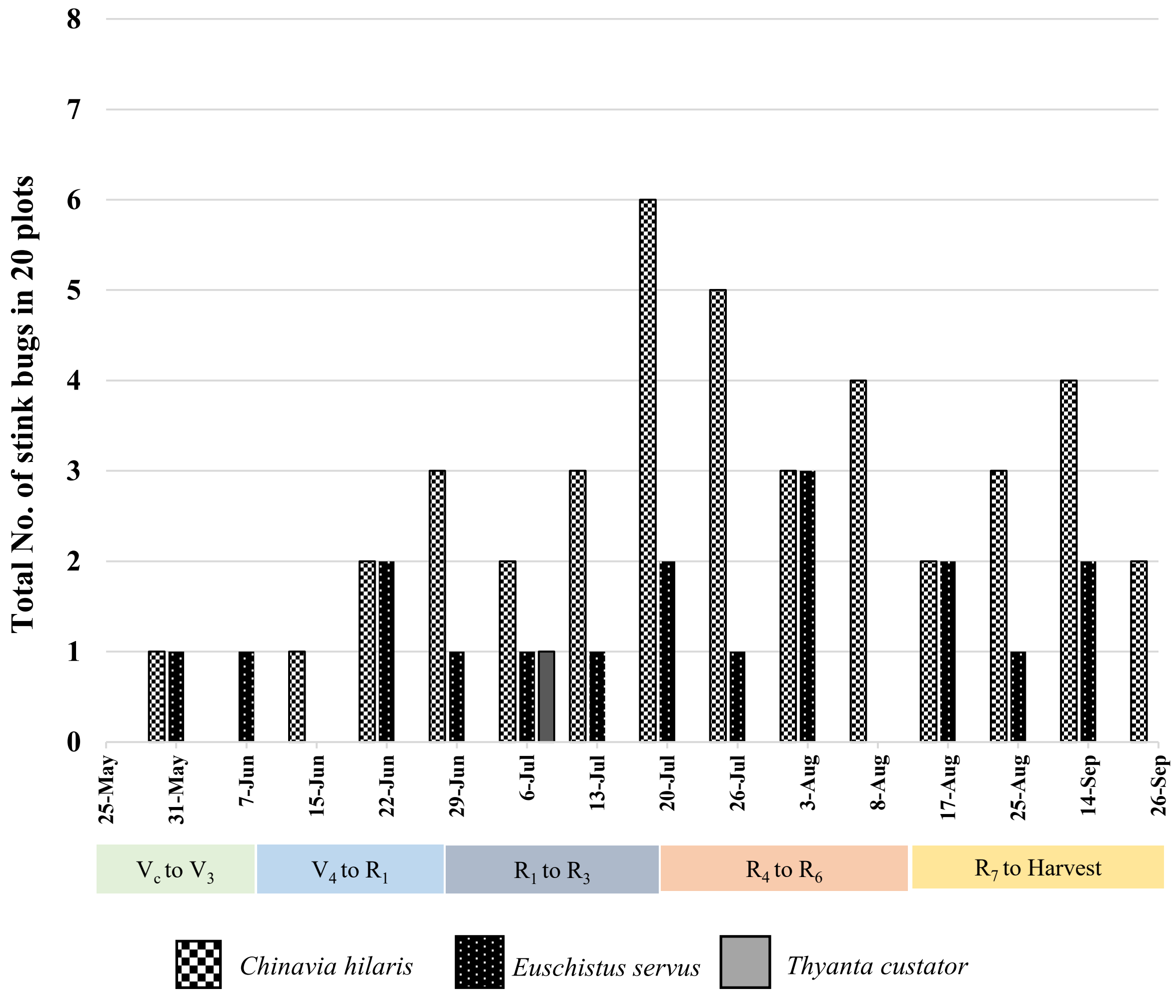

Figure 3.2 Total stink bug species per sampling date in full season soybean in 2018. Visual counts were conducted from May 25th to June 7th. Sampling with a sweep net was conducted from June 15th to harvest. V_X represents the vegetative stage and R_X represents the reproductive stage of the crop.

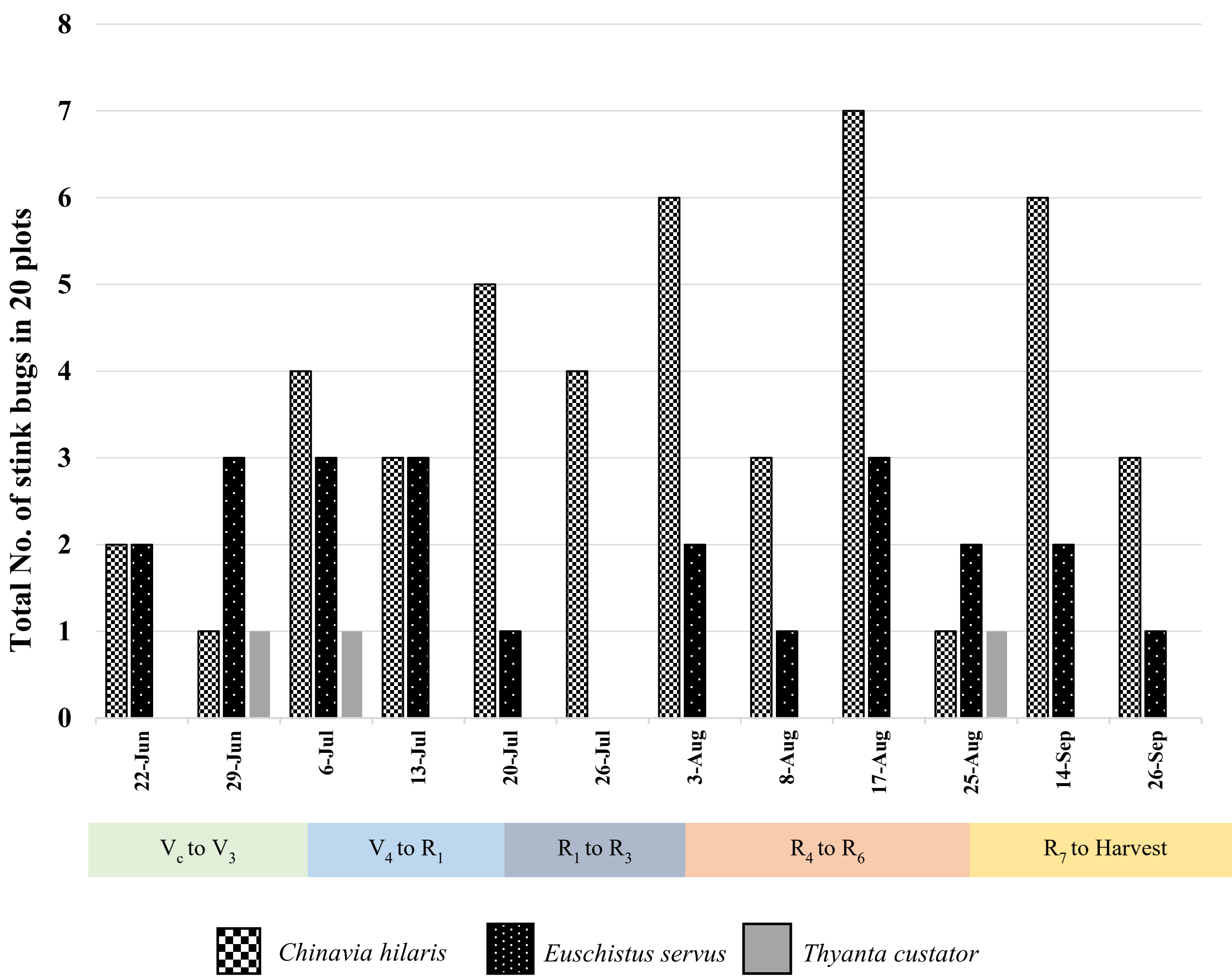

Figure 3.3 Total stink bug species per sampling date in double-crop season soybean in 2018. Visual counts were conducted from June 22nd to June 29th. Sampling with a sweep net was conducted from July 6th to harvest. V_X represents the vegetative stage and R_X represents the reproductive stage of the crop.

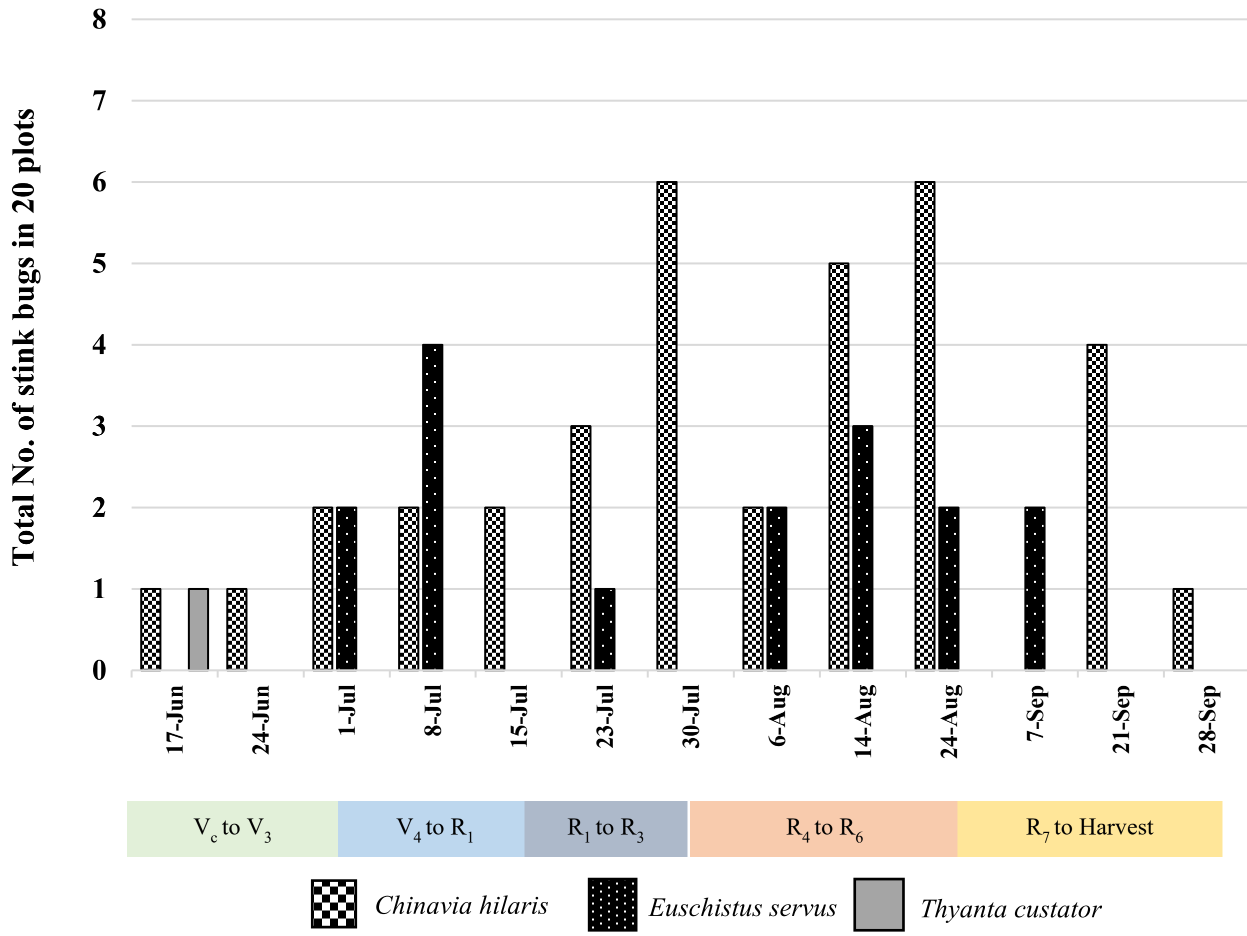

Figure 3.4 Total stink bugs by species per sampling date in full season soybean in 2019. Visual counts were conducted from June 17th to June 24th. Sampling with a sweep net was conducted from July 1st to harvest. V_X represents the vegetative stage and R_X represents the reproductive stage of the crop.

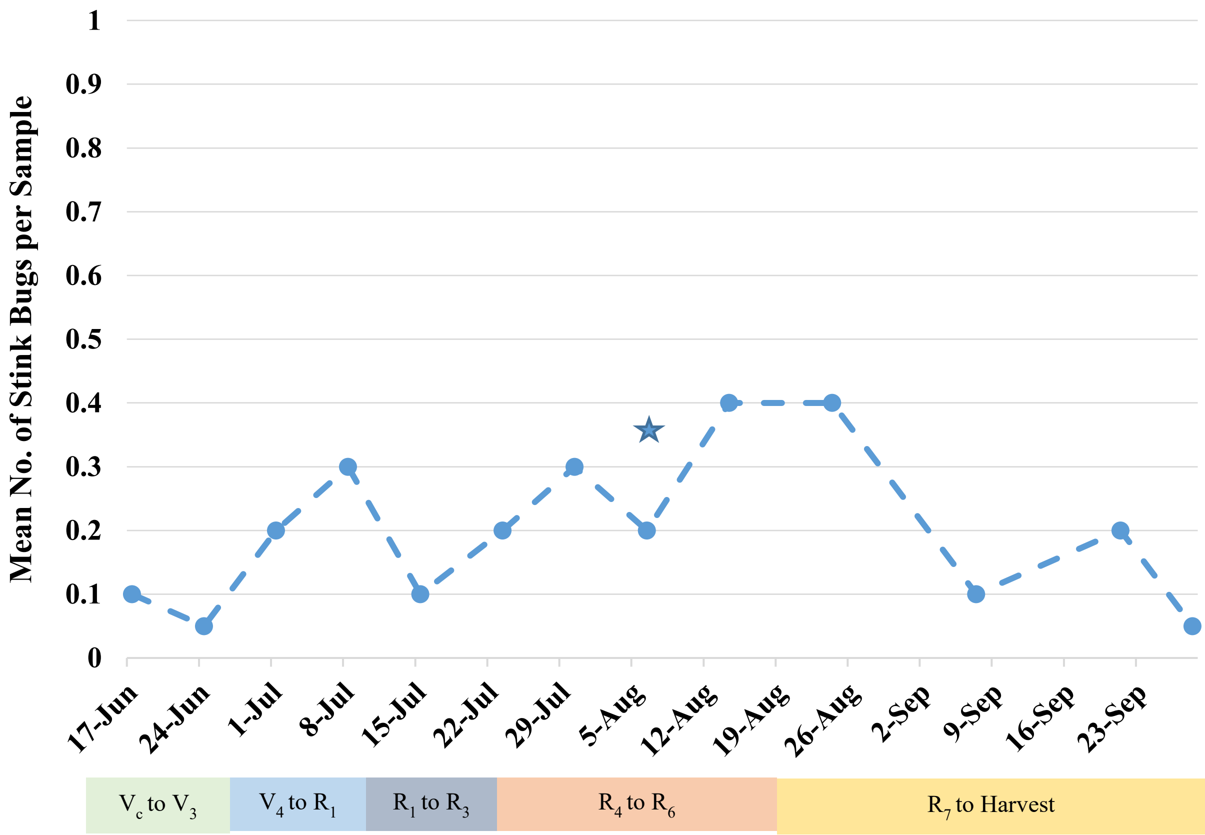

Figure 3.5 Mean number of stink bugs occurring in full-season soybean in 2019. Visual counts were conducted from June 17th to June 24th. Sampling with a sweep net was conducted from July 1st to harvest. V_X represents the vegetative stage and R_X represents the reproductive stage of the crop. Blue star indicates where full season soybean reached R_4.

Figure 3.6 Cumulative stink bug species composition collected from full-season soybean in 2018 in weekly sweep-net sampling.

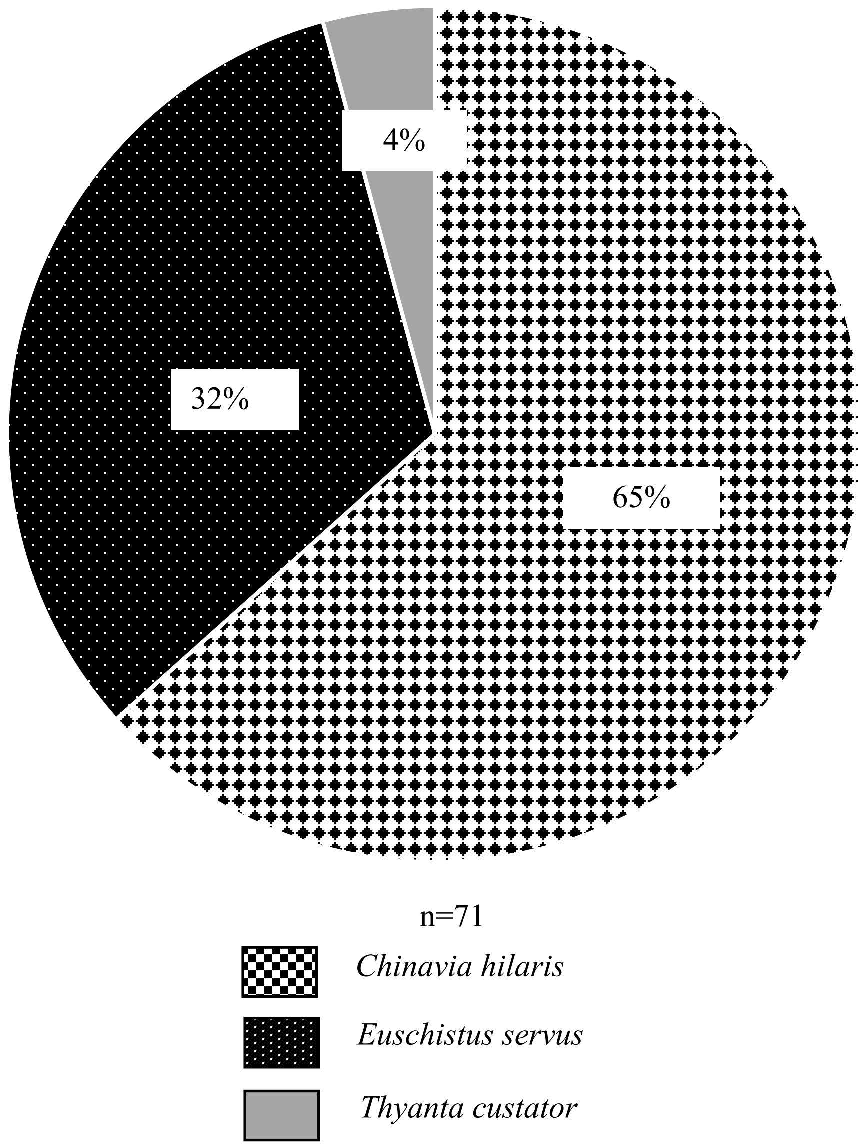

Figure 3.7 Cumulative stink bug species composition collected from double-crop season soybean in 2018 by weekly sweep net sampling.

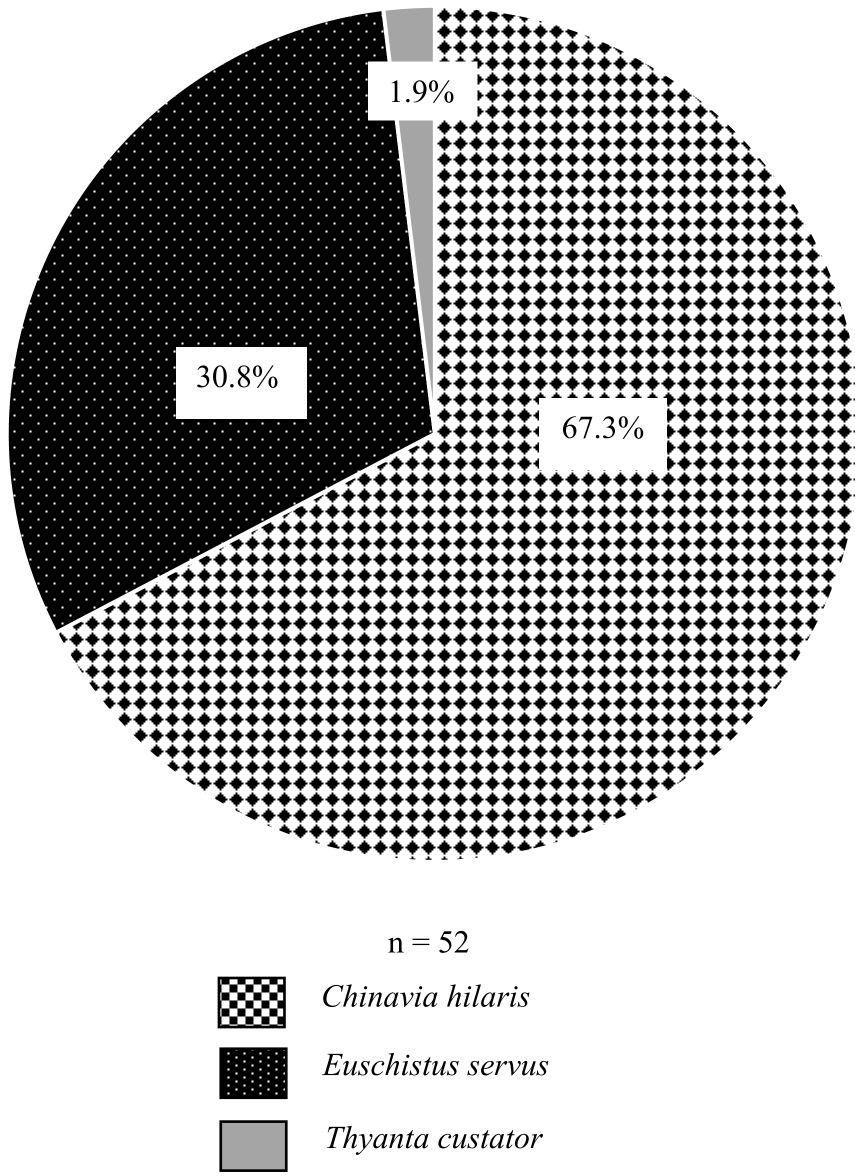

Figure 3.8 Cumulative stink bug species composition collected from full-season soybean in 2019 by weekly sweep net sampling.

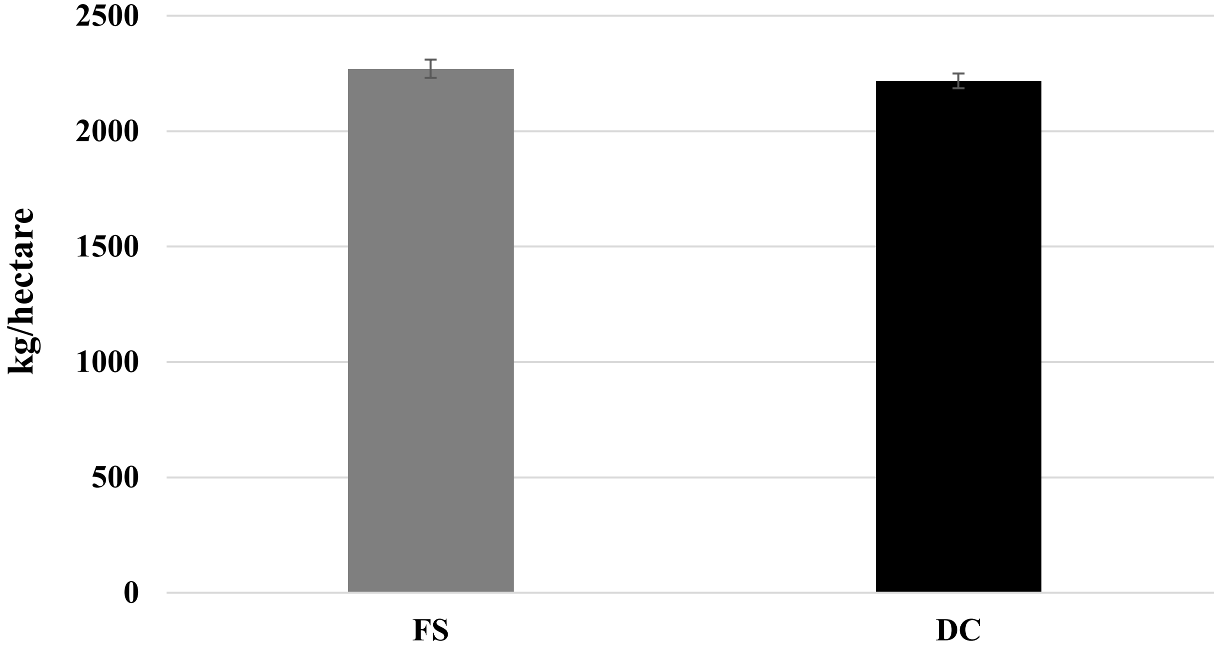

Figure 3.9 Yields (±SEM) of full season (FS) and double crop (DC) soybeans in 2018. No differences (P<0.05) were found between yields for both maturity groups ($F_{1,39}$=1.02 and p = 0.31).

Chapter 4: Comparison of control tactics for the management of stink bugs

4.1 Introduction

Soybean is a major cash crop in the state of Kentucky, producing 98.4 million bushels/acre in 2018, which was valued at $910.6 million (USDA-NASS, 2018). In Kentucky, soybean farmers rely heavily on insecticides as they are confident with control they have provided in the past and their rapid effectiveness. Stink bugs are a major pest of concern to quality of soybeans as they cause direct damage to seed pods (Koch et al, 2017). Stink bugs use their proboscis to penetrate soybean tissue and break it down with digestive enzymes (McPherson and McPherson, 2000). This results in pod loss, aborted or smaller seeds, and reduced germination (Todd and Herzog, 1980; Panizzi and Slansky, 1985; McPherson and McPherson, 2000).

To protect the yield and quality of soybean, applications of insecticides are often used in calendar-based programs to reduce the risk of yield losses associated with these soybean pests. While use of insecticides is a tactic in IPM, use of calendar sprays is not. Calendar sprays are predetermined sets of pesticide applications during a growing season, regardless of pest densities or presence. When planning pesticide use under IPM programs, economic thresholds are taken into consideration during the decision process, particularly for key pests that frequently reach economic levels. Economic thresholds for stink bug species attacking soybean in Kentucky are 3 stink bugs and 9 stinkbugs for 25 sweeps during R1-R3 and R4-R6 growth stages, respectively (Johnson et al., 2015).

Calendar applications of insecticide often occur along with a fungicide as a preventative measure as opposed to reactionary action as a result of pest levels. The calendar use of insecticides can result in economic and ecological issues in soybean crops (Kopit and Pitt-Singer, 2018). Unnecessary insecticide applications inflate pest control costs, can impact pollinators, reduce natural enemies of pests which in turn can trigger pest resurgence and secondary-pest outbreaks, and promote insecticide resistance (Kopit and Pitt-Singer, 2018).

Kentucky growers may use neonicotinoid treated seeds and different foliar applications of pyrethroid, carbamates, organophosphates, or insecticide premixes (Villanueva, 2017). Changing mode of action (MOA) may not be an economical alternative because insecticides with distinct MOA's may be more expensive. Constant exposure to the same MOA may reduce sensitivity to groups of insecticides with similar MOA (Snodgrass et al., 2005). Stink bug susceptibility to insecticides has been documented to vary by species; *Euschistus servus* is less susceptible to pyrethroids and organophosphates than *Chinavia hilaris* (Willrich et al, 2003; Snodgrass et al., 2005).

To develop sustainable long-term soybean practices, integrated pest management must be adopted in lieu of preventive calendar sprays. In this chapter I compared stink bug densities that occur with the use of calendar-based applications -- a single spray, two or three sprays, and economic threshold based (IPM) sprays and their effect on yields.

4.2 Methods and Materials

These field experiments were conducted at the University of Kentucky's Research and Education Center in Princeton, KY (37°05'49.6" N, 87°51'40.9" W) in 2018 and 2019. In 2018, the soybean field was preceded by winter wheat, *Triticum aestivum* (L.).

In 2018, the soybean field was preceded by winter wheat, *Triticum aestivum* (L.). In 2019, soybean was preceded by the 2018 soybean residues. A pre-emergence spray of herbicide, with s-metolachlor (Dual II Magnum®, Syngenta®) (rate of 0.63 kg a.i. /ha^{-1}) was applied to the full season soybean field on May 18th. A second application of herbicide was made June 4th with glyphosate

(Cornerstone® Plus, Agrisolutions™) at a rate of 1.24 kg a.i. /ha^{-1}. A final application of glyphosate at a rate of 1.24 kg a.i. /ha^{-1}. was made July 26$^{th.}$

In 2018 and 2019, soybean seeds were treated with systematic insecticide Gaucho® 600 SC (imidacloprid). Soybeans were planted with 38 cm row spacing using a four-row precision Kincaid Voltra Planter (Kincaid Equipment Manufacturing, Haven, KS). The plots were 6 m long and 1.5 m wide with 1.5 m wide alleys between each plot. Seeding rates were adjusted to 340,469 seeds/hectare for full season based on germination rates (90% in 2018 and 80% in 2019) reported on seed bag, 10% assumed stand loss, and 38.1 cm between rows. Cultivars, maturity groups, planting dates and seedling rates for studies conducted in 2018 and 2019 are shown on Table 4.1. A second planting date occurred in 2019 due to poor germination rates.

Treatments were categorized as "1-Spray", "3-Spray", and "IPM/Control" in 2018; "1-Spray", "2-Spray", and "IPM/Control" for 2019 with respects to the number of preplanned applications occurring in each plot, or the threshold trigger to apply insecticide. Treatments under "IPM/Control" would only receive insecticide applications if the economic threshold was met. Soybean was treated with a foliar application of Warrior II with Zeon Technology® at a rate of 0.03 kg a.i./ha^{-1} (lambda-cyhalothrin, Syngenta® Crop Protection, Greensboro, NC). Spray dates for 2018 and 2019 are shown on Table 4.2 and 4.3, respectively.

Due to rains and delayed planting, only two sprays were used in the 3-spray preventative program in 2019. Sampling for stink bugs was done with use of a sweep net; 10 pendulum sweeps were taken at the top to mid canopy of two rows of soybean. Economic thresholds for stink bugs at R1-R3 and R4-R6 growth stages were used to determine the need for chemical control in the IPM plots. With only 10 sweeps per plot, the threshold was scaled to 1.2 stink bugs and 3.6 stink bugs per 10 sweeps, with respect to soybean physiology. The number of all life stages of stink bugs were recorded.

Statistical Analysis 4.2.2

Arrangement of plots followed a randomized complete block design for the Control/IPM, 1-Spray, and 3-Spray treatments. A repeated-measures ANOVA test was analyzed with PROC GLIMMIX (SAS 9.4; SAS Institute Inc. Cary, NC) to compare the stink bug numbers across treatments over each season.

4.3 Results

In 2018, stink bug densities did not reach economic threshold, therefore no IPM based sprays were applied. While stink bug densities tended to be lower in the one-spray program, there were no significant differences in densities between the three treatments ($F_{2,18} = 2.03$, p= 0.15; Fig. 4.1) in 2018. Yields from each of the treatments were similar ($F_{2,9} = 0.35$, p= 0.71; Fig. 4.2).

In 2019, no insecticide applications were made based on economic thresholds because stink bug densities remained below threshold values, the highest mean density being on July 13th with 0.3 stink bugs per 10 sweeps in 20 plots (Fig 4.3). No differences were observed in stink bug densities between treatments ($F_{2,18} = 1.95$, p= 0.14; Fig. 4.3). Yields were similar for each of the treatments ($F_{2,9} = 2.20$, p= 0.17; Fig. 4.4).

In both years, the predominant species was *C. hilaris* accounting for 64% of all stink bugs collected in 2018 and 71% in 2019. This species was followed by *E. servus* with 34% in 2018 and 28.5% in 2019. *Thyanta crustator* was the species least abundant with 1.8% in 2018 and 0.5% in 2019.

4.4 Discussion

No differences in stink bug numbers or yield among treatments for both years were found across treatments, due to the low stink bug numbers. Small plot size and highly mobile nature of the stink bugs may have also contributed the non-significant differences in densities among treatments (McPherson and McPherson, 2000). When the small plots were disturbed, stink bugs may have moved between plots. During sampling, the stink bugs were observed to drop and fly away if the soybean was disturbed. Stink bugs are known to drop or moved from vegetation that has been disturbed; sampling the small plot may have caused them to relocate to adjacent vegetation (McPherson and McPherson, 2000). In years with low stink bugs populations, calendar sprays did not increase yields as sprays only have the potential to prevent yield loss. The practice of IPM based sprays reduced the number of insecticide applications without yield loss.

In both years, no threshold-based insecticide applications occurred due to densities not reaching economic threshold. Growers may reduce costs, such as wear and tear of equipment, fuel, labor, and insecticide costs, associated with insecticide applications (totaling about $40 a hectare) in years where densities are low through the use of weekly scouting in contrast to calendar-based insecticide applications. The cost of hiring soybean consultants may cost a grower from $15-22 depending on the number of hectares surveyed.

Natural predators occurring in soybean fields are often a forgotten ecological service to growers. Insecticides used in foliar applications for stink bugs are not target-pest specific and can also reduce their densities (Sosa-Gómez et al., 2009). Natural enemies such as *Telenomus podisi* (Ashmead) (Hymenoptera: Platygastridae), play an important role in parasitizing stink bug egg masses (Capinera, 2001). These natural enemies attack the host in its initial, most-susceptible phase of development, have short development cycles, a high searching capacity, a high reproductive potential and a predominance of females (Capinera 2001). Another pentatomid parasitoid native to Kentucky, *Trichopoda pennipes* (Fabricius) (Diptera:Tachinidae), can be greatly affected by insecticide use. Tillman (2006) showed that *T. pennipes* was more sensitive to insecticides such as cyfluthrin, dicrotophos, and oxamyl than its host, *Nezara viridula*. Applying unnecessary calendar sprays of insecticides reduces the densities and impact of natural enemies, particularly during periods of *T. pennipes* activity. This may result in higher levels of crop injury, need for additional sprays, or pest resurgence.

Along with the probability of inducing pest resurgence, secondary pest outbreaks can also occur with prophylactic insecticide applications. Secondary pest outbreaks occur when there is an increase in a non-target pest species after an insecticide application (Hardin et al., 1995). A case study on fresh-market tomatoes showed the biological control agent for the leafminer, *Liriomyza sativae* (Diptera: Agromyzidae), was negatively affected when applications for the tomato fruitworm were applied, leading to a resurgence of the leafminer (Johnson et al., 1980). In neighboring states of Kentucky, the invasive *Aphis glycines* (Matsumura) (Hemiptera: Aphididae) has been a notorious secondary pest. This species of aphid is resistant to many pyrethroids and can become a problem post application due to lack of natural enemies. Growers in states such as Illinois and Indiana may see yield losses of up to 50% (Ragsdale et al., 2007).

Unnecessary use of insecticides reduces sustainability through increased cost of production without a corresponding increase in yields, fostering more rapid development of insecticide resistance, potential to cause secondary pest outbreaks, and has ecological impact on natural enemies of pests and pollinators. Using weekly scouting and economic thresholds can limit unnecessary insecticide applications and may help growers better achieve sustainably sound management practices.

Table 4.1 Cultivar, maturity groups, and planting dates used for field trials in Princeton, KY; 2018 and 2019.

Cultivar	Maturity Group	Planting Date	Seeding Rate
470 RR/STSn[1]	4.7	05/18/2018	304,000 seeds ha-[1]
470 RR/STSn[1]	4.7	05/22/2019	324,000 seeds ha^{-1}
AG41X8 RR2X/SR[2]	4.1	06/06/2019	324,000 seeds ha^{-1}

Table 4.2 Application dates of each treatment (Warrior II with Zeon Technology®) during the 2018 soybean growing season.

Treatments	**July**	**August**	**September**
1-Spray	1 (July 20)	-	-
3- Spray	1 (July 20)	1 (Aug 3)	1 (Sep 14)
IPM/Control	-	-	-

Table 4.3 Application dates of each treatment (Warrior II with Zeon Technology®) in 2019 soybean growing season.

Treatments	**July**	**August**	**September**
1-Spray	1 (July 13)	-	-
2- Spray	1 (July 13)	1 (Aug 8)	-
IPM/Control	-	-	-

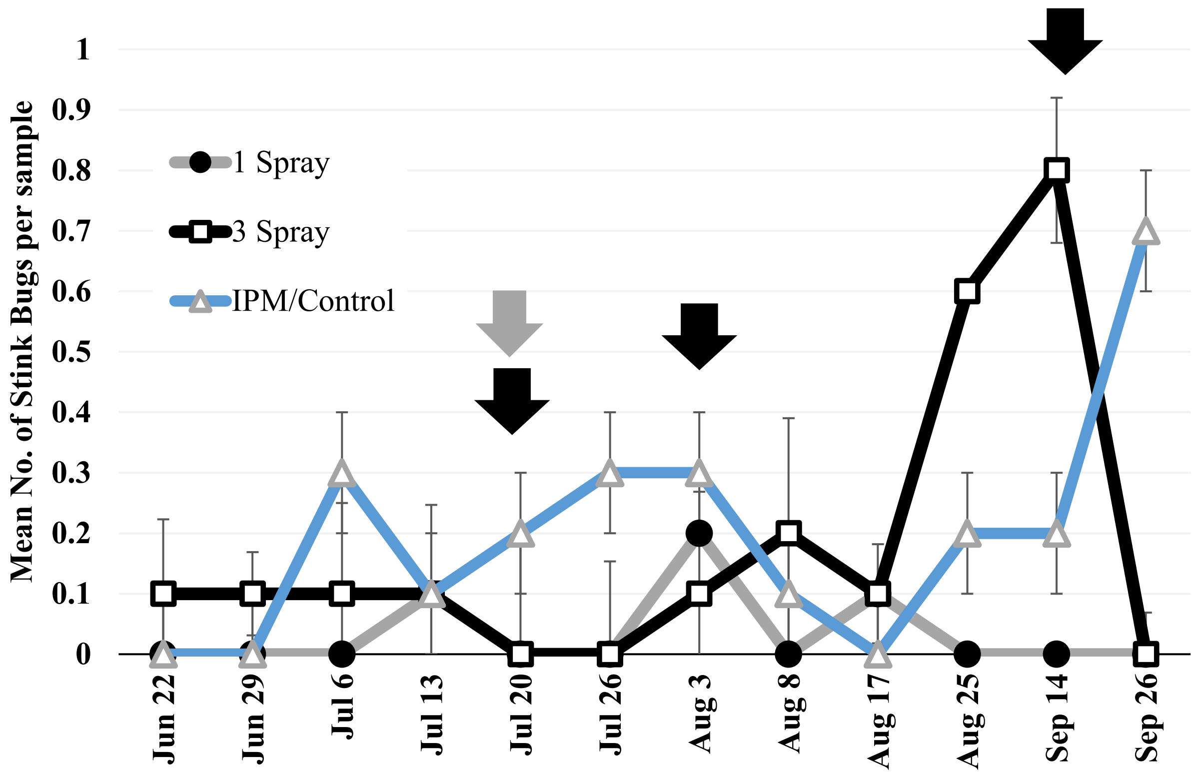

Figure 4.1 Mean numbers (±SEM) of stink bugs per 20 plots under two calendar spray regimes (one and three-spray) compared to IPM/Control based sprays in 2018. Grey arrow indicates application date for the one-spray program. Black arrows indicate the application date for the three-spray program. No differences were observed ($F_{2,18} = 2.03$, $p = 0.15$).

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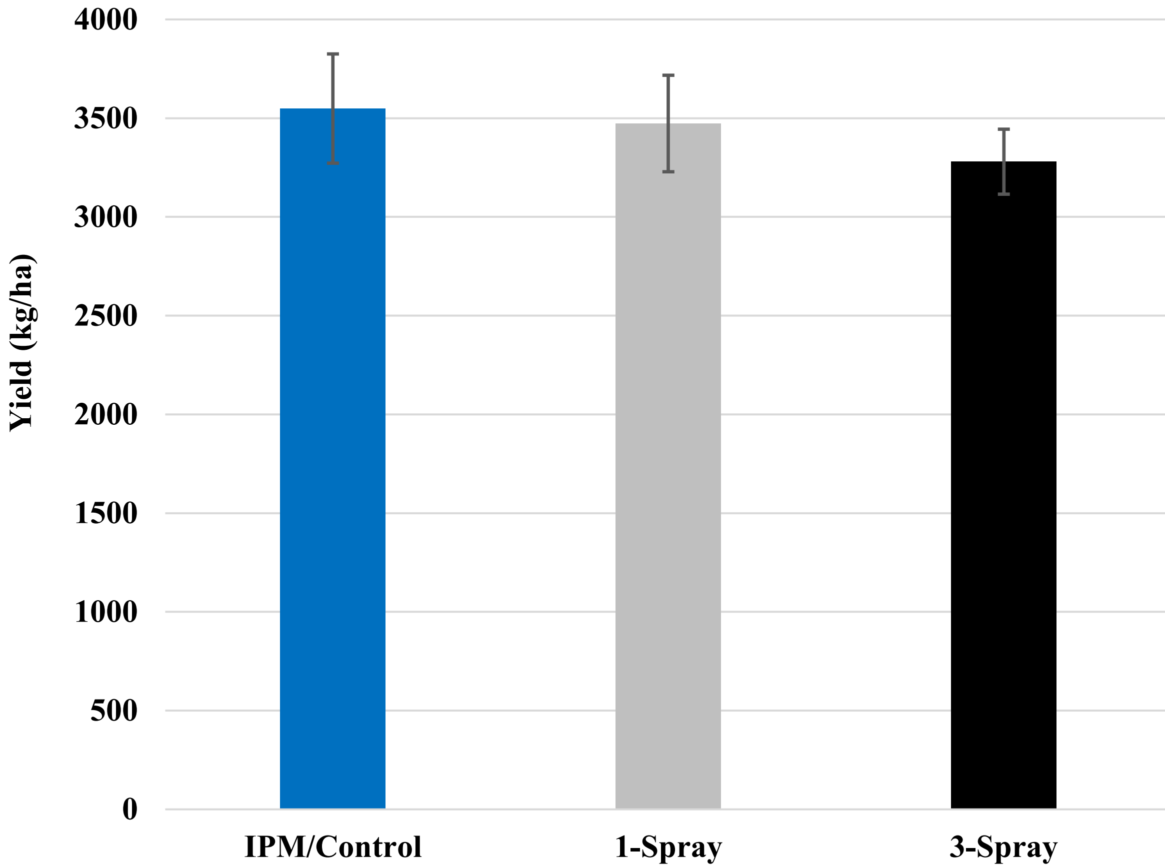

Figure 4.2 2018 Soybean mean yields (kg/ha) (±MSE) recorded for three treatments; a scout and spray only as needed IPM-based program and calendar based 1 and 3 spray programs. No significant differences in yields were observed (ANOVA; $F_{2,9} = 0.35$, $p = 0.71$).

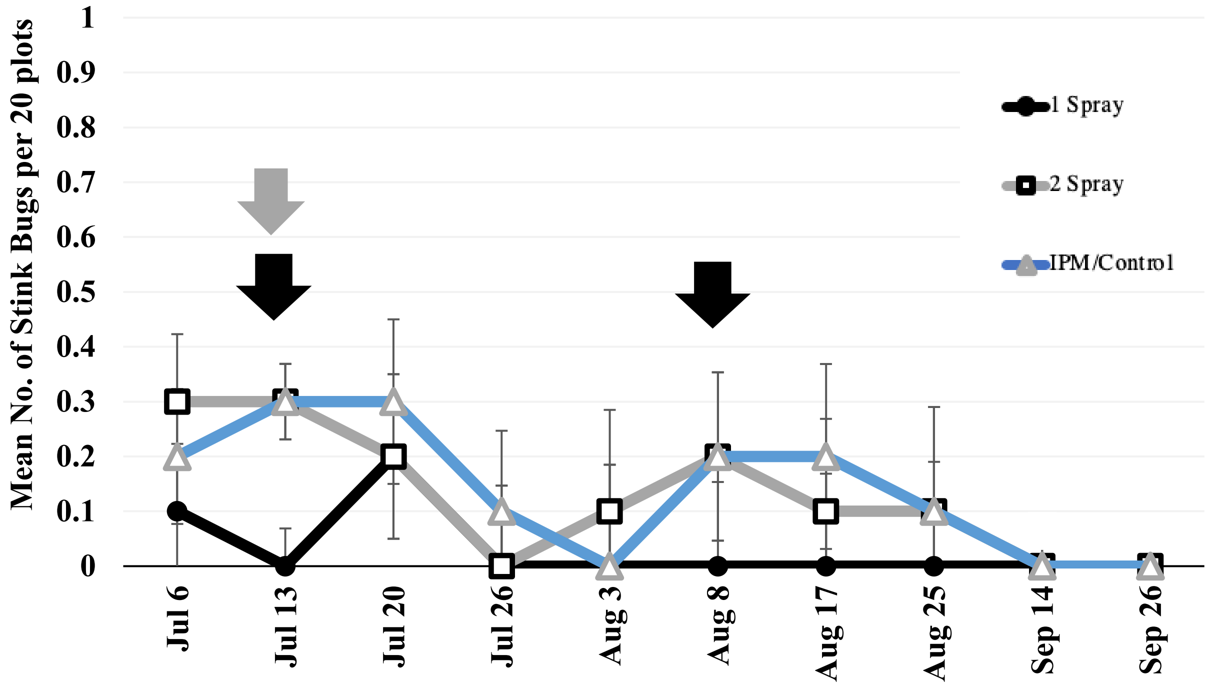

Figure 4.3 Mean numbers (±SEM) of stink bugs per 20 plots under two calendar spray regimes (one and two-spray) compared to IPM/Control in 2019. The grey arrow indicates the application date for the one-spray program. Black arrows indicate the application date for the 2-spray program. No differences in numbers of stink bugs/treatment were observed p= 0.14).

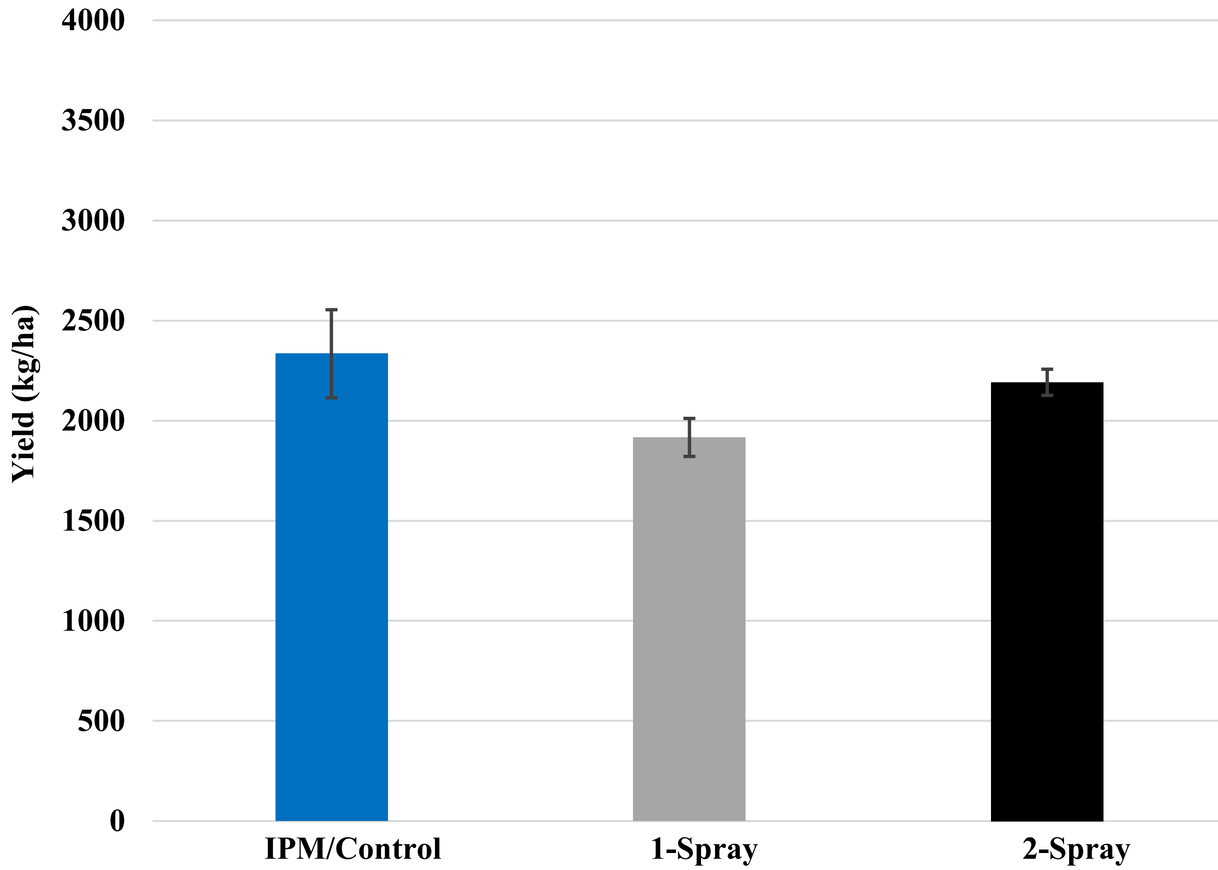

Figure 4.4 2019 Soybean yields (kg/ha) (±MSE) recorded for three treatments; preventive 1 and 2 spray programs, and a scout and spray only as needed IPM-based program. No significant differences in yield were observed (ANOVA; $F_{2,9} = 2.20$, $p= 0.17$).

Chapter 5 Summary

These studies provide information needed to address changes in management tactics to reduce stink bug densities in Kentucky soybean fields. The first study compared two sampling methods, a plastic 5-gallon bucket (to replace the outdated use of beat cloth) sampling with a sweep net; sweep net and bucket were used to estimate phytophagous stink bug species densities in 7 counties in Western and Central Kentucky. When compared to the recommended sampling method, a sweep net, the bucket sampling showed similar numbers of stink bugs captured in both interior and border areas of fields. Stink bug densities only differed significantly ($p = 0.037$) due to location in the field for both bucket and sweep net methods, where more stink bugs were seen in the border of fields. There were also no differences in stink bug densities found among early, mid, and late season sampling using both methods. Although an economic threshold must be developed before adoption of the bucket method, growers may be more inclined to use this sampling tool to the bucket's high accessibility and availability. Establishing an economic threshold incorporates the economic injury level of stink bugs on soybean as well as understanding the pest's population dynamics. Stink bugs, soybean phenology, pest population growth, and injury rates should be considered when creating an economic threshold for the bucket method.

Christian, McLean, Hickman, and Lyon counties in western Kentucky showed *Chinavia hilaris*to be the predominant species of the region, followed by *Euchistus* spp. and *Thyanta custator*. Daviess and Hardin counties in central Kentucky, showed a different species composition where *Euchistus spp.* and *Halyomorpha halys* were the most abundant species, respectively. The distribution of *Halyomorpha halys* in Kentucky may not be fully realized as it is still establishing in western Kentucky.

Numbers of stink bugs present in full-season and double-crop soybean were also evaluated in this study. In 2018, stink bug populations varied for each maturity group depending on growth stage of soybean. Full-season soybean was planted earlier (May 18th) and encountered more stink bugs during the late vegetative and early reproductive stages. Double-crop soybean was planted four weeks later (June 19th) also had higher stink bug densities occurring during late vegetative and early reproductive stages, however, this occurred later in the growing season than with the full season crop. When looking at growth phase, both maturity groups showed high stink bug numbers during late vegetative and early reproductive stages. No differences ($p > 0.05$) were found in stink bug numbers occurring in full and double-crop soybean. *Chinavia hilaris* were the major species (68.3%) infesting both maturity groups, followed by *Euschistus spp* (30%) and *Thyanta custator* (1.7%). In 2019, stink bugs began infesting similarly as 2018 full-season soybean, except densities remained steady until late reproductive stages. *Chinavia hilaris* was again the predominant species (63.4%) followed by *Euschistus spp* (32.4%) and *T. custator* (4.2%) of 71 specimens collected during the growing season. In this two-year study, stink bugs did not reach the economic threshold. This study provided an insight to the relationship between food availability and stink bug densities. There are many factors contributing to a grower's decision on maturity groups: yield performance of soybean variety, lodging, disease resistance, grain composition, and weed resistance (Venard et al., 2017).

The final objective compared chemical control tactics used to reduce stink bug densities. Calendar sprays were compared to scouting and spraying as needed according to integrated pest management thresholds. The treatments included a 1-spray preventive program, 3-spray preventive program, and a scout and spray, only if necessary, for IPM program in 2018; and a 1-spray, 2-spray, and IPM program in 2019. In 2018 stink bugs did not reach economic thresholds

(1.2 stink bugs per 25 sweeps from bloom until R_1 and 3.6 stink bugs per 25 sweeps from R_4 to R_6) in any of the treatments and no IPM sprays were conducted. While stink bug densities tended to be lower throughout the season in the one-spray program, there were no significant differences in numbers of stink bugs/sweep among treatments. In 2019, economic thresholds were not met in any of the treatments and no differences in stink bug numbers were observed among treatments. With both years no differences in yield were observed among treatments; insecticide applications do not increase yields; they are used to prevent yield losses to pests and stink bug densities were too low to cause economic losses. Results obtained in this objective clearly show that in years with low pest densities, growers may reduce costs associated with insecticide applications as it has no positive effect on yields. Growers may also conserve ecological services provided by natural enemies, which helps to reduce the incidence of pest resurgence and a secondary-pest outbreaks.

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<u>Extension Publications:</u>

Soybean Stem Borer: An Unnoticed Bug That May Cause Problems during Harvest and Reduce Yields in Soybeans **Yaziri Gonzalez** and Raul Villanueva*,* **Kentucky Pest News, September 19, 2017**

Soybean Stem Borer: An Unnoticed Bug That May Cause Problems during Harvest and Reduce Yields in Soybeans **Yaziri Gonzalez** and Raul Villanueva*,* **Mid-America Farmer Grower, September 19, 2017**

Entomopathogenic Fungus May Cause High Mortality on Aphids, **Yaziri Gonzalez** and Raul Villanueva**, Mid-America Farmer Grower,** Vol.37 No. 15, pg. 13, **April 14, 2017**

Entomopathogenic Fungus May Cause High Mortality on Aphids, **Yaziri Gonzalez** and Raul Villanueva**, Kentucky Pest News, April 04, 2017**

<u>Awards:</u>

Local Food Systems Summit Scholarship, 2020 $75

Richard's Graduate Student Research Activity Award, 2019 $650

UK Department of Entomology Travel Award, 2019 $ 250

New Horizons Scholarship, 2018 $500

The Tracy Farmer Institute for Sustainability and the Environment/ Appalachian Center

Sustainability Forum: **Outstanding Poster Award, 2018 $300**

The Food Connection at UK, **Student Opportunity Grant, 2018-2019 $6,500**

<u>Presentations:</u>

Supporting Food Production through Extension in an Amish Community and Educating New Agricultural Professionals in Kentucky 2018-2019, **Yaziri Gonzalez**, Izabela Gomes, and Raul Villanueva, **Local Food Systems Summit Scholarship,** Poster, February 26, 2020

Comparing Prophylactic Sprays and Integrated Pest Management Tactics to Control Stink Bugs in Soybeans, **Yaziri Gonzalez** and Raul Villanueva, **Entomological Society of America**, Poster, November 18, 2019

Comparing Prophylactic Sprays and Integrated Pest Management Tactics to Control Stink Bugs in Soybeans, **Yaziri Gonzalez** and Raul Villanueva, **Ohio Valley Entomological Association**, Presentation, October 18, 2019

Management of Stink Bugs on Soybean in Kentucky, **Yaziri Gonzalez**, **University of Kentucky Corn, Soybean, and Tobacco Field Day**, Presentation, July 23, 2019

Inspiring young minds to learn agriculture using entomological activities, Z. Viloria, W. Dunwell, R. Bessin, E. Ritchey, D. Becker, A. Martin, **Y. Gonzalez**, I. Gomes, R. Davila and R. T Villanueva, **Entomological Society of America North Central Branch Meeting**, Poster, March 18, 2019

Supporting Food Production through Extension in an Amish Community and Educating New Agricultural Professionals in Kentucky, **Yaziri Gonzalez**, Izabela Gomes, and Raul Villanueva, **Tracy Farmer Institute for Sustainability and the Environment Sustainability Forum**, Poster, December 7, 2018

Supporting Food Production through Extension in an Amish Community and Educating New Agricultural Professionals in Kentucky, **Yaziri Gonzalez**, Izabela Gomes, and Raul Villanueva, **Entomological Society of America at Vancouver, BC, Canada**, Poster, November 10, 2018

Evaluation of Damage by the Rice Stink Bug on Barley, **Yaziri Gonzalez** and Raul Villanueva, **Entomological Society of America at Vancouver, BC, Canada**, Presentation, November 11, 2018

Evaluation of Damage by the Rice Stink Bug on Barley, **Yaziri Gonzalez** and Raul Villanueva, **Ohio Valley Entomological Association**, Presentation, October 19, 2018

Mild 2016-17 Season Deemed Suitable for Entomopathogenic Fungus and Parasitoid Activity on Aphid Populations in Barely, **Yaziri Gonzalez** and Raul Villanueva, **The Xerces Society Biological Control Short Course,** Presentation, August 09, 2018

Management and Surveillance of Stink Bugs on Soybean in Kentucky, **Yaziri Gonzalez** and Raul Villanueva, **University of Kentucky Corn, Soybean, and Tobacco Field Day**, July 24, 2018

Evaluation of Damage by the Rice Stink Bug on Barley, **Yaziri Gonzalez** and Raul Villanueva, **Entomological Society of America North Central Branch Meeting**, Presentation, March 20, 2018

Mild 2016-17 Season Deemed Suitable for Entomopathogenic Fungus and Parasitoid Activity on Aphid Populations in Barely, **Yaziri Gonzalez** and Raul Villanueva, **Entomological Society of America 2017 Annual Meeting**, Poster, November 7, 2017

Mild 2016-17 Season Deemed Suitable for Entomopathogenic Fungus and Parasitoid Activity on Aphid Populations in Barely, **Yaziri Gonzalez** and Raul Villanueva, **Ohio Valley Entomological Association**, Presentation, October 20, 2017

Mild 2016-17 Season Deemed Suitable for Entomopathogenic Fungus and Parasitoid Activity on Aphid Populations in Barely, **Yaziri Gonzalez** and Raul Villanueva, **Mid-South Association of Wheat and Feed Grain Scientist,** Presentation, August 16, 2017

Organized Workshops:

Field Day for Amish Growers, May 6, 2019

Field Day for Amish Growers, August 3, 2018