12-2015

Stink Bugs: Spatial Distribution, Pecan Phenological Susceptibility and Sampling Program

Brian Cowell
University of Arkansas, Fayetteville

Stink Bugs: Spatial Distribution, Pecan Phenological Susceptibility and Sampling Program

A Dissertation submitted in partial fulfillment
Of the requirements for the degree of
Doctor of Philosophy in Entomology

By

Brian Daniel Cowell
College of the Ozarks
Bachelor of Science in Biology, 2008
Missouri State University
Masters of Natural and Applied Sciences, 2011

December 2015
University of Arkansas

This dissertation is approved for recommendation to the graduate council.

Dr. Donn Johnson
Dissertation Director

Dr. Elena Garcia
Committee Member

Dr. Russell Mizell
Committee Member

Dr. Fred M. Stephen
Committee Member

Dr. Robert Wiedenmann
Committee Member

ABSTRACT

An effective management program for stink bugs (SBs) in pecan groves requires knowledge of: stages of the pecans susceptible to SB damage; strata of the tree with SB damaged nuts; a practical SB monitoring method; and, effects of landscapes contributing SBs into pecan groves.

Stink bugs produced feeding punctures in pecan shucks at all phenological stages. Pecans punctured before the dough stage drop from the tree. Kernel damage occurs in the pecans’ dough stage, whereas mature pecans are not damaged.

The pecans collected from the whole tree using the tree shaker had significantly less punctures than the pecans collected from lower limbs. Stink bug feeding damage occurred more in the lower pecan canopy than the middle or upper canopy. Pecans collected in late-September near harvest had significantly more SB punctures and damage in the lower strata of the pecan trees than the middle or the upper strata.

The SB counts were compared from four SB monitoring methods (baited yellow pyramid traps, UV-light traps, visual surveys and canopy knock-down sprays). The most practical method for pecan growers was the baited yellow pyramid trap.

Yellow pyramid traps baited with *Euschistus* (Hemiptera: Pentatomidae) aggregation pheromone were used to monitor movement of SBs from adjacent landscapes to pecan groves. SB trap counts were compared to percentages of SB punctured or damaged pecans. The grove center acted as a refuge for SBs. The forest tree line and soybean landscape contributed more SBs to a pecan grove than other landscapes. The number of SBs or percentages of SB punctured nuts did not equate to percentages of SB damaged nuts. SB damaged nuts remained relatively

low until the water stage. I suggested using baited yellow pyramid traps for making SB pest management decisions during susceptible water through dough pecan nut stages.

ACKNOWLEDGMENTS

I would like to thank the many people who have helped and supported me throughout my research and made this dissertation possible. First of all I'd like to thank my advisor, Dr. Donn T. Johnson, for his endless guidance, patience and editorial reviews through this dissertation project, and assistance in the field during the collection of stink bugs and pecans. I would also like to thank the members of my committee: Dr. Donn Johnson, Dr. Elena Garcia, Dr. Russell Mizell, Dr. Fred Stephen, and Dr. Robert Wiedenmann who helped guide my research and offer new perspectives.

I would also like to thank the USDA National Institute of Food and Agriculture, Hatch project Development of practices for sustainable, local production of specialty crops in the South accession number: 0223689; 2010 and 2011 USDA/Specialty Crops Research Initiative Block Grant and Arkansas Agricultural Department Partnered with the Arkansas Pecan Growers Association and participating pecan growers; and University of Arkansas Agricultural Experiment Station for funding and supporting me and my research.

Special thanks to Barbara Lewis for helping me process pecan samples along with her overwhelming support and encouragement. A special thanks to Mr. Robert Carruthers for his great support of this project and for transporting an Orbit lift and helping collect pecan nuts from different strata of the pecan canopy in several pecan orchards. I would also like to thank Virgil Piazza, Kevin Durden, Rickie Lee Hicks, Cory Johnson, Cate Clark, Bennie Tillis, and Clay Wingfield for their help in collecting and processing stink bug and pecan samples. Thank you to all the participating Arkansas pecan growers that allowed me to conduct my studies in their pecan groves and for their participation in my research.

Finally I would like to thank my family including my parents Dan and Brenda, my brother and sister, Brendan and Brittany, my fiancée, Jami, and all my friends for their support and encouragement through the ups and downs of my studies.

TABLE OF CONTENTS

LIST OF TABLES **Pages**

Chapter 6:

LIST OF FIGURES **Pages**

Chapter 2:

Chapter 3:

Chapter 4:

Chapter 6

LIST OF PAPERS

Chapter 2:

Cowell, B., D.T. Johnson, M.E. Garcia, and R. Mizell. 2015. Monitoring insect and pest damage in pecan in Arkansas. ISHS ActaHort. 1070:151-157.

Chapter 1

Introduction to Pecans and Stink Bugs

INTRODUCUCTION

The Pecan

The pecan, *Carya illinoinensis* (Wangenh.) K. Koch, is the most valuable native North American nut crop (Thompson and Conner 2012). There are thirteen *Carya* species (Family Juglandaceae) native to the USA, but only seven are grown for their nut consumption. Pecans are hardwood trees and the wood is used for things such as tool handles, veneer, flooring, and smoking wood for meats (Thompson and Conner 2012).

Pecan trees naturally grow in well drained loam soils that receive an average rainfall of 30 inches per year. Pecans are monoecious, produce both male and female flowers on the same tree between the months of March and May. The pecan tree has alternating compound leaves with 9-17 leaflets. The average pecan fruit measures 1-2 inches long with a diameter of half an inch, including the husk and the nut (Stevens 2010), but some of the improved cultivars can grow much larger. In the fall, when the pecans reach full maturity the husk will split open along its sutures and the nut will be released and eventually fall to the ground (Stevens 2010).

The pecans native range spans from the lower portions of Indiana, Illinois, Iowa and eastern Kansas south to western Texas and across Louisiana, western Mississippi to northern Alabama (Stuckey and Kyle 1925). The pecan range was expanded, after introduction of improved pecan cultivars, the range of commercial trees extends from Ontario, Canada south to Oaxaca, Mexico; along the Atlantic coast from Virginia to southern Georgia; and California. Pecans are also being commercially grown in South Africa, Israel, Egypt, Australia, Argentina, Peru, Brazil (Thompson and Conner 2012), and China (Sun and He 1982). Of all pecans produced in the world, 98% come from 15 Southern United States and northern Mexico (Thompson and Conner 2012; Vilsack and Clark 2014). The top-ten producing states, along with

their percentages in pecan production can be found in Table 1. In 2014, the USDA National Agricultural Statistics Service reported 543,486 acres of pecans in the United States (Vilsack and Clark 2014). The average price of pecans harvested in 2014 was $1.91 per pound (Rafanan 2015).

There are two major groups of pecans, the native pecans and the improved cultivars. Some of these improved cultivars are: ‘Barton’, ‘Comanche’, ‘Choctaw’, ‘Wichita’, ‘Apache’, ‘Sioux’, ‘Mohawk’, ‘Caddo’, ‘Shawnee’, ‘Cheyenne’, ‘Cherokee’, ‘Chickasaw’, ‘Shoshoni’, ‘Tejas’, ‘Kiowa’, ‘Pawnee’, ‘Houma’, ‘Osage’, ‘Oconee’, ‘Navaho’, ‘Kanza’, ‘Creek’, ‘Hopi’, ‘Nacono’, ‘Waco’, ‘Lakota’, ‘Mandan’, and ‘Apalachee’(Thompson and Conner 2012). ‘Pawnee’ is currently the most popular cultivar worldwide by way of number of trees being propagated. Some improved cultivars show resistance to disease, fungi, and insects, while the native pecans are much more susceptible than theses resistant cultivars (Thompson and Conner 2012).

Pecan Fruit Phenology:

Smith (2010) stated that bud break for pecan in central Oklahoma is typically the first or second week in April. Since Oklahoma has weather similar to much of Arkansas, this time frame will most likely hold true for Arkansas pecan phenology. Pecans are wind pollinated heterodichogamous trees that have two mating types: protogyny (female function before male); and protandry (male function before female) with pollination occurring during mid- to late-May. After pollination the pecan fruit grows slowly until the end of June to the beginning of July. The fruit then expands rapidly. During this fast expansion stage the nutlet is in its water stage. The liquid that fills the pecans during water stage contains some sugars (Finch and van Horn 1936). From mid- to late-August the pecans enter a gel stage. At this stage the shell (pericarp) begins to

harden and the fruit can no longer enlarge (Smith 2010). The gel layer that forms on the inside of the shell during gel stage has been found to consist of mostly sugars and no fats (Finch and van Horn 1936). During late-August the nuts enter into the dough stage (Smith 2010) converting most of the sugar to the solid white cotyledon tissue which has high fat content and very little sugar (Finch and van Horn 1936). When the fruit ripens the pecans enter into the shuck split stage. This stage normally occurs from early-September to early-November depending on the cultivar. Once the shuck is split the fruit is ripe and is ready to be harvested or will fall off the tree (Smith 2010).

Rationale and Significance

Pecans are considered to be the most valuable native nut crop in North America (Thompson and Conner 2012), with an approximate value of $508 million in the United States (Rafanan 2015). There are a total of 19,253 pecan farms and 543,486 acres of pecan trees in the United States. In the state of Arkansas there are 277 farms with 11,591 acres used in pecan production (Vilsack and Clark, 2014). The Arkansas pecan production and total sales in 2014 were 3.5 million pounds for a total of $4.6 million (Rafanan 2015). Most pecan orchards in Arkansas are small, with 69% of the 277 farms having 15 acres or less and only 9% of the farms with 100 acres or more (Vilsack and Clark 2014). There are many small orchards in Arkansas that are not counted so the total amount of acres in pecan production may be under represented. Currently, Arkansas is one of the least-efficient (Wood 2001) and least-profitable pecan producing states, with an average price of $1.32 per pound compared to the national average of $1.91 per pound (Rafanan 2015). This is most likely due to the high proportion of native pecans sold in Arkansas and damage by unmanaged pests and diseases. In 2014, Arkansas produced 1.3 million pounds of native pecans for $0.84 per pound and 2.2 million pounds of improved pecans

priced at $1.60 per pound (Rafanan 2015). Some of the high quality nuts from improved cultivars of pecans harvested and sold to Hong Kong, China before November received a premium price of $2.90 to $3.25 per pound (Pecan South 2014).

Stink Bugs

Several families of Hemiptera: Pentatomidae (stink bugs) and Coreidae (leaffooted bugs) attack pecans throughout the year (Hudson and Pettis 2006). Stink bugs are also major pests in commercial agriculture crops such as beans, brambles, cotton, okra, peas, pecan, small grains, soybean and stone fruit. The SB damage in soybeans alone was estimated to cost more than $13 million in damage and control costs in the state of Georgia alone (Douce and McPherson 1991). In 1985 in Georgia, the SBs and leaffooted bugs were considered among the most important insect pests on pecans because their damage caused decreased nut yield and quality. In the pecan industry, these hemipterans caused $3.5 million loss (Deuce and Suber 1986). In 1997, in Georgia, kernel feeding hemipterans such as SBs cost pecan growers approximately $1.8 million in damages and control costs (Ellis and Dutcher 1999).

The efficiency and quality of Arkansas pecan production could be increased substantially by the implementation of a pest management program, especially for SBs. North America is home to more than 200 SB species (Krupke 2007). Within those 200 species, my focus will be on plant-feeding SBs that are attracted to broadleaf field crops, weeds, and pecan. More research should focus on the biology and ecology of SBs to create an improved management strategy (Reisig 2011).

Stink Bug Complex and Biology

Hudson and Pettis (2006) mentioned that the SB complex in pecans in the southeastern U.S. included: Southern green SB, *Nezara viridula* (L.), brown SB, *Euschistus servus* (Say),

dusky SB, *Euschistus tristigmus* (Say), green SB, *Chinavia hilaris* (Say), leaffooted bugs, *Leptoglossus phyllopus* (L.), and others. The main SBs found in Arkansas pecan groves were brown, dusky, and green SBs. There were very few leaffooted bugs and no southern green SBs found (Cowell et al. 2015).

Stink bugs change appearance during their different life stages. The green SB nymph is reddish brown and as it matures becomes light green with black and white stripes on the abdomen. The late-stage nymphs are green with yellow and black or green stripes on the abdomen and a black spot in the center. Once the green SB becomes an adult black bands become visible on the antennae. The brown SB nymph is light brown with brown spots down the middle of the abdomen. When the SB becomes an adult it is totally brown and has rounded shoulders (Lorenz et al. 2011). The dusky SB is similar to the brown SB except it has pointed shoulders and the underside of the abdomen has single or multiple dark spots in the center towards the rear of the light-colored abdomen (Kamminga et al. 2009).

The geographical ranges of the brown SB, green SB and dusky SB are reported to span from Quebec to the southern United States. However, they cause more damage and injury in the southern United States (Carter et al. 1996). The brown, dusky, and green SB adults overwinter along fence rows, under boards, ditch banks, dead weeds, stones, ground cover, and under the bark of trees. These SBs begin to become active during the first warm days of spring (Polk et al. 1995). First spring emergence of SBs in Florida typically occurs in late-March or April when temperatures rise above 21°C (Gomez and Mizell 2008).

During mid-May to mid-June, in North Carolina both the brown and the green female SBs deposit up to several hundred eggs in clusters averaging 36 eggs on leaves, stems and occasionally on pods (Carter et al. 1996). Eggs typically hatch in 6-7 days with the nymphs

remaining clustered until the third or fourth instar (Stewart et al. 2010). This clustering behavior of SB nymphs increased uptake of atmospheric water which protects nymphs against desiccation (McPherson and McPherson 2000). It takes approximately five weeks for SBs to develop through five instars and molt to the adult stage (Carter et al. 1996). Overwintered adults and first summer generation of nymphs feed on wild plants such as shrubs, vines, and many broadleaf weeds especially legumes or early-season fruits until commercial crops bear fruit (Gomez and Mizell 2008). The second generation of SBs regularly develops in field crops (Gomez and Mizell 2008) such as cotton, grain sorghum, peanut, soybean, and watermelon and later disperses to pecan (Toews 2010).

Areas in the U.S. from Virginia to the north reported only one brown SB generation per year, while southern states like Arkansas have two generations per year (Carter et al. 1996). The two summer generations of brown SB and dusky SB have adult numbers peak from May through June and in August. The green SB on the other hand only has one generation which peaks from mid- to late-June (Polk et al. 1995).

Stink Bugs feed on many parts of a plant including the flowers, stem, foliage and vegetative parts, but most importantly feed on the more nutritious seed, nut and fruit. Stink bugs also have a large variety of host plants including but not limited to things such as shrubs, vines, broadleaf weeds, corn, soybean, sorghum, okra, millet, snap beans, peas and cotton. Legumes are preferred hosts (Gomez and Mizell 2008).

A large number of adult SBs, but not immatures, have been found on pecan trees during the late-summer and fall. This is an indicator that SBs do not breed or lay eggs on pecan trees (Gill 1923, Hudson and Pettis 2006) but may reproduce earlier in the herbaceous weeds on the orchard floor or on other host plants in adjacent landscapes (Hudson and Pettis 2006). Ground

cover practices that eliminate SB host plants before seed heads appear were reported to help minimize local SB densities (Polk et al. 1995).

Stink Bug Landscape Ecology

Stink bugs are polyphagous and can disperse during the season to feed on many host plant species, especially when those are in the preferred nutrition stage, e.g., seeds in the milk stage or ripening fruit (Hogmire and Leskey 2006, and Mizell et al. 2008). Velasco and Walter (1992) reported that SBs disperse to and feed on several host plant species during the season before reaching the most preferred host, soybean, in late-summer. In the fall, SBs disperse into pecan groves to feed on maturing pecan nuts and locate overwintering sites (Polles 1977). As SBs disperse to a new crop, they aggregate in higher numbers at the crop perimeter known as an edge effect (Tillman et al. 2009).

Since plants are only in the SB preferred feeding stage for a short amount of time this creates a narrow temporal window of available high quality food for SBs which may be responsible for the SB aggregation behavior (Tillman et al. 2009, Mizell et al. 2008). Similarly, Martinson et al. (2015) has demonstrated that brown marmorated stink bugs, *Halyomorpha halys* (Stal), have the ability to detect and disperse to food resources as they become available throughout the season.

Other factors may also affect the movement of the SBs throughout the landscape. As Tillman et al. (2009) noted, a tractor applying fungicide in one field caused the SBs to be flushed into an adjacent field.

Stink bugs are highly mobile and disperse into and out of various host crops as seeds or nuts mature (susceptible stage) which makes them difficult to control by insecticide applications alone. Dispersal of SBs occurs both horizontally at the landscape level and vertically into the

pecan tree canopy. Brown and green SBs fly through the pecan groves at heights less than 1m or just above the height of ground vegetation (Mizell and Tedders 1995). Both the brown and dusky SBs were found throughout the whole pecan tree. However, brown SBs were found at the ground level than any other strata within the pecan grove. In contrast, the arboreal dusky SBs were found at greater densities in the upper portions in the tree (Cottrell et al. 2000). Adult SBs are strong fliers and will readily disperse between adjacent hosts (Polk et al. 1995). Tillman et al. (2009) stated that that improvement of SB management practices will require conducting more studies of spatiotemporal patterns and landscape ecology of SBs.

Stink Bug Damage

According to Hudson et al. (2011), SBs are present in pecan groves all year long, but economic loss occurs only from late-August to late-September, during shell hardening (dough stage) and early-maturity. It has been reported that while feeding SBs use amylase to break down the host plant sugars and starches (Hori 2000). External SB damage can be diagnosed by looking for fluid seeping out of the shuck puncture site (Yates et al. 1991). Stinkbugs feed by puncturing pecans during the period when the nut is in the liquid endosperm stage (water stage) through shell hardening. The puncture site turns black within one hour after being punctured. By the second day the entire punctured vascular tissue between the shuck and the shell will darken, and within four to five days the immature nut blackens (black pit) causing the nut to drop (Woodroof and Woodroof 1928). Previously, black pit was thought to be caused by a fungus *Coniothyrium caryogenum* Rand, but was later known to be caused only by the insect punctures (Demaree 1922). In contrast, SB feeding during the dough stage and later causes a bitter tasting dark spot called kernel spot to form on the edible kernel inside the pericarp of the pecan nut but these nuts will not drop (Osburn et al. 1966, Hudson and Pettis 2006). Kernel spot cannot be detected until

the pecans are shelled (Hudson and Pettis 2006). Stink bugs also have the ability to feed on fully developed nuts through the hard shells even after harvest (Hudson and Pettis 2006), but it is unknown if this also results in kernel spot.

Monitoring

Several sampling methods have been used to survey SB densities in multiple habitats including: D-Vac; Malaise traps (Dutcher and Todd 1983); visual surveys (Pecan IPM PIPE 2011, Hudson 2014, Leskey et al. 2012); insecticidal canopy knock down sprays (Hudson 2014); black light traps (Lee 2007, Blinka et al. 2007, Dutcher and Todd 1983); sweep net; limb jarring; black pyramid traps baited with pheromone lure (Leskey et al. 2012); and yellow pyramid traps baited with aggregation pheromone (Mizell and Tedders 1995). These SB sampling methods had limited effectiveness in making pest management decisions because there are currently no scientifically-based action thresholds. Of all of these sampling methods, only four are recommended to monitor for SBs in pecans including: baited yellow pyramid traps (Mizell et al. 1997); black-light traps (Parker et al. 2005); visual surveys; and canopy knock down sprays (Hudson 2014).

The yellow pyramid trap described by Mizell and Tedders (1995) and Hogmire and Leskey (2006) consists of a yellow pyramid trap baited with rubber septum charged with 40 µl of the *Euschistus* spp. aggregation pheromone, methyl (2E, 4Z)-decadienoate (Aldrich et al. 1991). Hogmire and Leskey (2006) captured three main SB species with this baited pyramid trap including brown, dusky and green SBs. Mizell et al. (1997) recommended that the best SB management decision required monitoring 3-5 of these baited pyramid traps along the border of the pecan grove and also in the interior. This monitoring method was directed towards the *Euschistus* genus of SBs (brown and dusky SBs) because of the use of the *Euschistus* spp.

aggregation pheromone, but it also captured a small number green SBs due to the trap's attractive yellow color. The *Euschistus* spp. aggregation pheromone alone was not attractive to green SBs. These traps may be improved for capturing and attracting green SBs by adding the Atroban Extrak insecticide ear tag (Schering-Plough Animal Health Corporation, Union, NJ) (Hogmire and Leskey 2006) and the green SB attraction pheromone that has various isomers of methyl 2,4,6-decatrienoate (Aldrich et al. 2007). However, this pheromone is not commercially available probably due to prohibitive cost of synthesis.

Lee (2007) and Blinka et al. (2007) attracted green SBs to black-light traps and suggested they could be used to monitor SB densities in the pecan tree canopy. Parker et al. (2005) recommended that these black-light traps be operated at 20 feet up in the tree canopy, but this was in order to attract moths, beetles, and SBs. When monitoring only SBs a more variable, but appropriate height would be right above the height of the expected ground vegetation (Mizell and Tedders 1995).

Both visual surveys and canopy knock down spray methods have been used to determine if SBs in the pecan trees exceeded the action threshold for treatment. Hudson (2014) said if a visual survey of pecan clusters found more than one cluster in forty with SBs present then it was recommended a SB insecticide. Hudson (2014) noted that if five SBs were found per knock down spray sample then apply a SB insecticide. The canopy knock down spray method involved placing a plastic sheet underneath 20% of a pecan tree canopy and then apply a knock down spray to the lower canopy.

Management

Chemical Control

Insecticides: Currently, there is a transition from high-risk organophosphate insecticides that were effective against SBs to reduced-risk compounds that are less effective against the SB complex. The organophosphate insecticide, methyl parathion, was cancelled for use against brown SB (Willrich et al. 2003). The recommended insecticides reported as effective against SBs include: Imidan 70 WP (phosmet, organophosphate), Mustang Max 0.8 EC (zeta-cypermethrin, pyrethroid), Warrior 1 CS (lambda-cyhalothrin, pyrethroid), Voliam Express (chlorantraniliprole, diamides plus lambda-cyhalothrin, pyrethroid) (Studebaker 2011, Hudson and Pettis 2006), Orthene (acephate, organophosphate), Brigade WSB (bifenthrin, pyrethroid), Proaxis (gamma-cyhalothrin, pyrethroid) and Lannate SP (methomyl, carbamate) (Nessler 2008). Control of SBs improved by integrating insecticide treatments with SB host weed management program inside the grove (Ritchie et al. 2005).

Cultural Control

Sanitation: Stink bugs could be suppressed if pecan grove surrounding overwintering sites were removed and a SB host weed management program was implemented inside the pecan groves (Ritchie et al. 2005). Broadleaf weed management program near and in the grove could lower the potential risk for SBs to disperse into a pecan grove (Ritchie et al. 2005). Nessler (2008) suggested year-round management of SBs by keeping adjacent field borders free of host weeds that support SB feeding and reproduction. Toews (2010) suggested reducing SB densities in the grove and adjacent overwintering sites in and around the grove by regularly mowing grass/weeds and maintaining a weed-free herbicide strip under the pecan tree dripline.

Trap Crop: A SB host trap-crop system has the potential to be used as part of a SB management program (Hudson and Pettis 2006). Pecans are mainly damaged by SB during the dough stage, so an attractive SB-host trap crop, such as soybean, could be planted adjacent to the pecans to in order to produce attractive, SB-susceptible pods slightly earlier and through the SB-susceptible pecan dough stage. This would attract and concentrate SBs in the trap crop. Weekly sweep net sampling of trap crops could be used to monitor SBs in order to determine the correct timing to spray the trap crops with insecticide. The goal would be to use trap cropping to attract and kill SBs so fewer disperse to and feed on pecan nuts. Concentrating SBs into a smaller area, such as a trap crop, could make it easier to manage SBs and prevent pecan nut kernel damage.

Natural Control

Biological Control: There is no commercially available biological control tactic developed for SBs. However, there are some parasitoids and several species of birds that prey on SBs but many predators are repelled when SBs release a defense odor (Gill 1923). The most important egg parasitoid is: *Telenomus podisi*, but others include: *Trissoleus euschisti*; *Ooencyrtus* sp.; *Anastatus* sp.; *Pearsalli* (Yeargan 1979); and *T. basalis* (Squitier 2010). A wasp, *Astata* sp., also parasitized stink bugs (Bohart and Menke 1976).

REFERENCES CITED

Aldrich, J.R., A. Khrimian & M.J. Camp. 2007. Methyl 2,4,6-decatrienoates attract stink bugs and tachinid parasitoids. J. Chem. Ecol. 33: 801-815.

Aldrich, J.R., M.P. Hoffmann, J.P. Kochansky, W.R. Lusby, J.E. Eger, and J.A. Payne. 1991. Identification and attractiveness of a major pheromone component for Nearctic *Euschistus* spp. stink bugs (Heteroptera: Pentatomidae). Environ. Entomol. 20: 477-483.

Blinka, E.L., J.S. Bacheler, J.R. Bradley, and J.W. Van Duvn. 2007. Stink bug distribution based on black light trap captures across North Carolina in relation to surrounding agricultural host plant ratios, pp. 1711-1712. In Beltwide Cotton Conferences, New Orleans, Louisiana.

Bohart, R.M., and A. S. Menke. 1976. Sphecid wasps of the world: a generic revision. University of California Press.

Carter, C.C., T.N. Thomas, D.L. Kline, T.E. Reagan, W.P. Barney. 1996. Insect and related pests of field crops. North Carolina Cooperative Extension Service AG-271.

Cottrell, T.E., C.E. Yonce, and B. W. Wood. 2000. Seasonal occurrence and vertical distribution of *Euschistus servus* (Say) and *Euschistus tristigmus* (Say) (Hemiptera: Pentatomidae) in pecan orchards. J. Entomol. Sci. 35: 421-431.

Cowell, B., D.T. Johnson, M.E. Garcia, and R. Mizell. 2015. Monitoring insect and pest damage in pecan in Arkansas. ISHS ActaHort. 1070:151-157.

Demaree, J.B. 1922. Kernel-spot of the pecan and its cause. USDA Bull. 1102.

Deuce, G.K., and E.F. Suber. 1986. Summary of losses from insect damage and costs of control in Georgia, 1985. Univ. of Georgia Spec. Publ. 55.

Douce, K. and R. McPherson. 1991. Summary of losses from insect damage and costs of controls in Georgia. 1989. Georgia Agric. Expt. Sta. Spec. Publ.70.

Dutcher, J.D., and J.W. Todd. 1983. Hemipteran kernel damage of pecan. Misc. Public. Entomol. Soc. Amer. 13: 1-11.

Ellis, H.C. and J.D. Dutcher. 1999. Summary of loss from insect damage and cost of control in Georgia, 1997: XVII Pecan insects. University of Georgia, The Bugwood Network.

Finch, A.H. and C.W. van Horn. 1936. The physiology and control of pecan filling and maturity. University of Arizona. Bull. No. 62.

Gill, J.B. 1923. Important pecan insects and their control. USDA Farmers' Bull. No. 1364.

Gomez, C., and R.F. Mizell. 2008. Brown stink bug - *Euschistus servus* (Say). University of Florida. Dept. Entomol. and Nematol. Publ. EENY-433

Hogmire, H.W., and T.C. Leskey. 2006. An improved trap for monitoring stink bugs (Heteroptera: Pentatomidae) in apple and peach orchards. J. Entomol. Sci. 41:9-21.

Hori, K. 2000. Possible causes of disease symptoms resulting from the feeding of phytophagous Heteroptera, p. 11-35. In: Schaefer CW, Panizzi AR (eds) Heteroptera of economic importance. CRC Press, Boca Raton.

Hudson, W.J., and Pettis G.V. 2006. Pest management strategic plan for pecans in the Southeastern U.S. 39pp. Southern Region Integrated Pest Management Center.

Hudson, W. J. Brock, S. Culpepper, W. Mitchem, and L. Wells. 2011. 2011 Georgia pecan pest management guide. Georgia Pecan Grower's Assoc. Bull. 841:1-16.

Hudson, W. 2014. Commercial Pecan Insect Control (Bearing Trees). University of Georgia Extension, spray guide.

Koppel, A. L., D. A. Herbert, Jr., T. P. Kuhar, and K. Kamminga. 2009. Survey of stink bug (Hemiptera: Pentatomidae) egg parasitoids in wheat, soybean and vegetable crops in southeast Virginia. Environ. Entomol. 38: 375-379.

Kamminga, K., D. A. Herbert, S. Malone, T. P. Kuhar, J. Greene. 2009. Field guide to stink bugs; of agricultural importance in the upper southern region and Mid-Atlantic States. Virginia Coop. Ext. Pub. 444-356.

Krupke, C. 2007. Stink bugs: Consperse stink bug *Euschistus conspersus* Uhler, green stink bug or green soldier bug *Acrosternum hilare (Say).* Washington State University Tree Fruit Research & Extension Center: Orchard Pest Management. http://jenny.tfrec.wsu.edu/opm/displaySpecies.php?pn=190

Lee, D. 2007. Number of stink bugs growing in Missouri soybean fields. Univ. of Missouri Commercial Agricultural Program. http://agebb.missouri.edu/commag/news/archives/v16n1/news16.htm

Leskey, T.C., B.D. Short, B.R. Butler, and S.E. Wright. 2012. Impact of the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål), in Mid-Atlantic tree fruit orchards in the United States: case studies of commercial management. Psyche 2012: 1-14.

Lorenz, G., D. Johnson, G. Studebaker, C. Allen, and S. Young. 2011. Insect pest management in soybeans, Chapter 12. *In* Arkansas Soybean Handbook, University of Arkansas Cooperative Extension Service MP197.

Martinson, H.M., P.D. Venugopal, E.J. Bergmann, P.M. Shrewsbury, and M.J. Raupp. 2015. Fruit availability influences the seasonal abundance of invasive stink bugs in ornamental tree

nurseries. Published on line 25 June 2015. http://link.springer.com/article/10.1007/s10340-015-0677-8

McPherson, J.E., and R.M. McPherson. 2000. Stink bugs of economic importance in America north of Mexico. CRS Press, New York.

Mizell, R.F. III, and W.L. Tedders. 1995. Use of the modified Tedders trap to monitor stink bugs in pecan. Proc. Southeastern Pecan Growers Assoc. 88:36-40.

Mizell, R.F. III, and W.L. Tedders, and J.A. Aldrich. 1997. Stink bug monitoring - an update. Proceedings of the Southeastern Pecan Growers Association 90: 50-52.

Mizell, R.F., T.C. Riddle, and A.S. Blount. 2008. Trap cropping system to suppress stink bugs in the Southern Coastal Plain. Proc. Fla. State Hort. Soc. 121:377–382.

Nessler, S. 2008. Pest management strategic plan for snap beans in Virginia, North Carolina, and Delaware. Southern Region IPM Center. http://www.ipmcenters.org/pmsp/pdf/VA-NC-DEsnapbeanPMSP.pdf

Osburn, M.R., W.C. Pierce, A.M. Phillips, J.R. Cole, and G.E. Kenbright. 1966. Controlling insects and diseases of pecans. USDA Agric. Handbook 240: Rev. 1-55.

Parker, M. L., W.E. Mitchem, K.A. Sorensen, B. Bunn, and S.J. Toth, Jr. (ed.). 2005. Crop Profile for Pecans in North Carolina. North Carolina Cooperative Extension Service 11 pp. Revised. http://content.ces.ncsu.edu/pecans.pdf

Pecan ipm PIPE. 2011. Pecan ipm toolbox – Insect monitoring and control. Retrieved on 29 Nov. 2011 from: http://pecan.ipmpipe.org/toolbox/insect_monitoring_control/stink_survey.cfm

Pecan South. 2014. The Pecan Newsletter. Vol. 33 (8).

Polk, D.F., H.W. Hogmire, and C.M. Felland. 1995. Peach-direct pests: stink bugs, pp. 51-52. *In* H.W. Hogmire (ed.), The Mid-Atlantic Orchard Monitoring Guide (NRAES-75). NRAES, Ithaca, New York.

Polles, S.G. 1977. Black pit and kernel spot of pecans: special emphasis on southern green stinkbug. Proc. Southeastern Pecan Growers Assn. 70:47-52.

Rafanan, M. 2015. Pecan report. USDA Agric. Marketing Service Fruit and Vegetable Programs Market News Division 32(24):1-3.

Reisig, D.D. 2011. Insecticidal management and movement of the brown stink bug, *Euschistus servus*, in corn. J. Insect Sci. 11:168.

Ritchie, D., M. Parker, K. Sorensen, J. Meyer, W. Mitchem, and S. Toth, Jr. 2005. Crop profile for peaches in North Carolina. National Information System for the Regional IPM Centers.

Retrieved on 15 Nov. 2012 from: http://www.ipmcenters.org/cropprofiles/docs/ncpeaches.pdf

Smith, M. 2010. Pecan phenology. Oklahoma Pecan Growers Association LI (4):4. http://okpecangrowers.com/yahoo_site_admin/assets/docs/2010quarterly04.51122900.pdf

Squitier, J.M. 2010. Featured creature fact sheets: southern green stink bug, *Nezara viridula* (Linnaeus) (Insecta: Hemiptera: Pentatomidae). EENY-016 University of Florida. (http://edis.ifas.ufl.edu/in142).

Stevens, J. 2010. Pecan *Carya illinoinensis* (Wangenh.) K. Koch. USDA Natural Resource Conservation Service Plant Fact Sheet 8298.

Stewart, S., A.T. McClure, and R. Patrick. 2010. Soybean insects: stink bugs. University of Tennessee Institute of Agriculture W200.

Stuckey, H.P., and Kyle, E.J. 1925. Pecan-growing. *In* L.H. Bailey (ed.), The Rural Science Series. The MacMill Company, N.Y.

Studebaker, G. 2011. Insecticide recommendations for Arkansas 2011. University of Arkansas Division of Agriculture Research and Extension MP144.

Sun, Z.J., and S.A. He. 1982. The history, present, and prospect of pecans in China. Pecan South 9(5):18-23.

Thompson, T.E., and P.J. Conner. 2012. Pecan, pp. 771-801. *In* M.L. Badenes and D.H. Byrne (Eds.), Fruit Breeding, Handbook of Plant Breeding, Vol. 8. Springer Science+Business Media, LLC.

Tillman, P.G, T.D. Northfield, R.F. Mizell, and T.C. Riddle. 2009. Spatiotemporal patterns and dispersal of stink bugs (Heteroptera: Pentatomidae) in peanut-cotton farmscapes. Environ. Entomol. 38: 1038-1052.

Toews, M.D. 2010. Stink bug ecology in southeastern farmscapes, pp. 72-77. *In* K. Stevenson (ed.), Proc. 103rd Annual Convention of the Southeastern Pecan Growers Association.

Velasco, L.R.I., and G.H. Walter. 1992. Availability of different host plant species and changing abundance of the polyphagous bug *Nezara viridula* (Hemiptera: Pentatomidae). Environ. Entomol. 21:751-759.

Vilsack, T., and C.Z.F. Clark. 2014. 2012 Census of Agriculture: United States Summary and State Data. Vol .1, Part 51.

Willrich, M.M., B.R. Leonard, and D.R. Cook. 2003. Laboratory and field evaluations of insecticide toxicity to stink bugs (Heteroptera: Pentatomidae). J. Cotton Sci. 7:156-163.

Wood, B.W. 2001. Production unit trends and price characteristics within the United States pecan industry. HortTechnology 11:110-118.

Woodroof, J.G., and N.C. Woodroof. 1928. The dropping of pecans. Natl. Pecan Growers' Assn. Bull. 2(28):30-34.

Yates, I.E., W.L. Tedders and D. Sparks. 1991. Diagnostic evidence of damage on pecan shells by stink bugs and coreid bugs. J. Amer. Soc. Hort. Sci. 116:42-46.

Yeargan, K.V. 1979. Parasitism and predation of stink bug eggs in soybean and alfalfa fields. Environ. Entomol. 8:715-719.

Table 1. Top ten pecan producing states in the US and the percentage each produces (Rafanan 2015).

Rank	**State**	**Pounds x 1000**	**% Of U.S**
1	Georgia	73,000	27.71
2	New Mexico	65,000	24.68
3	Texas	60,000	22.78
4	Arizona	21,000	7.97
5	Oklahoma	19,000	7.21
6	Louisiana	14,000	5.32
7	California	5,000	1.9
8	Arkansas	3,500	1.33
9	Alabama	1,900	0.72
10	Mississippi	1,000	0.38
Top 10 states		263,400	99.26
Total United States		265,370	100

Chapter 2
Monitoring Insect and Pest Damage in Pecan in Arkansas

Keywords: pheromone trap, brown stink bug, *Carya illinoinensis*

This chapter covers preliminary research which has been slightly modified from a previously published article in ActaHort. The citation follows:

Cowell, B., D.T. Johnson, M.E. Garcia, and R. Mizell. 2015. Monitoring insect and pest damage in pecan in Arkansas. ISHS ActaHort. 1070:151-157.

ABSTRACT

The numbers of brown stink bugs [*Euschistus servus* (Say)] per baited yellow pyramid trap were compared across pecan groves [*Carya illinoinensis* (Wangenh.) K. Koch] as part of a survey to establish benchmarks in Arkansas. After mid-June 2012, biweekly counts were made from three pyramid traps set on ground at four sides and the center in each of seven pecan groves that differed in adjacent crops. Each trap was baited with *Euschistus* aggregation pheromone and captured mostly brown stink bugs, *Euschistus servus*. The Humphrey, AR, grove had soybeans planted along 50% of the perimeter and from late-August to mid-October had greater brown stink bug trap counts and percentage nut damage than recorded in the other six groves. A grove in Blackwell, AR had a significant trap location effect with greater counts of brown stink bugs in the center than perimeter locations on five sample dates. The perimeter of this grove was cropped as follows: 50% fallow or pasture; 30% in rice, 20% in soybean. Trap location had less effect on stink bug trap catch in the other six groves. Percentage damage by stink bug, pecan nut casebearer [*Acrobasis nuxvorella* (Neunzig)], hickory shuckworm [*Cydia caryana* (Fitch)] and pecan weevil [*Curculio caryae* (Horn)] are reported for these seven groves in 2012. In the future, I will relate biweekly changes in nut damage to counts of stink bugs both in the pecan canopy and in ground pyramid traps and describe how stink bug damage differs among pecan cultivars at different phenological stages.

INTRODUCTION

The pecan, *Carya illinoinensis* (Wangenh.) K. Koch is the most valuable native North American nut crop (Thompson and Conner, 2012). With 581,809 acres of pecan grown in the United States (USDA National Agricultural Statistics Service, 2007). In Georgia, 1985, stink bugs and leaf footed bugs (Coreid) decreased nut yield, quality, and caused $3.5 million loss of pecans (Deuce and Suber, 1986).

Pecan nuts are punctured and fed on by stink bugs during early development when the nut is in the liquid endosperm stage, also known at the water stage. This feeding damage is referred to as black pit or black heart and causes nut drop (Woodroof and Woodroof, 1928). The puncture is visible on the shuck and extends to the nut meat. Fluid often oozes at the site of a puncture. The path of the puncture turns black internally (Woodroof and Woodroof, 1928). Stink bug feeding on immature nuts will cause the nuts to drop within 5 days (Woodroof and Woodroof, 1928), whereas feeding on mature nuts causes darkened spots to develop on the nut (Hudson and Pettis, 2006). Also, stink bugs have the ability to feed on fully developed nuts and can feed through the hard shells even after harvest (Hudson and Pettis, 2006).

Hudson and Pettis (2006) mentioned that the stink bug complex in pecans in the southeastern U.S. included: Southern green stink bug, *Nezara viridula* (L.); brown stink bug, *Euschistus servus* (Say); dusky stink bug, *Euschistus tristigmus* (Say); green stink bug, *Chinavia hilaris* (Say); and leaffooted bugs, *Leptoglossus phyllopus* (L.). In Georgia, stink bug adults, such as *N. viridula*, *E. servus*, *E. tristigmus*, have been collected as early as April 6th on new pecan leaves and shoots right after bud break (Dutcher and Todd, 1983).

The objectives were to determine types of pests damaging pecan nuts in Arkansas, if stink bug trap counts differ between groves and trap locations; compare stink bug trap counts to percentage nut damage; and compare stink bugs counts trap to those jarred from pecan trees.

MATERIALS AND METHODS

Monitoring

The trap design for biweekly recording of stink bug numbers per trap was a 1.25m yellow pyramid trap with a 0.4m base that tapers to a 2.5cm tip (Hogmire and Leskey 2006). A screen funnel cage was fastened to the top of the pyramid and baited biweekly with lure charged with 30-40ul of the *Euschistus* spp. aggregation pheromone, methyl (2E, 4Z)-decadienoate (Bedoukian Research, Inc., Danbury, CT). These pyramid traps were placed at seven pecan groves located in AR, USA (Humphrey, Garland City, Hope, Mayflower, Fayetteville, and two locations in Blackwell). Three traps were staked in place in each pecan grove perimeter (N, E, S, and W) and center. Biweekly, lures were replaced, stink bugs identified to species (Arnold and Drew 1988) and numbers recorded.

Damage Assessment

Biweekly, I removed 10 nuts from trees located at each pyramid trap site for a total of 150 nuts per grove. All nuts were visually inspected for stink bug puncture of shucks and meat damage. The pecan shuck was cut away or cracked under each apparent stink bug puncture to confirm that puncture extended to meat and formed a small dark spot on the pecan shell. If a pecan weevil [*Curculio caryae* (Horn)] egg or larvae of either a pecan nut casebearer [*Acrobasis nuxvorella* (Neunzig)] or hickory shuckworm [*Cydia caryana* (Fitch)] was found in the meat, the type of pest damage was recorded.

Knock Down Spray

The counts of stink bugs were determined in the canopy by spraying pressurized water using a standard gas powered, power washer connected to a 15 gal tank in each of three groves (Humphrey, Mayflower, and Blackwell Grove 2). A pecan tree in the North, South, and center of each grove was sprayed with a pyrethroid (Fanfare 2EC, bifenthrin) on 9 July and with water biweekly from August 8 to September 18. The subsequent use of only water increased the safety to both the tree sprayer and the person collecting bugs from the ground cloth. The pressurized spray was applied to the lower pecan tree canopy to knock insects out of trees (3 trees per grove). During spraying, water-drenched insects fell from the sprayed tree onto a 20'X20' plastic ground cloth. The collected insects were placed in labeled bags, later identified to species and recorded the number per sprayed tree.

ANALYSIS

The data were analyzed by analysis of variance using PROC GLM using SAS and means separated by *t*-test (*SAS*® 9.3, *SAS* Institute, Cary, NC).

RESULTS AND DISCUSSION

Monitoring

In 2012, the vast majority of the stink bugs caught in baited yellow pyramid traps were brown stink bugs (*E. servus*). First and second summer generations of stink bugs peaked in traps in late-June and late-August, respectively (Fig. 1). Only the Humphrey grove traps had more than 20 stink bugs per trap from early September into October. Stink bug counts were very low all year in pecan groves in Hope, Garland City and the UA Farm in Fayetteville (Fig. 1).

The stink bug trap counts in the Mayflower grove may have been affected by aerial insecticidal sprays applied to the surrounding rice and soybeans fields as needed in 2012 and 2013. Silencer insecticide was applied in the Blackwell Grove 1 on 15 and 31 August and in the Humphrey grove on 31 August. Only the later treatment had little effect on stink bug counts in the Humphrey grove.

Another factor affecting stink bug presents could be prevalence of stink bug hosts and plant canopy density inside and outside the grove. The Hope grove had limited stimuli to attract stink bugs: no pecan nuts on tree; and drive rows and adjacent landscape were mowed short to prevent heading. The Garland City grove had a nut crop but had tall grass in and around the groves. This grass reduced the visual distance of attraction to stink bugs. The UA Farm grove had a light pecan nut crop, drive rows were mowed to prevent heading and the adjacent landscape was a grass pasture with very few stink bug host plants. Other groves had adjacent habitats (soybean fields and woodlots) that may be supporting high stink bug densities. Humphrey grove had a woodlot and lake on the north side and early soybeans (harvested in October) planted on the south and east sides. The south side of the Mayflower grove had soybeans planted in June and had hay on the other three sides. There were no significant differences in mean number of stink bugs per trap by location (LSD = 50.6) in the Humphrey grove (Fig. 2) or the Mayflower grove. On 5 July, Blackwell Grove 1 had significantly ($F = 3.9$; df = 2, 4; $P < 0.047$) more stink bugs in the center of the pecan grove and south (large grass levy with more pecans on the other side) than on the west side (fallow ground) (Fig. 3). In Blackwell Grove 2, five sample dates (20 and 27 June, 5 and 30 July and 16 August) all had significantly more stink bugs ($F = 4.2$; df = 2, 4; $P < 0.04$; $F = 6.2$; df = 2, 4; $P < 0.01$; $F = 4.4$; df = 2, 4; $P <$

0.04; $F = 5.0$; df = 2, 4; $P < 0.03$; $F = 23.5$; df = 2, 4; $P < 0.004$, respectively) in the center of the pecan grove than other trap locations (Fig. 4).

The age of each pecan grove varied: Humphrey was over 100 years old, Mayflower was 60 years old, and the two Blackwell groves were less than 25 years old. The Humphrey and Mayflower groves consisted of older cultivars of pecans (Stuart and Elliot) compared to more contemporary cultivars (Kanza, Pawnee and Oconee) in the two Blackwell groves. The two Blackwell groves did not have adjacent tree lines, whereas a tree line bordered both the east and south sides of the Mayflower grove and the north side of the Humphrey grove. These tree lines provided shade and broadleaf understory for SBs. Blackwell Grove 2 only had a small patch of trees on the south side (Fig. 4). The Mayflower and Humphrey groves both had more stink bug damaged nuts than did the two Blackwell groves (Table 1).

Damage Assessment

In 2012, the first nut samples were assessed for damage by stink bug (SB), pecan weevil (PW) and internal Lepidoptera (IL) biweekly from 16 August to harvest (Table 1). The pecan groves in Humphrey and Mayflower had more nut feeding damage than the other groves. This may be due to the fact that neither pecan groves was sprayed for pests in the previous years or until later in 2012. The damage caused by stink bugs remained relatively low in three groves (<5.4%) but Mayflower had slightly more stink bug damage (8.7%) and Humphrey had the greatest stink bug damage (28.6%) out of all the pecan groves. The pecan weevil damage was zero to very light in all pecan groves on most dates with the exception of Humphrey, which increased with time until the damage reached its peak with 21% on Oct 10^{th}. The internal Lepidoptera caused light damage in all the pecan groves with the exception of Garland City, which ended the season with 26.7 % damage during the last collection date on Oct 10^{th}. The

pecan grove in Humphrey had a pyrethroid insecticide applied aerially on September 1, but this treatment did little against stink bugs that had already caused 18% damage and had no residual effect on pecan weevils emerging in September and October.

Knock Down Spray

Knock down spray samples were collected at Blackwell, Humphrey and Mayflower. Only the first knock down spray applied on July 9th captured rough stink bugs, *Brochymena quadripustulata* (F.) (Fig. 5). The subsequent biweekly knock down sprays applied to trees in August and September were only water. Until August 28, the brown stink bugs numbers gradually increased in these three groves until a pyrethroid insecticide was applied on August 28 to both Humphrey and Mayflower. On September 10, both Blackwell and Humphrey groves were sprayed with a pyrethroid insecticide. From August 28 on, the brown stink bug numbers drop in these trees (Fig. 5).

CONCLUSIONS

The results from this research have indicated that stink bugs have two very distinguishable population peaks in Arkansas. Differences in mean numbers of stink bug on sides of each pecan grove show us that the surrounding habitats such as in Humphrey (Fig. 3) and Blackwell Grove 1 (Fig. 3) have an effect on the pests entering the pecan grove. With this knowledge, growers could reduce stink bug numbers by keeping their pecan grove perimeters and understory mowed to prevent heading of grasses or flowering/seed development of stink bug host weeds.

The damage assessment of pecan nuts in these groves under different management programs has indicated that the management of weeds and pests in the pecan groves understory

greatly reduced stink bug damage and improved pecan quality. As Hall (2009) states, stink bug infestations severity can be reduced by eliminating weeds that are hosts to stink bugs from around and in pecan groves and that stink bug feeding on pecans can cause significant crop loss.

The most numerous stink bug species found by the knock down tree sprays in the three Arkansas pecan groves was the brown stink bug (Fig. 5). The use of insecticidal knock down sprays was one of the typical methods used in sampling stink bugs (Ellis et al., 2000). This information was supported by the pheromone baited pyramid trap data which has also caught mostly the majority of brown stink bugs in its catches. In pecan orchards, 93% of all pentatomids captured in pyramid traps baited with *Euschistus* aggregation pheromone were reported to be *E. servus* and *E. tristigmus* (Yonce and Mizell, 1997).

Future studies include assessing stink bug damage to different pecan cultivars at successive nut phenological stages and monitoring for stink bugs in pecan groves with a black light trap. Black light traps have been used in previous studies (Blinka et al. 2007) to attract and catch green stink bugs. These black light traps May confirm that the majority of stink bugs damaging pecan nuts are in fact brown stink bugs. Future studies will determine the phenological stage when pecan nuts are susceptible to damage by stink bugs and develop a monitoring recommendation that allows growers to determine if stink bugs are present during this susceptible period to improve timing of insecticide spray to prevent stink bug damage to pecan nuts.

ACKNOWLEDGEMENTS

Special thanks to Barbara Lewis, Kevin Durden, Clint Trammel, Bennie Tillis, and participating pecan growers for their assistance and providing pecan groves for these studies. Partial funding was provided by the University of Arkansas Agricultural Experiment Station and the Arkansas Agriculture Department Specialty Crop Block Grant Program.

REFERENCES CITED

Arnold, D. C. and Drew W.A. 1988. The Pentatomoidea (Hemiptera) of Oklahoma. Oklahoma State University, Tech. Bull. T-166.

Blinka, E. L., Bacheler, J., Bradley, J. R., and Van Duyn, J. W. 2007. Stink bug distribution based on black light trap captures across North Carolina in relation to surrounding agricultural host plant ratios, pp. 1711-1712. In Beltwide Cotton Conferences.

Deuce, G.K. and Suber E.F. 1986. Summary of losses from insect damage and costs of control in Georgia, 1985. Univ. of Georgia Spec. Publ. 55.

Dutcher, J.D. and Todd J.W. 1983. Hemipteran kernel damage of pecan. Misc. Publ. Entomol. Soc. Amer. 13:1-11.

Ellis, H. C., Bertrand, P. and Crocker T. F. 2000. Georgia pecan pest management guide. Georgia Coop. Ext. Serv. Bull. No. 841.

Hall, M.J. 2009. Stink bugs and leaffooted bugs on pecans. Louisiana State University Agricultural Center, Publ. 3134.

Hudson, W.J. and Pettis G.V. 2006. Pest management strategic plan for pecans in the Southeastern U.S. http://www.ipmcenters.org/pmsp/pdf/SEPecan.pdf

North Carolina Cooperative Extension Service. 2011. Stink bugs. http://ipm.ncsu.edu/ag271/soybeans/stink_bugs.html

Thompson, T.E. and Conner P.J. 2012. Pecan, pp. 771-801. In: M. L. Badenes and D. H. Byrne (Eds.). Fruit breeding, handbook of plant breeding, Vol. 8. Springer Science + Business Media, LLC.

United States Department of Agriculture, National Agriculture Statistic Service. 2007. Total acres of all pecans: 2007. http://www.nass.usda.gov/research/2007mapgallery/album/Crops_and_Plants/Fruits,_Tree_Nuts,_Berries,_Nursery_and_Greenhouse_Crops/slides/Total%20Acres%20of%20All%20Pecans.html

Woodroof, J.G. and Woodroof N.C. 1928. The dropping of pecans. Natl. Pecan Growers’ Assn. Bull. 2(28):30-34.

Yonce, C. E. and Mizell R. F. 1997. Stink bug trapping with a pheromone. Proc. Southeastern Pecan Growers Assoc. 90:54-56.

Table 1. Biweekly percentage pecan nut damage by stink bug (SB), pecan weevil (PW) and pecan nut casebearer or hickory shuckworm (IL) in five pecan groves in Arkansas USA (2012).

	Blackwell 1			Blackwell 2			Mayflower			Humphrey			Garland City		
Date	SB	PW	IL	SB	PW	IL	SB	PW	IL	SB	PW	IL	SB	PW	IL
Aug. 16	0	0	0	0	0	0	10	0	0	15	0	0	.	.	.
Aug. 30	0	0	0	0	0	0	4	0.7	0	18	0.7	0.7	.	.	.
Sept. 13	3	0	0	3	0	0	4.7	0	0.7	6	0	11	.	.	.
Sept. 18	.	.	.	.	.	.	.	.	.	.	.	.	4	0	12
Sept. 27	4	0	5.3	2.7	0	2	8.7	2.7	3.3	21	2.7	10	.	.	.
Oct. 10	2.7	0	3.3	2	0.7	2	7.3	21	4.7	21	21	11	5.3	0	27
Oct. 25	2	1.3	2	.	.	.	2.7	29	1.3	29	29	10	.	.	.

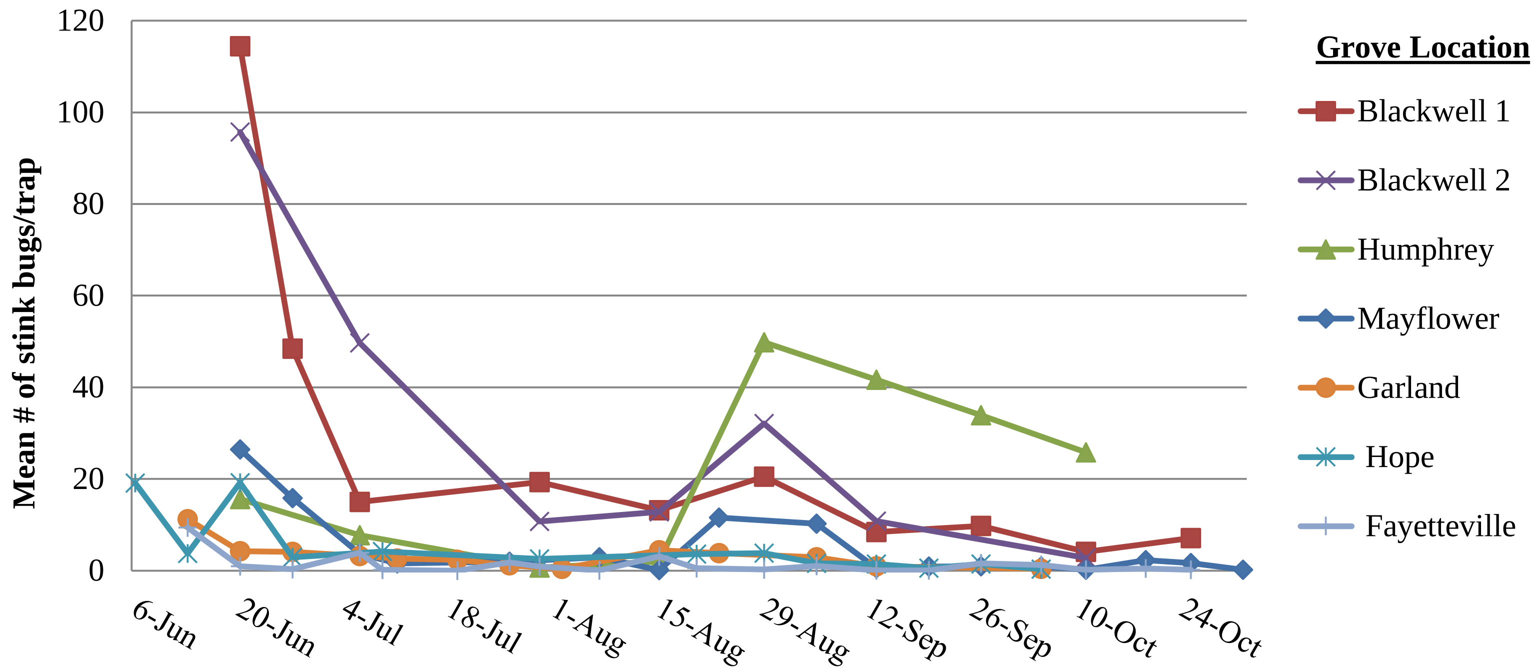


Figure. 1. Mean number of brown stink bugs caught in yellow pyramid traps baited with *Euschistus* aggregation pheromone in several pecan groves in Arkansas USA (2012).

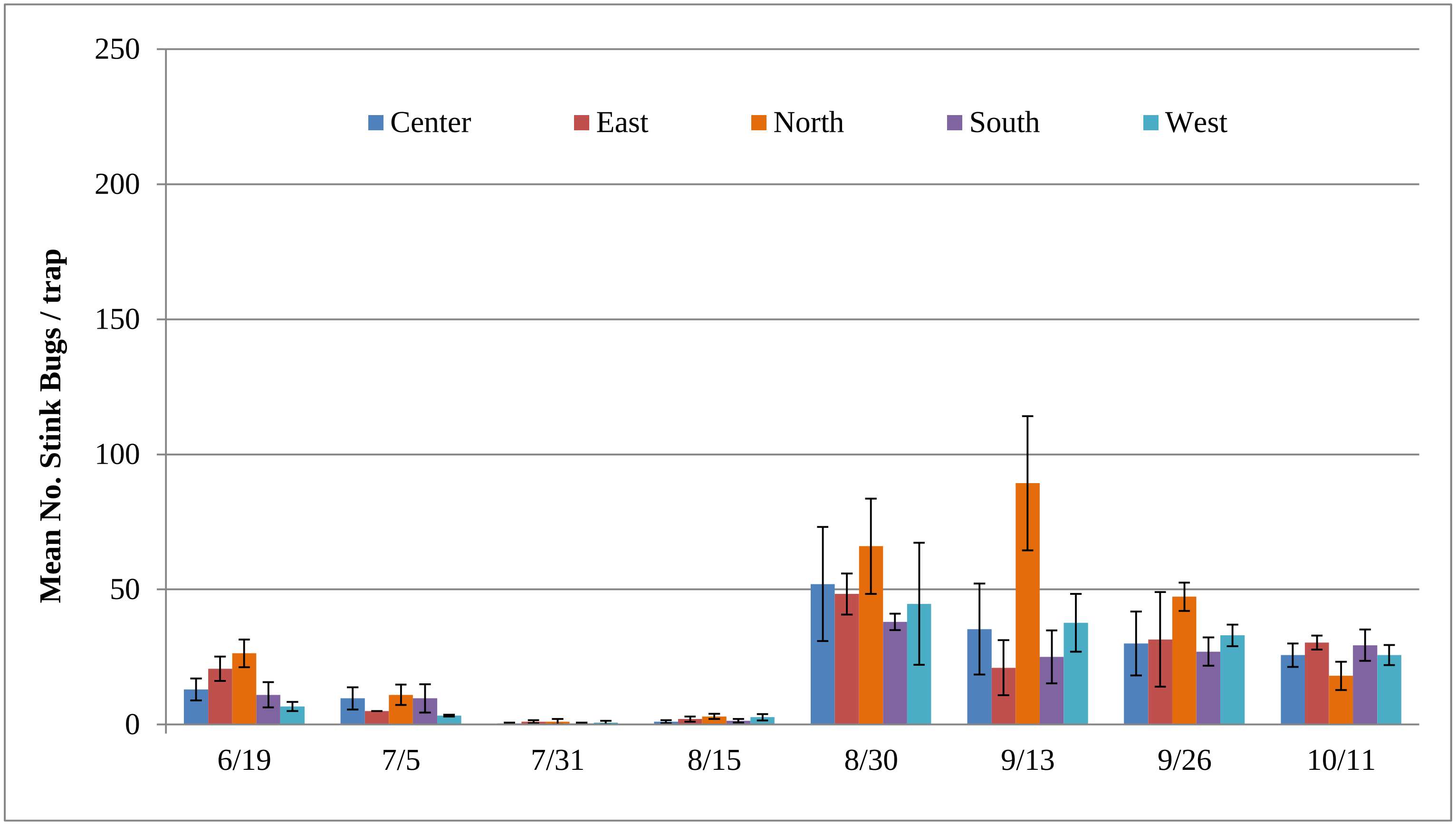


Figure. 2. Mean number (± SE bars) of stink bugs per yellow pyramid trap baited with *Euschistus* aggregation pheromone by location in pecan grove in Humphrey, AR USA (2012). The surrounding habitats by location are as follows: Center = pecans trees, East = rice, North = rice, South = soybean, West = pasture and river. ($P > 0.05$)

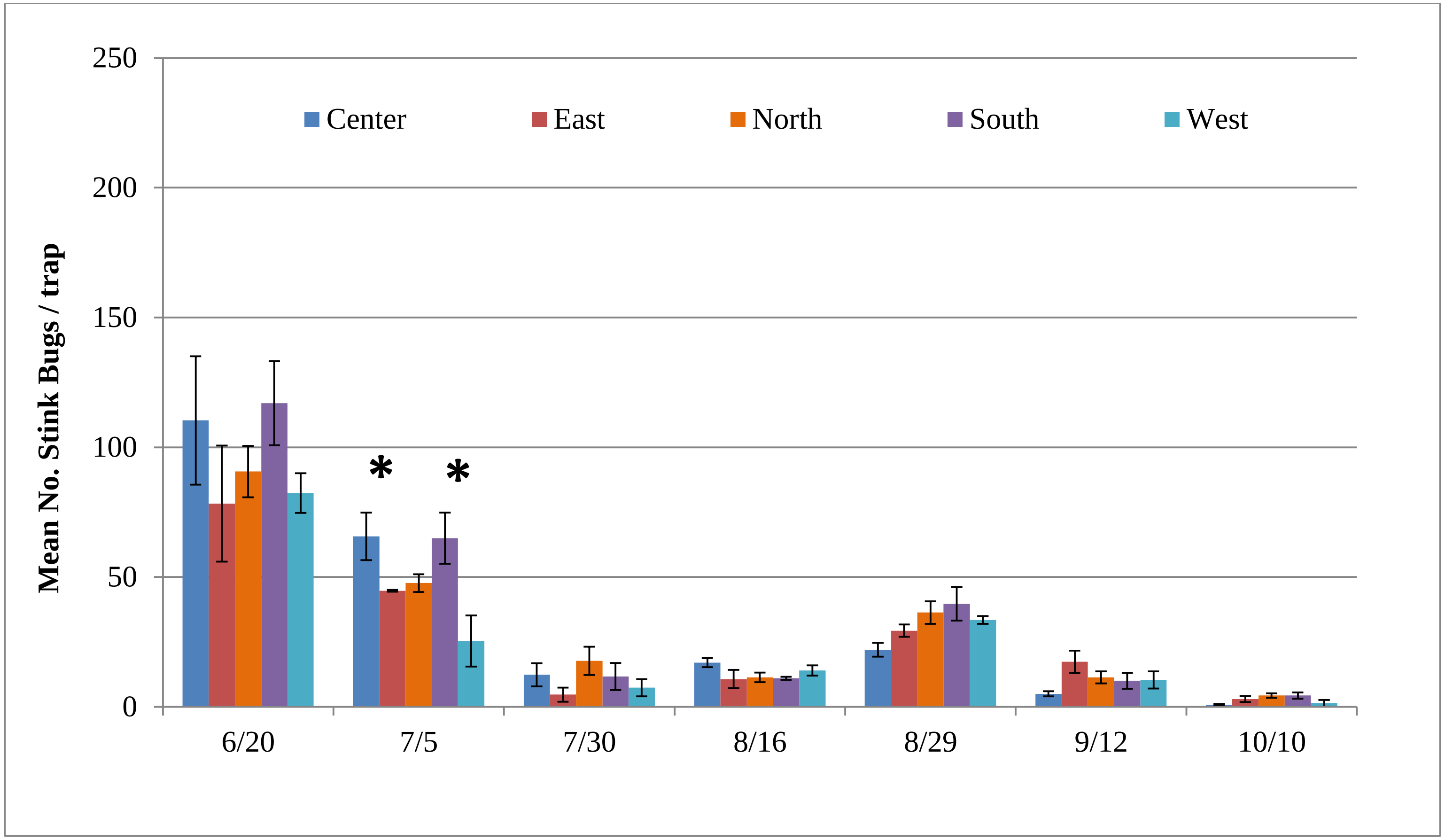


Figure. 3. Mean number (± SE bars) of stink bugs per trap by location in pecan Grove 1 in Blackwell, AR USA (2012). The surrounding habitats by location are as follows (Center = pecans trees, East = fallow, North = fallow and NE pecan, South = grass levy pecans and river, West = fallow). (* *P* < 0.05, significant mean differences only on 7/5)

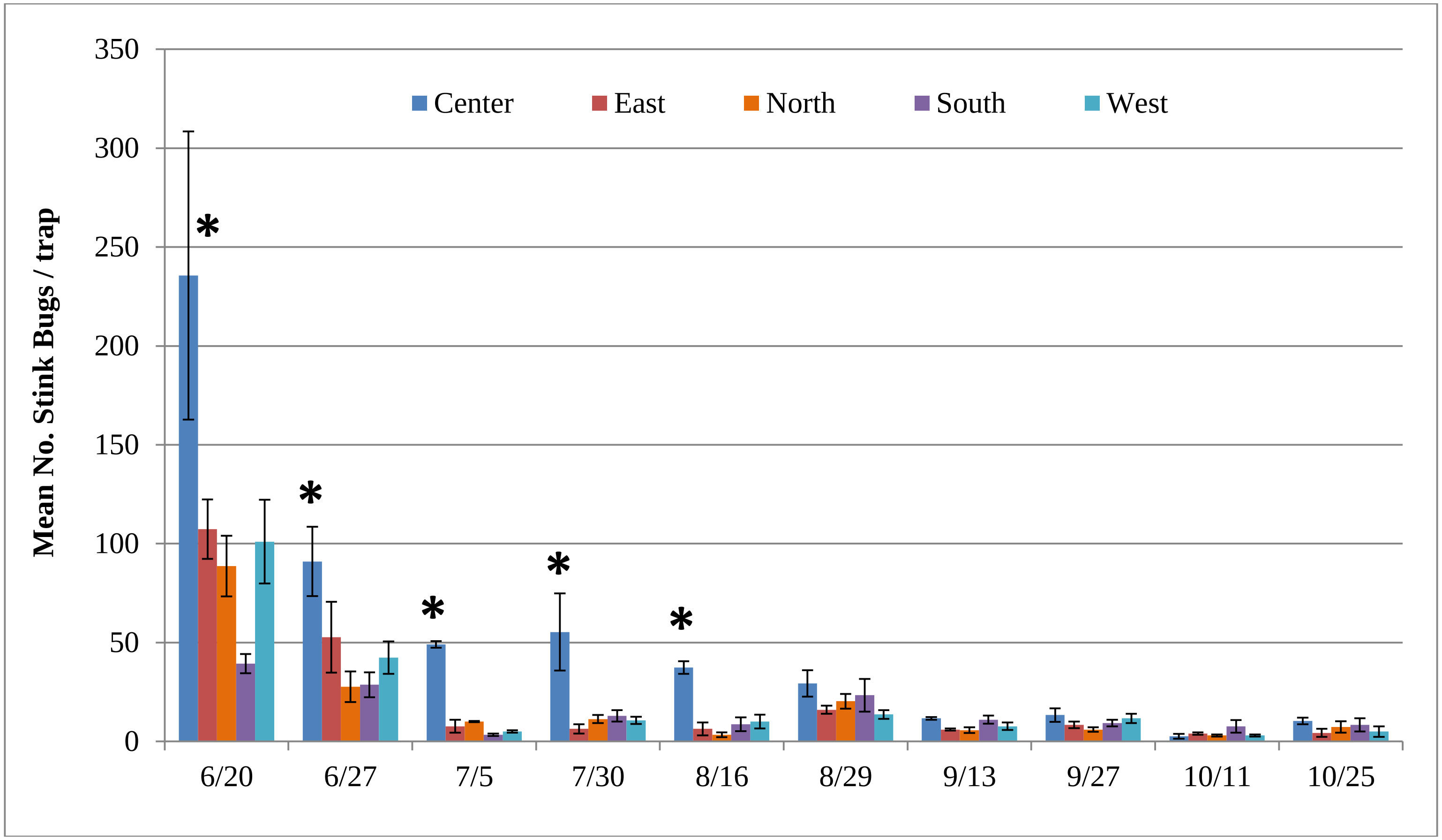


Figure. 4. Mean number (± SE bars) of stink bugs per yellow pyramid trap baited with *Euschistus* aggregation pheromone by trap location in pecan Grove 2 in Blackwell, AR USA (2012). The surrounding habitats by location are as follows: Center = pecans trees, East = soybean, North = woods and lake, South = soybean, West = lawn. (* $P < 0.05$, significant mean differences within sample date)

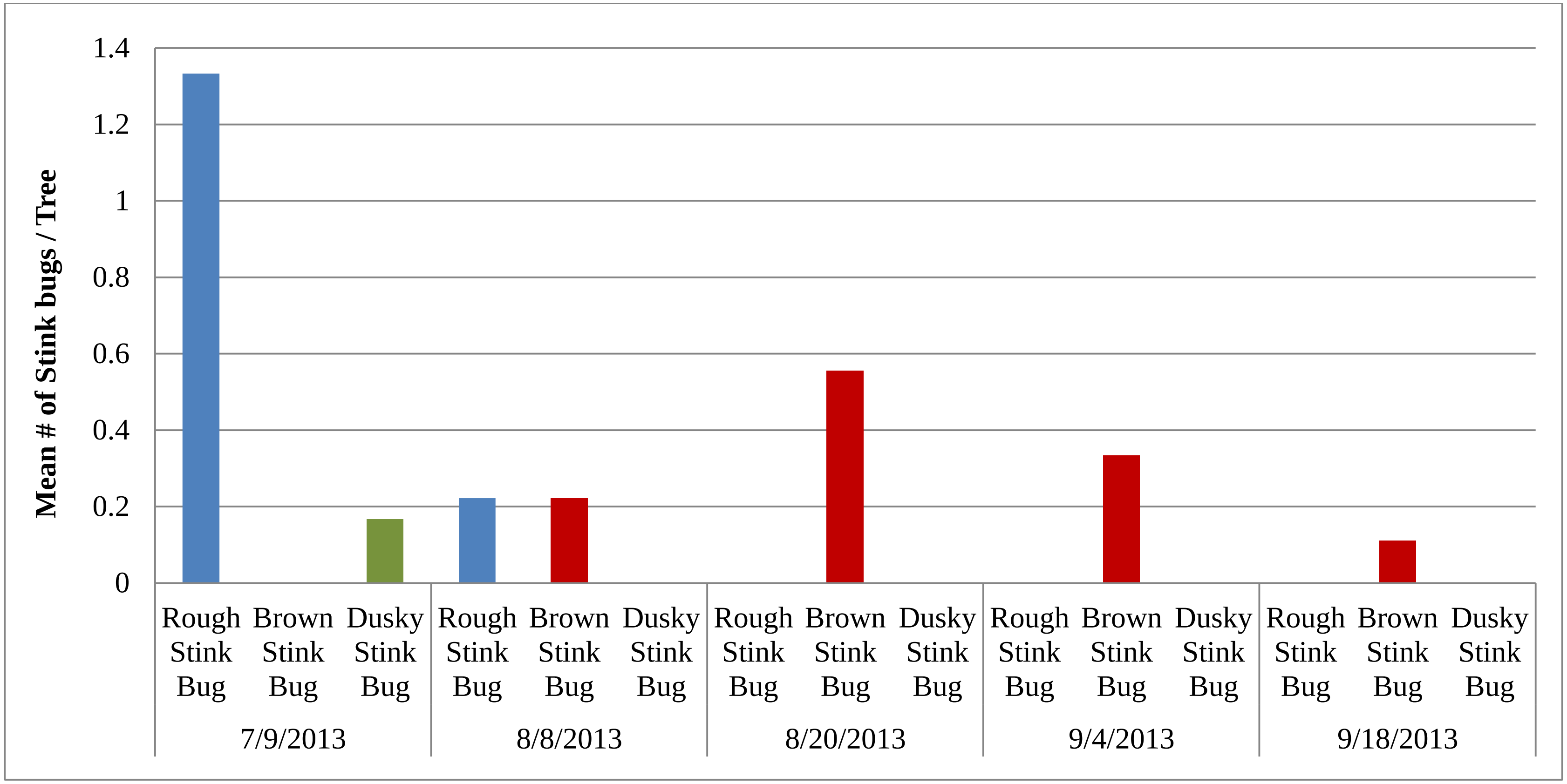


Figure. 5. Mean numbers of three species of stink bugs by date jarred from three trees by a pyrethroid spray (July 9) or pressure water spray (other dates) in each pecan grove in Humphrey, Mayflower, and Blackwell Grove 2 in Arkansas USA (2013).

Chapter 3

Brown Stink Bug (Hemiptera: Pentatomidae) Damage to Pecans at Different Phenological Nut Development Stages

ABSTRACT

Stink bugs feed on pecan nuts, *Carya illinoinensis* (Wangenh.) K. Koch, throughout the growing season. The objective of this study was to determine the most susceptible phenological stage(s) of the pecan nut to both stink bug induced nut drop and kernel damage which, respectively, reduced nut yield and quality. A brown stink bug, *Euschistus servus* (Say), was enclosed in a screened cup cage with a pecan nut in different phenological growth stages from nutlet to mature. All punctures, pecan drop and kernel damage occurred within five days after initiation of feeding in these cages. Stink bugs continually produced feeding punctures in the shuck at all phenological stages. Stink bug feeding caused significantly more pecan drop during water and gel stages than the earlier or later nut growth stages excluding the gel/ early dough stage and no pecan drop during the dough, early-mature, and mature stages. The pecans dropping from trees due to stink bug injury during nutlet expansion to early-water stage was not significantly different from natural pecan drop. Stink bug induced drop due to feeding injury during the early-water to gel / early-dough stages may reduce overall yield. Stink bug feeding caused damage to pecan kernels during the water, gel, and gel / early-dough stages. Black kernel spot damage by stink bugs that reduced nut quality was greatest in the dough stage. Thereafter, kernel spot damage decreased through early-mature nut stage. No kernel spot damage occurred in either mature or post-harvest nut stages.

INTRODUCTION

Plant feeding insects such as stink bugs (SB) (Hemiptera: Pentatomidae) are economically important pests which can decrease pecan nut yield and quality. In Georgia, 1985, stink bugs and leaffooted bugs (Hemiptera: Coreidae) were the most important pecan insect pests whose feeding caused a $3.5 million loss of kernel quality (Deuce and Suber 1986).

Pecans in the southeastern United states are fed on by a SB complex which include: brown stink bug (BSB), *Euschistus servus* (Say); dusky SB, *Euschistus tristigmus* (Say); green SB, *Chinavia hilaris* (Say); leaffooted bugs, *Leptoglossus phyllopus* (L.); southern green SB, *Nezara viridula* (L.); and others (Hudson and Pettis 2006). These SBs are extremely polyphagous insects. SBs feed primarily on seeds during the milk (also called water) stage, e.g., filling with mostly sugars (Mizell et al. 2008). Many of plant feeding hemipterans including pentatomids use amylase in their feeding process (Hori 2000). This amylase breaks down the host plant sugars and starches so that these insects can feed. These sucking insects attack pecan nuts throughout the year and can even feed through the hardened shell of pecans (Hudson and Pettis, 2006). The most prevalent Hemipteran species in pecan groves is the BSB (Cowell et al. 2015, Hogmire and Leskey 2006).

Brown stink bugs can have two generations per year in Arkansas. The overwintered adults emerge, fly and lay eggs on hosts producing seeds or fruits in April and May. The first and second summer generation of adults emerge in June and from Aug. to Sep. (Carter et al. 1996, Cowell et al. 2015). Brown stink bugs also have a large variety of host plants including but not limited to broadleaf shrubs, blackberries, vines, corn, soybean, sorghum, okra, millet, snap beans, peas and cotton. Legumes are the most preferred hosts (Gomez and Mizell, 2008).

Stinkbugs readily move to a new food source when current host plants no longer have seeds in the preferred milk stage (Mizell et al. 2008).

Smith (2010) stated that in central Oklahoma, which is climatically similar to much of Arkansas, bud break for pecan is typically the first or second week in April. Woodroof and Woodroof (1928) suggest that if the pecan flowers are not adequately pollinated the nutlets will be aborted from the tree. After pollination the pecan nut grows slowly until the end of June to the beginning of July. The nut then expands rapidly during the water stage (Smith 2010), with water and some sugars (Finch and Horn 1936). From mid- to late-August the pecans enter a gel stage. At this stage the shell (pericarp) begins to harden and the fruit can no longer enlarge (Smith 2010, McKay 1947). The gel layer that forms on the inside of the shell consists mostly of sugars and no fats (Finch and Horn 1936). Stink bug feeding from water through shell hardening will cause darkening of the inside of the pecan (black pit) and the nuts will drop from the tree (Osburn et al. 1966). During late-August the nuts enter into the dough stage (Smith 2010) when sugars are converted to fat to form the solid white cotyledon (Finch and horn 1936). Stink bug feeding during dough stage causes bitter tasting dark spots (kernel spot) to form on the kernel of the pecan nut but these damaged nuts will not drop (Osburn et al. 1966). This type of internal damage cannot be detected until the pecans are shelled (Hudson and Pettis, 2006). The pecans shuck splits after the pecan nut ripens from early-September to early-November depending on the cultivar. Once the shuck is split the fruit is ripe and is ready to be harvested (Smith 2010). Harvested pecans can be fed on through the hardened shells by SBs (Hudson and Pettis, 2006), but it was not demonstrated that this feeding caused kernel spot damage. Dispersal of SBs into pecan groves and feeding on pecan nuts was reported as promoted by presence of pecan nuts developing through the SB susceptible stages (Mizell et al. 2008). According to Hudson et al.

(2011), SBs were present in pecan groves all year long but feeding damage that reduced kernel quality and caused economic loss occurred from late-August to late-September from shell hardening (dough stage) to early-maturity.

This study was conducted in order to determine if feeding by one BSB on one nut in a screen cage at different phenological nut stages results in different percentages of nut drop, black heart and kernel spot damages to pecan nuts.

MATERIALS AND METHODS

In Blackwell, AR from July to the end of October in 2013 and 2014, live adult BSBs were collected every two weeks from yellow pyramid traps (Hogmire and Leskey 2006; Mizell and Tedders 1995). The most active and viable BSBs were maintained in a rearing cage (BugDorm insect breeding cages model # 1468C; Rancho Dominguez, CA) in the laboratory at 24°C and 78% RH until used in the pecan nut feeding study. In 2013, dead SBs were removed daily from the BSB cage that contained a water source (50 ml jar of water with a cotton wick) and food (green bean pods) each replaced daily (personal communication, Bill Ree). In 2014, BSBs were kept in 19 liter plastic buckets covered with nylon screening to help increase the humidity within the bucket to increase survival. Each bucket contained a 1 liter jar of water holding a resting substrate of freshly cut heading grass (changed every 3 days) and soybean pods, a more preferred host (Nessler 2008). Once pecans developed past the water/gel stage the BSBs were maintained in a screen cage enclosing leaves and a cluster of pecan nuts in a pecan grove at the University of Arkansas Agricultural Research and Extension Center (AAREC) in Fayetteville, AR.

The BSB feeding cage study was conducted on the ‘Kanza’ pecan cultivar in the pecan grove at the AAREC in Fayetteville, AR (36° 5'25.44"N 94°11'20.94"W) from late June to the end of the growing season in November. The feeding cage was a modification of the paper cup cage described by Dutcher et al. 2001). It consisted of: 1 liter Styrofoam drinking cup (6.5 cm bottom diameter x 10.5 cm top diameter x 18 cm height) cut the length of one side and across to the center of the bottom; and covered with a 52 cm long by 12 cm diameter cylindrical sleeve of ProtekNet insect netting mesh opening of 1.0 mm x 0.6 mm (Dubois Co., Canada). The cup and insect netting were slipped over a pecan branch with all nuts but one removed. To prevent external insect feeding damage netting was tied on both ends so that the pecan nut would not touch the screen (Fig. 1A). Shortly after pecan nuts set in early-June, 200 and 300 pecan clusters in 2013 and 2014, respectively, were thinned to one pecan per cluster and a cage placed over each (Fig. 1B). This prevented insect damage to the pecan nuts prior to initiation of the cage feeding study. Extra pecan nuts were caged on trees to allow for natural nut drop in order to ensure adequate number of nuts in cages for each feeding period.

2013. Five SB-free control cages each had one pecan nut whereas five BSB feeding cages each had one pecan nut and one adult BSB that was removed after five days of feeding. On the fifth day the nut was removed from each control and BSB feeding cage. The shuck of each pecan was examined for presence BSB stylet feeding puncture mark(s) (smaller than this period “.”). A sharp knife was used to peel away the pecan shuck below the puncture mark to see if the SB stylet puncture either penetrated through the shuck (darkened line) to the shell or through the shell (puncture mark) and caused black heart or kernel spot damage. The phenological stage of each nut was recorded (left column in Fig. 2 A-I). The 2013 cage study was repeated biweekly, from August 14 to November 9, for a total of 140 pecans.

2014. The cage study was modified to determine if: (1) BSB feeding caused pre-water stage pecans to be aborted and dropped from the pecan tree; (2) BSB feeding would continue to damage the pecans after maturity; and (3) if there was a latent period from the time that BSBs punctured the shuck until the damage became apparent. The cage study was conducted from July 7 to November 7. Every ten days one BSB was placed in each of 15 cages with a single pecan nut. This was replicated in 15 control cages which were BSB-free. The first two samples of pecans collected in July had only 5 control cages. A BSB was allowed to feed on a nut in each of 15 cages for 5 days. After five days the BSBs were removed from all cages. Five control, BSB-free cages and five BSB cages were inspected 5, 10, and 15 days after initiation of BSB feeding. If the pecan nut had dropped in the cage it was then removed and examined for damage as described above. There were 270 pecans used in the 2014 cage study.

2015. Two studies were conducted to confirm that BSB feeding does not damage pecans after maturity. The pecans used in this study were 'Kanza' pecan cultivar collected in October 2014 from the University Of Arkansas Fruit Research Station in Clarksville, AR. These pecans were kept stored in a refrigerator at $4^{o}C$. The first study was conducted by placing half of a shelled pecan kernel inside each of one hundred 100 mm diameter Petri dishes. A wet cotton ball served as a water source and one BSB was allowed to feed for 5 days. On day 5, the BSB was removed and each half pecan kernel was examined for BSB damage. The second study was conducted by placing an intact pecan nut (with shell) and a water-moistened cotton ball inside each of one hundred 100 mm Petri dish and one BSB allowed to feed for 5 days. On day 5 the BSBs were removed and the pecans were shelled and examined for BSB damage.

ANALYSIS

The nuts removed on specific dates were not all in the same phenological stage. Therefore, the numbers of punctured, damaged, or dropped nuts from each study were re-grouped by phenological stage instead of by date before performing statistical analysis. The data were binary (damaged or not damaged) so a 95% confidence limit was calculated using PROC MEANS to determine the exact upper and lower confidence limits (*SAS*® 9.3, *SAS* Institute, Cary, NC). During all the phenological stages, all nut damage and drop had occurred by the fifth day of BSB feeding so there were no significant differences among 5, 10, and 15 days after the start of the five day BSB feeding injury period in 2014 so data were pooled in that study.

RESULTS

The BSBs in cages punctured 100% of the pecans nuts in all phenological stages but damage (black heart and kernel spot) varied by phenological nut stage. Damage only occurred during water and gel stages in 2013 and during water, gel, and gel/dough stages in 2014 (Tables 1, 2) (middle column in Fig. 2 D-H). The BSBs damaged all the pecans during the water, gel, and gel/dough stages. This feeding damage was significantly greater than proportions damaged in later nut phenological stages in 2013 for dough (0.56 proportion), early-mature (0.2) and mature (0) nut stages (Table 1); and in 2014 for the nutlet (0.42), expanding nutlet (0.6) and early-water (0.47); dough (0.74), early-mature (0.48), and mature nut stages (0) (Table 2). The BSB-free control cages had no punctures or damage in either year.

In 2014, the mean proportion pecan drop caused by BSBs was significantly different by phenological stage. The water and gel stages had significantly more pecans drop from the tree than the nutlet, expanding nutlet, and early-water stages whereas these later stages including the

gel / dough stage had significantly more pecans drop than the “0” pecan drop recorded for dough, early-mature, and mature stages (Table 2). The mean proportion of pecans that naturally dropped in cages both with and without BSB feeding (control) was not significantly different during the nutlet and expanding nut phenological stages (Table 2).

In 2015, 100% of the kernels in either mature pecans in shell or mature shelled kernels fed upon by BSBs showed no visible SB feeding damage.

DISCUSSION

My findings from the 2013 and 2014 cage study showed that pecans in the cage free of BSBs had no darkened puncture lines (Undamaged Control) as illustrated in photographs of the nut in different phenological stages (left column in Fig. 2 A-I). However, BSBs punctured all pecan nuts in all phenological stages when allowed to feed on pecan nut within a screen cage (middle column in Fig. 2 A-I). This observation agreed with Woodroof and Woodroof (1928) who stated that SB feeding punctures caused the cells around the puncture to turn black within one hour. Even though BSBs punctured all pecan nuts across all phenological stages, only pecans in the water and gel nut stages suffered significantly higher kernel damage (2013 and 2014) and pecan drop (2014) than other nut stages (right column in Fig. 2 G, H). Stink bug damage to the water or gel stage caused the liquid endosperm and surrounding tissues to turn black and the pecan shuck to darken quickly. As the pecan shell hardened, it developed through the gel stage where the gel like substrate built up against the walls of the pecan by converting sugars to fats and oils before entering the gel / early dough stage (Fig. 2 F). During gel / early dough stage the amount of SB damage to the pecan did not decrease but the severity of the damage is greatly reduced. Stink bug feeding on the endosperm and cellular gel damage during the gel / early

dough stage had some visible damage to the pecan cotyledon and visible darkened punctures through the shuck. The dough stage (Fig. 2 G) was reached when the pecan shell was completely hardened and was completely filled with cotyledon. Stink bug feeding during the dough stage caused small kernel spot to appear on the kernel which caused a bitter taste when eaten. As the pecan entered the early-mature stage (Fig. 2 H), it was in the process of drying but the pecan shuck had yet to open and the pecan was less susceptible to BSB damage. Once the pecan was fully dried and the pecan shuck opened, the pecans were in their mature stage (Fig. 2 I) when BSB damage was reduced to zero. Stink bugs were reported to have the ability to feed on fully developed nuts even after harvest (Hudson and Pettis 2006), but I did not observe any feeding damage to the kernel in the 2013, 2014 or 2015 studies.

When comparing the proportion of pecans which had kernel damage during each nut phenological stage, I found that the nut stages most susceptible to kernel damage by BSB feeding were the water and gel stages in 2013 and the water, gel and gel / early dough stages in 2014. The nut stages before and those after had little to no kernel damage. This was attributed to the fact there were sugars present in the pecan from the water stage through the early dough stage which the BSB digestive enzyme (amylase) (Hori 2000) could break down. As the pecans mature and the sugars are converted into fats there is little sugar left for the amylase to act on, therefor damage is reduced. Crane et al. (1935) stated that the nut stages of pecan most susceptible to SB injury were the watery stages.

Once the pecan shell has hardened and the seed coat is about halfway filled by the embryo of the kernel, such as in the gel / early dough stage, the nut can withstand a great amount of damage without dropping (Woodroof and Woodroof, 1928). According to Hudson and Pettis (2006), SBs have the ability to feed through the hard shells of fully developed pecan even after

harvest. As indicated from my findings, punctures were continually occurring throughout all phenological nut stages but kernel damage caused by feeding no longer occurred once the pecan was in the more mature stages. This was confirmed by the 2015 study which showed that BSBs did not damage mature pecans.

In this study, the water and gel stages had significantly more pecan nut drop after BSB feeding than the other stages with no nut drop occurring in the dough, early-mature, and mature stages. This pattern of SB induced nut drop until dough stage was reported by Dutcher et al. (2001) and Wood (1992). When the more mature nuts were fed upon, darkened spots developed on the nut kernel (Hudson and Pettis, 2006). SB kernel damage would not change the pecan yield but it would reduce the quality of the yield and price per pound received by a grower. This cage study also confirmed that BSB feeding on nuts during the nutlet and expanding nut stages did not increase nut drop nor reduce total crop yield more than natural nut drop. Pecan trees lose a large portion of the nuts to natural nut drop caused by lack of fertilization or self-pollination before the shell hardening gel stage (Sparks and Madden 1985).

A future study needs to evaluate the following SB management recommendation to prevent SB induced drop (yield loss) and kernel damage (quality loss): Starting at water stage, growers begin weekly checking of nuts in each pecan cultivar to determine which blocks have nuts in a SB-susceptible stage. If growers also detect SBs in those pecan trees, it would be appropriate to apply an insecticide reported as effective against all SBs, especially BSB.

REFERENCES CITED

Carter, C.C., T.N. Thomas, D.L. Kline, T.E. Reagan, W.P. Barney. 1996. Insect and related Pests of Field Crops. North Carolina Cooperative Extension Service AG-271.

Cowell, B., D.T. Johnson, M.E. Garcia, and R. Mizell. 2015. Monitoring insect and pest damage in pecan in Arkansas. ISHS ActaHort. 1070:151-157.

Crane, H.L., M.B. Hardy, F.N. Dodge, and N.H. Loomis. 1935. Effect of bagging on the drop of pecan clusters. Amer. Soc. Hort. Sci. Proc. 32: 38-42.

Deuce, G.K., and E.F. Suber. 1986. Summary of losses from insect damage and costs of control in Georgia, 1985. Univ. of Georgia Spec. Publ. 55.

Dutcher, J.D., R.E. Worley, P. Conner, and S. Doves. 2001. Pecan varietal differences in hemipteran kernel damage. J. Entomol. Sci. 36:445-452.

Finch, A.H. and C.W. Van Horn. 1936. The physiology and control of pecan filling and maturity. University of Arizona. Bull**.** No. 62.

Gomez, C., and R.F. Mizell. 2008. Brown stink bug - *Euschistus servus* (Say). University of Florida. Dept. Entomol. and Nematol. Publ. EENY-433

Hogmire, H.W., and T.C. Leskey. 2006. An improved trap for monitoring stink bugs (Heteroptera: Pentatomidae) in apple and peach orchards. J. Entomol. Sci. 41:9-21.

Hori, K. 2000. Possible causes of disease symptoms resulting from the feeding of phytophagous Heteroptera, p. 11-35. *In*: Schaefer CW, Panizzi AR (eds) Heteroptera of economic importance. CRC Press, Boca Raton.

Hudson, W.J., and G.V. Pettis 2006. Pest management strategic plan for pecans in the Southeastern U.S. http://www.ipmcenters.org/pmsp/pdf/SEPecan.pdf

Hudson, W. J., Brock, S. Culpepper, W. Mitchem, and L. Wells. 2011. 2011 Georgia pecan pest management guide. Georgia Pecan Grower’s Assoc. Bull. 841:1-16.

McKay, J.W. 1947. Embryology of pecan. J. Agric. Res. 74:263-268.

Mizell, R. F., III, T. C. Riddle, and A. S. Blount. 2008. Trap cropping system to suppress stink bugs in the southern coastal plain. Proc. Florida State Hort. Soc. 121:377–382.

Mizell, R. F., III, and W.L. Tedders. 1995. Use of the modified Tedders trap to monitor stink bugs in pecan. Proc. Southeastern Pecan Growers Assoc. 88:36-40.

Osburn, M.R., W.C. Pierce, A.M. Philips, J.R. Cole, and G.E. Kenbright. 1966. Controlling insects and diseases of pecans. USDA, Agricultural Handbook 240: Rev. 1–55.

Smith, M. 2010. Pecan phenology. Oklahoma Pecan Growers Association LI (4):4. http://okpecangrowers.com/yahoo_site_admin/assets/docs/2010quarterly04.51122900.pdf

Sparks, D., and G. D. Madden. 1985. Abortion of fruit, flowers linked to three stages. Pecan South 19:14-28.

Wood, B.W. 1992. Factors influencing fruit-drop of pecan. Ann. Rpt. Northern Nut Growers Assoc. 83:68-71.

Woodroof, J.G., and N.C. Woodroof. 1928. The dropping of pecans. Natl. Pecan Growers' Assn. Bull. 2(28):30-34.

Table 1. In 2013, the mean proportion (lower, upper 95% confidence intervals) of nuts punctured or damaged during each pecan nut phenological stage inside a screen cage after brown stink bugs fed on pecan nuts for five days (Feeding) or were brown stink bug-free (Control). The caged pecan nuts free of brown stink bugs (Control) had no punctures or damage.

Phenology	**N = Feeding**	**N = Control**	**Damaged**
Water	5	5	1 (1, 1)a
Gel	5	5	1 (1, 1)a
Dough	9	10	0.56 (0.22, 0.89)b
Early Mature	5	5	0.2 (0, 0.6)b
Mature	10	10	0 (0, 0)bc

Means were statistically different if there was no overlap between the 95% confidence interval. Columbs with the same lower case letter are not statistically different.

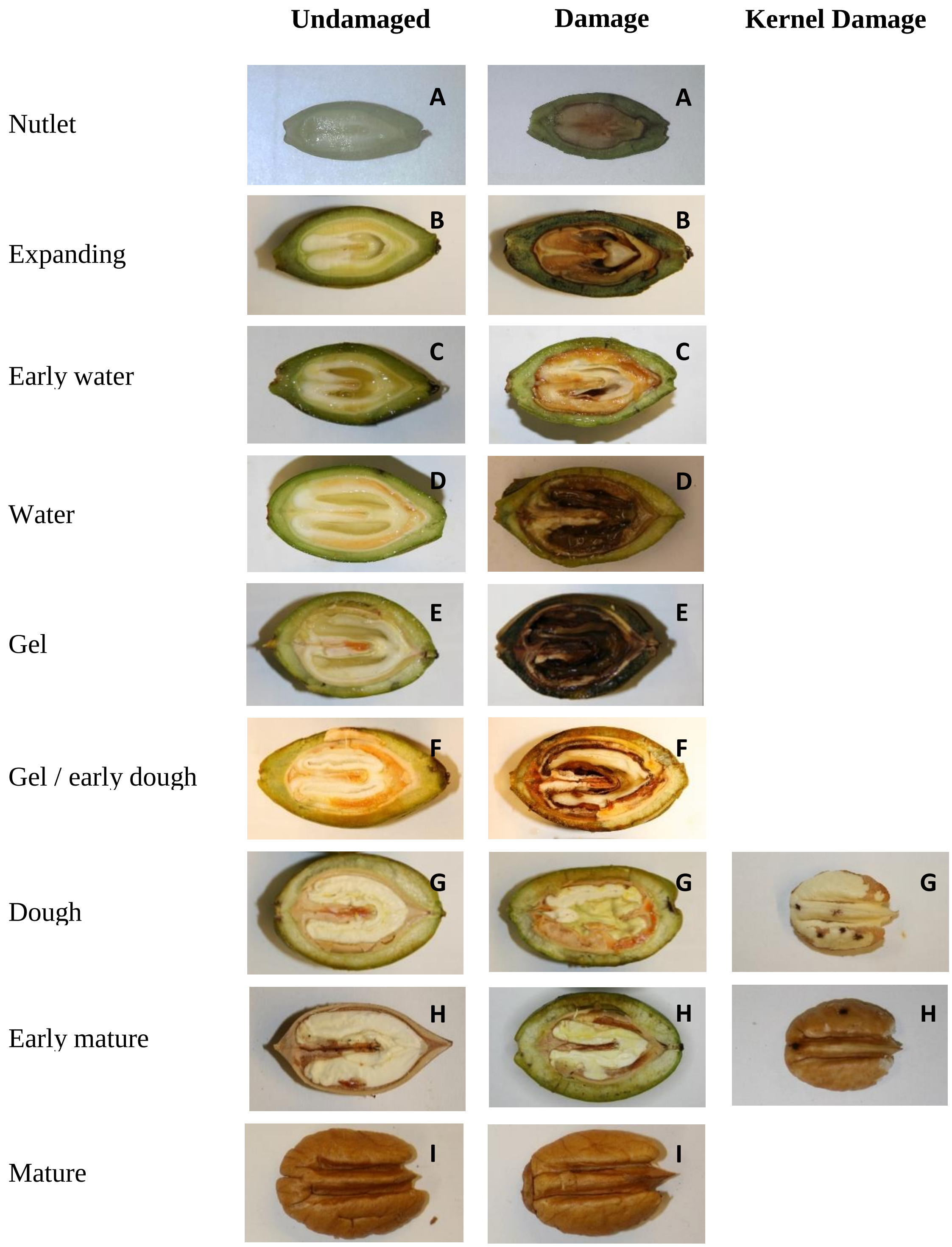
Table 2. In 2014, the mean proportion (lower, upper 95% confidence intervals) of nuts punctured, damaged and/or that dropped during each pecan nut phenological stage after brown stink bugs feed on pecan nuts for five days (Feeding) or were brown stink bug-free (Control). The caged pecan nuts free of brown stink bugs (Control) had no punctures or damage but had natural drop.

	Number		Proportion (lower, upper 95% confidence intervals)		
Phenology	**Feeding**	**Control**	**Damage**	**Drop**	**Control Drop**
Nutlet	12	5	0.42 (0.17, 0.67)b	0.54 (0.31, 0.77)bA	0.6 (0.2, 1)aA
Expanding	10	10	0.6 (0.3, 0.9)b	0.4 (0.1, 0.7)bA	0.5 (0.2, 0.8)aA
Early Water	15	15	0.47 (0.2, 0.73)b	0.4 (0.13, 0.67)bA	0 (0, 0)bB
Water	19	20	1 (1, 1)a	1 (1, 1)aA	0 (0, 0)bB
Gel	10	10	1 (1, 1)a	1 (1, 1)aA	0 (0, 0)bB
Gel/ Early Dough	5	5	1 (1, 1)a	0.6 (0.2, 1)abA	0 (0, 0)bB
Dough	35	35	0.74 (0.6, 0.89)b	0 (0, 0)cB	0 (0, 0)bB
Early Mature	25	25	0.48 (0.28, 0.68)b	0 (0, 0)cB	0 (0, 0)bB
Mature	30	30	0 (0, 0)c	0 (0, 0)cB	0 (0, 0)bB

Means were statistically different if there was no overlap between the 95% confidence interval. Columbs with the same lower case letter are not statistically different. Rows with the same upper case letter are not statistically different.

Figure 1. Screen cage consisting of a 1 liter Styrofoam cup covered with plastic insect netting A) tied over the terminal of a 'Kanza' pecan branch B) with or without a brown stink bug inside allowed to feed on a single pecan nut.

Figure. 2. Comparison of healthy pecans removed from screen cages kept free of brown stink bugs (Undamaged Control; left column) to types of damage to pecan visible after removal from screen cage where a brown stink bug fed on the nut (Damage; middle column) and when it caused economic damage to kernel (kernel spot) (Kernel Damage; right column) during given pecan phenological stages.



Chapter 4

The Stratification of Stink Bug (Hemiptera: Pentatomidae) Feeding Punctures and Damage within the Pecan Canopy

ABSTRACT

Stink bug (SB) punctures and damage were assessed in the pecan tree canopy in several pecan groves in Arkansas. Nuts were collected by each of three sampling methods: lower canopy by hand; whole pecan canopy using a pecan trunk shaker; and lower (0 – 3 m), middle (3 – 6 m) and upper (6 – 9 m) pecan canopy using an Orbit lift pruning tower. When comparing the pecans collected using the tree shaker to pecans collected by hand from the lower limbs it was found that the proportion of pecans punctured by SBs from the pecans collected using the tree shaker was significantly less than the proportion collected by hand from the lower limbs. This suggested that SB feeding damage occurred more in the lower pecan canopy than the middle or upper canopy. The nut samples collected in late-September near harvest via the Orbit lift had significantly more SB punctures and damage in the lower strata of the pecan trees than either the middle or the upper strata.

INTRODUCTION

The most valuable native North American nut crop is the pecan, *Carya illinoinensis* (Wangenh.) K. Koch (Thompson and Conner, 2012), with an approximate value of $508 million in the United States in 2014 (Rafanan 2015).

Damage to pecans by pecan pests such as stink bugs (SBs) (Hemiptera: Pentatomidae) can reduce pecan yield and nut quality (Harris 1983). In Georgia, 1997, kernel feeding hemipterans such as stink bugs (SB) cost pecan growers approximately $1.8 million (Ellis and Dutcher 1999). The predominant SBs that damage pecan nuts in the southeastern U.S. include: Southern green SB, *Nezara viridula* (L.); brown SB, *Euschistus servus* (Say); dusky SB, *Euschistus tristigmus* (Say); green SB, *Chinavia hilaris* (Say); leaffooted bugs, *Leptoglossus phyllopus* (L.); and other incidental species (Hudson and Pettis 2006).

Stink bug feeding punctures appear as thin, clear fluid oozing from the small SB puncture site on the pecan and internally turn black along the stylet sheath in the shuck (Yates et al. 1991). Stink bugs feeding on pecan nuts during the liquid endosperm stage or water stage before the shells have hardened will cause the inside of the immature nut to turn dark, this condition is referred to as black pit or black heart and causes nut drop within five days (Woodroof and Woodroof 1928, Osburn et al. 1966). Stink bug feeding on maturing nuts from dough stage to harvest can cause dark, bitter tasting spots to develop called kernel spot (Hudson and Pettis 2006, Osburn et al. 1966). This type of kernel injury cannot be detected until after the pecans are shelled (Osburn et al. 1966). Also, according to Hudson and Pettis (2006), SBs have the ability to feed on fully developed nuts and can even feed through the pecan’s hard shell after harvest.

Different scouting techniques are used to aid decision-making about the need and timing of insecticide treatments against SBs. The yellow pyramid trap described by Mizell and Tedders

(1995) and Hogmire and Leskey (2006) has been used to monitor the movement and presents of the SBs. The yellow pyramid trap is baited with rubber septum charged with 40 µl of the *Euschistus* spp. aggregation pheromone, methyl (2E, 4Z)-decadienoate (Aldrich et al. 1991). Hogmire and Leskey (2006) successfully used the aggregation pheromone as bait in yellow pyramid traps to capture three main SB species including: brown SB, *E. servus*; dusky SB, *E. tristigmus*; and green SB, *C. hilaris*. Dispersal and location of large SB infestations can be tracked and controlled as needed through usage of yellow pyramid traps. Although the yellow pyramid traps attract both the green and brown SBs the *Euschistus* spp. aggregation pheromone specifically attracts the genus *Euschistus* making it so the traps are more effective at capturing the brown and dusky SBs, other methods are needed to monitor green SBs and leaffooted bugs.

According to Lee (2007), UV black light traps are an effective way of monitoring green SBs that are prevalent in Arkansas, Georgia, and Louisiana. For habitats adjacent to pecan grove, such as cotton and soybean fields, sweep net and beat sheet sampling methods are recommended for monitoring all species of SBs (Todd and Herzog 1980).

In order to scout for SBs or leaffooted bugs in the pecan tree itself there are two main recommended methods: visual counts and knock-down sprays. If one SB is found per 40 pecan terminals checked during the visual counts or if five or more SBs are found per knock down spray with a plastic sheet covering 20% of the area under a tree then a control method is recommended (Hudson 2014). These recommendations were not based on science studies but on a best guess by researchers.

The previously mentioned monitoring methods were restricted to monitoring the lower canopy of the pecan trees. This could be problematic because pecan trees are the largest of the hickories and can grow up to 150 feet tall (Stevens 2010). Wright et al. (2007) reported that there

was a significant difference in southern green SB damage by stratum with most of the damage occurring in the ground strata in Hawaii Macadamia orchards. This idea of SB damage being stratified throughout the height of the tree is also supported by Jones and Caprio (1994) who stated that southern green SB damage was always significantly greater in ground samples of Macadamia nuts than samples taken from the canopy.

Several SBs species have been detected at different heights in the pecan canopy. Two species of SB, *E. servus* and *E. tristigmus*, were captured in pecan groves of which the majority caught on the ground were *E. servus* while due to their arboreal nature the majority caught higher in the canopy were *E. tristigmus* (Cottrell et al. 2000). Even though SBs may be present and able to fly to the tops of the pecan trees, the majority of their feeding takes place on the lower limbs (Demaree 1922).

The objective of this study was to determine if SB damage was evenly distributed vertically throughout the pecan tree canopy.

MATERIALS AND METHODS

Three sampling methods used to assess SB feeding: punctures and damage throughout the strata of the pecan tree included sampling by: hand, tree shaker, and an Orbit lift. The sampling by mechanical tree shaker and by hand were conducted on 12 August 2014 while the sampling done by use of an Orbit lift was done on 18 September 2014.

Tree Shaker. Sampling by mechanical tree shaker was conducted (12 August 2014) at three pecan groves (Blackwell 2, Blackwell 5, and Atkins). These three pecan groves were chosen because they were having their heavy crop load thinned by way of mechanical pecan tree shaker in accordance with pecan management recommendations (Upson et al. 2001). The trees

were shaken causing the thinned pecans to fall to the ground until the grove owners desired load density is reached. For the first location (Blackwell 2) 100 pecans were collected off the ground from each of four thinned trees in each perimeter of the pecan grove (N, E, S, W, plus the grove center) totaling 2000 pecan nuts. The second location (Blackwell 5) had 100 pecans collected off the ground from each of three thinned trees in the East and West pecan grove perimeters totaling 600 pecan nuts. The third location (Atkins) had 100 pecans collected off the ground from each of three thinned trees on the East and West pecan grove perimeter and the center totaling 900 pecan nuts.

Stink Bug Puncture and Damage. After transport to the laboratory all nuts were visually inspected and quantified the numbers of SB punctures on the shell of the pecan and kernel damage to the nut meat. The pecan shucks under each apparent SB puncture were cut away to confirm that puncture continues through the shuck and forms a small dark spot on the pecan shell. Punctured shells were cracked to note if feeding caused a dark kernel spot in nut (kernel damage). When this small dark spot was present it was recorded as a SB feeding site. The dissection and inspection of each pecan nut took about one minute per pecan.

Ten pecan nuts per tree were collected from the lowest branches of pecan trees that could be reached by hand from the same three pecan groves where the tree shaker samples were taken. Totals of 150, 60, and 90 pecan nuts were collected from pecan groves Blackwell 2, Blackwell 5 and Atkins, respectively. All the collected pecans were again inspected and dissected in the previously mentioned manner.

Stink Bug Damage. Pecan nuts were collected from three heights in the pecan canopy at five pecan groves (Blackwell 2, Blackwell 3, Blackwell 4, Blackwell 5 and Atkins). The lower (0 – 3 m), middle (3 – 6 m) and upper (6 – 9 m) pecan canopy heights were sampled with the aid of

a measuring tape and a GVF 25' Orbit lift pruning tower (Gillison's Variety Fabrication, Inc.) (Fig. 1). One pecan grower transported his Orbit lift to these five pecan groves and assisted all day in nut collection. In each of four pecan groves, 50 pecan nuts were collected from each of three different heights from five randomly selected trees totaling 750 pecan nuts per grove. At the Atkin pecan grove, 50 pecan nuts were collected from three heights of six trees of which only the lower and middle heights of four trees were less than 6 m tall for a total of 700 pecan nuts. The operator positioned the Orbit lift at the appropriate heights of the tree to collect the pecans from each of the heights by hand. These pecan nuts were stored at 2^{o}C and all 3,700 nuts were assessed within 14 days of collection for damage as mentioned method above. In order to ensure that there was no discrepancy in the way the pecans were graded, only one person inspected each nut for SB punctures of the shell (Fig. 2), and used the electric Kinetic Kracker (Lee Manufacturing Company, Martin, TN) to crack each nut in order to scan the kernel to record the numbers of pecan nuts with SB kernel spot damage (Fig. 3).

ANALYSIS

The factors of pecan grove and interaction of pecan grove by canopy sample height had insignificant effects on number of punctured thinned nuts so these data were pooled across groves for each study before preforming statistical analysis. These data were analyzed by Logit analysis using PROC GLIMMIX and mean separations done by LSMEANS (SAS Institute 2012). The numbers of SB punctures, SB damaged kernels, pecan weevil damage, hickory shuckworm damage and the comparison of damage between the hand collected pecans and the tree shaken collected pecans were analysed as a binomial distribution of either damaged or not damaged pecans. One pecan grove, Blackwell 5, had branches that were trimmed up so high that

samples from a lower canopy (0-3 m) could not be obtained. Therefore, only two different pecan groves (Blackwell 2 and Atkins) were used in analysis that compared SB damage from hand sampling nuts to tree shaking nuts. Similarly, four pecan groves (Blackwell 2, Blackwell 3, Blackwell 4, and Atkins) were used in the analysis that compared SB puncture and damage of pecans across three different heights. Only two pecan groves (Blackwell 3 and Blackwell 4) were compared for pecan weevil damage whereas three pecan groves (Blackwell 3, Blackwell 4, and Atkins) were compared for damage caused by hickory shuckworm.

RESULTS

Tree Shaker Versus Hand Collection. On 12 August 2014, the pecans collected from the ground after the tree shaker mechanically thinned nuts from the tree in the Blackwell 2 and Atkins groves had 1% ± 0.2 SB punctures, significantly less than the 8% ± 2.4 SB punctures found in pecan nuts hand collected from the lower pecan tree canopy (F = 34.92; df = 1, 51; P = < .0001).

Stink Bug Punctures and Damage. On 18 September 2014, pecan nuts were collected from 3 height ranges from four pecan groves. All four pecan groves had SB punctures and SB damage of pecan nuts. The four pecan groves averaged 7.3% ± 0.66 SB punctures in the lower 0-3 m strata of the pecan tree which was significantly more (F = 3.54; df = 2, 56; P = 0.036) than recorded from either the middle 3-6 m (1.7% ± 0.52) or upper 6-9 m (0.9% ± 0.3) strata of the pecan trees (Fig. 4).

The same four pecan groves averaged of 1.7% ± 0.42 SB damage at the lower 0-3 m strata of the pecan tree which was significantly more (F = 5.16; df = 2, 56; P = 0.0087) than

either the 0.6% ± 0.32 or 0.4 ± 0.2 SB damage at the middle 3-6 m and upper 6-9 m strata of the pecan trees, respectively (Fig. 5).

DISCUSSION

My studies demonstrates that mean percentages of SB punctures on pecan nuts were significantly higher in samples taken by hand from the lower strata of the pecan canopy than nut samples taken after shaking the whole canopy of the tree. Similarly, Wright et al. (2007) found that the macadamia nuts collected by hand off the ground consistently showed twice as much southern green SB damage (SBs presumably fed on nuts on the ground) as the macadamia collected directly from the canopy by a tree shaker. They also noted that macadamia nuts collected from the lower limbs had more southern green SB damage than nuts from higher in the tree. Jones and Caprio (1994) stated that macadamia nuts collected from the ground always had significantly greater damage than those collected from the tree canopy. The present study demonstrated that SB damage was more prevalent in the lower canopy than in the entire tree.

The study comparing effects of pecan tree strata found that there were significantly more SB punctures and SB damage in the lower strata than either the middle or upper strata. These findings support resulted from the pecan tree shaker study. Wright et al. (2007) compared southern green SB damage of macadamia nuts collected from the lower, middle, and upper strata of the tree, shaken from the tree and those that accumulated on the ground. They found that the nuts that had accumulated on the ground had approximately twice the amount of SB damage as the macadamia nuts collected from the canopy. In addition, they noted a significant strata effect with more SB damage occurring in the lower strata, which I also found in this study. The reason that most the SB punctures were found in the lower canopy is most likely due to the fact that one of the major SBs found in pecan groves (brown SB)preferred habitats closer to the ground..

Cottrell et al. (2000) captured significantly more brown SBs in pyramid traps placed on the ground than traps in the pecan canopy.

These studies demonstrated that SBs fed more on pecans that were located below 3 m in the pecan tree canopy. Stink bug punctures and damage occurred throughout the pecan canopy but significantly more occurred in the lower canopy. Current SB monitoring techniques tend to sample for SBs just above ground level (pheromone baited pyramid traps) or in and around the lower canopy (UV traps hung from lower canopy; visual counts on nuts; and knock down sprays of lower canopy). Given the majority of SBs were present in the lower canopy an airblast sprayer application of insecticide against SBs to the lower canopy may be more effective than an aerial application.

Growers can use this information on feeding habits of SBs to improve the pest management program and minimize reductions in quantity and quality of the pecans due to SB pests.

REFERENCES CITED

Aldrich, J.R., M.P. Hoffmann, J.P. Kochansky, W.R. Lusby, J.E. Eger, and J.A. Payne. 1991. Identification and attractiveness of a major pheromone component for Nearctic *Euschistus* spp. stink bugs (Heteroptera: Pentatomidae). Environ. Entomol. 20: 477-483.

Cottrell, T.E., and B.W. Wood. 2008. Movement of adult pecan weevils Curculio caryae (Coleoptera: Curculionidae) within pecan orchards. Agric. For. Entomol. 10: 363-373.

Cottrell, T.E., C.E. Yonce, and B.W. Wood. 2000. Seasonal occurrence and vertical distribution of *Euschistus servus* (Say) and *Euschistus tristigmus* (Say) (Hemiptera: Pentatomidae) in pecan orchards. J. Entomol. Sci. 35: 421-431.

Demaree, J.B. 1922. Kernel-spot of the pecan and its cause. USDA Bull. 1102.

Ellis, H.C., and J.D. Dutcher. 1999. Summary of loss from insect damage and cost of control in Georgia, 1997: XVII Pecan insects. University of Georgia, The Bugwood Network.

Harris, M. K. 1983. Integrated pest management of pecans. Annual Rev. Entomol. 28: 291–318.

Hogmire, H.W., and T.C. Leskey. 2006. An improved trap for monitoring stink bugs (Heteroptera: Pentatomidae) in apple and peach orchards. J. Entomol. Sci. 41:9-21.

Hudson, W. 2014. Commercial pecan insect control (bearing trees). University of Georgia Extension, Spray Guide.

Hudson, W.J., and G.V. Pettis. 2006. Pest management strategic plan for pecans in the Southeastern U.S., p. 39. *In* Southern Region Integrated Pest Management Center.

Jones, V.P., and L.C. Caprio. 1994. Southern green stink bug (Hemiptera: Pentatomidae) feeding on Hawaiian macadamia nuts: the relative importance of damage occurring in the canopy and on the ground. J. Econ. Entomol. 87: 431–435.

Lee, D. 2007. Number of stink bugs growing in Missouri soybean fields. Univ. of Missouri Commercial Agricultural Program. http://agebb.missouri.edu/commag/news/archives/v16n1/news16.htm

McVay, J.R., G.H. Hedger, and R.D. Eikenbary. 1991. Preliminary investigations on field implementation of the hickory shuckworm sex pheromone, pp. 159-162. In: Pecan husbandry: challenges and opportunities, First Natl. Pecan Workshop Proc. USDA Agric. Res. Serv. Publ. 96.

Mizell, R.F. III, and W.L. Tedders. 1995. Use of the modified Tedders trap to monitor stink bugs in pecan. Proc. Southeastern Pecan Growers Assoc. 88: 36-40.

Osburn, M.R., W.C. Pierce, A.M. Phillips, J.R. Cole, and G.E. Kenbright. 1966. Controlling insects and diseases of pecans. USDA Agric. Handbook 240: Rev. 1-55.

Rafanan, M. 2015. Pecan report. USDA Agric. Marketing Service Fruit and Vegetable Programs Market News Division 32(24): 1-3.

SAS Institute. 2012. SAS 9.4 PROC user's manual, version 6.1. SAS Institute Inc., Cary, NC.

Stevens, J. 2010. Pecan *Carya illinoinensis* (Wangenh.) K. Koch. USDA Natural Resource Conservation Service Plant Fact Sheet 8298.

Tedders, W. L. and Gottwald, T.R. (1986). Evaluation of an insect collecting system and an ultra-low volume spray system on a remotely piloted vehicle. J. Econ. Entomol. 79(3): 709–713.

Thompson, T.E., and P.J. Conner. 2012. Pecan, pp. 771-801. *In* M.L. Badenes and D.H. Byrne (Eds.), Fruit breeding, handbook of plant breeding, Vol. 8. Springer Science+Business Media, LLC.

Todd, J. W., and D. C. Herzog. 1980. Sampling phytophagous Pentatomidae on soybean, pp. 38-478. *In*: M. Kogan and D. C. Herzog (eds.), Sampling methods in soybean entomology. Springer-Verlag, N.Y.

Upson, S., C. Rohla, J. Locke, and J. Springer. 2001. Pecan production 101: establishing and managing an improved variety pecan enterprise in the southern Great Plains. The Noble Foundation Agric. Division NF-HO-12-012.

Wright, M.W., P.A. Follett, and M. Golden. 2007. Long-term patterns and feeding sites of southern green stink bug (Hemiptera: Pentatomidae) in Hawaii macadamia orchards, and sampling for management decisions. Bull. Entomol. Res. 97: 569–575.

Woodroof, J.G., and N.C. Woodroof. 1928. The dropping of pecans. Natl. Pecan Growers' Assn. Bull. 2(28): 30-34.

Yates, I.E., W.L. Tedders, and D. Sparks. 1991. Diagnostic evidence of damage on pecan shells by stink bugs and coreid bugs. J. Amer. Soc. Hort. Sci. 116:42-46.

Figure 1. GVF 25’ Orbit lift pruning tower (Gillison’s Variety Fabrication, Inc.) used to sample pecan nuts in canopy at three height ranges: low (0-3 m), middle (3-6 m) and high (6-9 m) (Photo: D. Johnson).

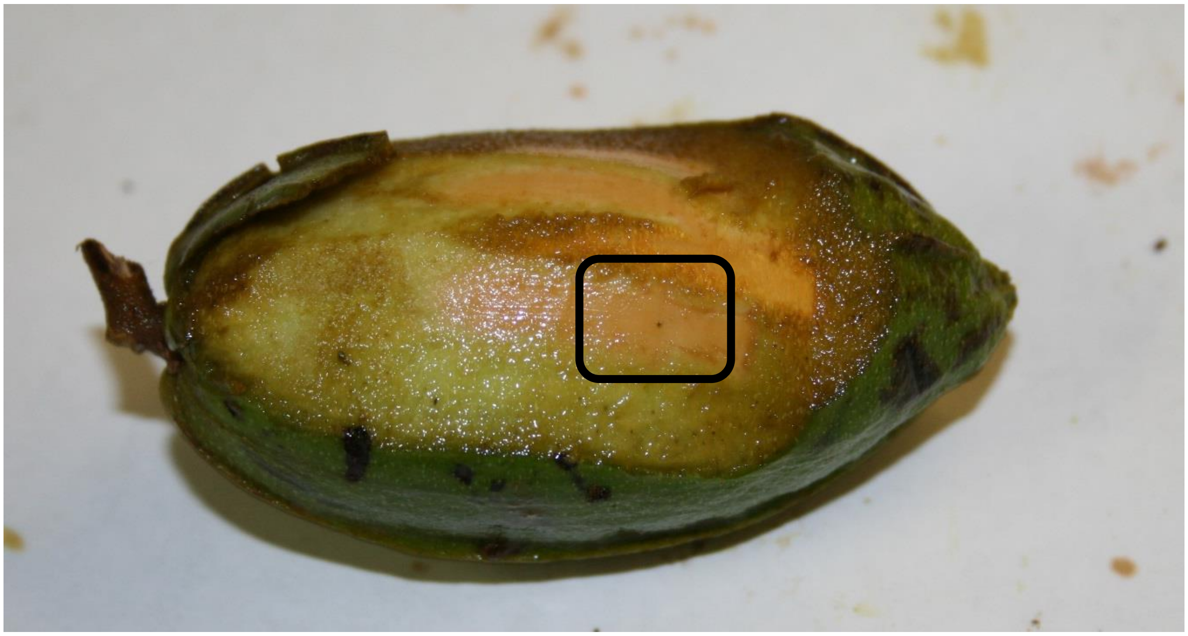


Figure 2. Stink bug puncture penetrating through pecan shuck and leaving dark puncture wound on pecan shell (inside rectangle) from pecan collected on 18 September 2014.

Figure 3. Stink bug damage on pecan meat causing the dark kernel spot (inside rectangle) of a pecan collected on 18 September 2014.

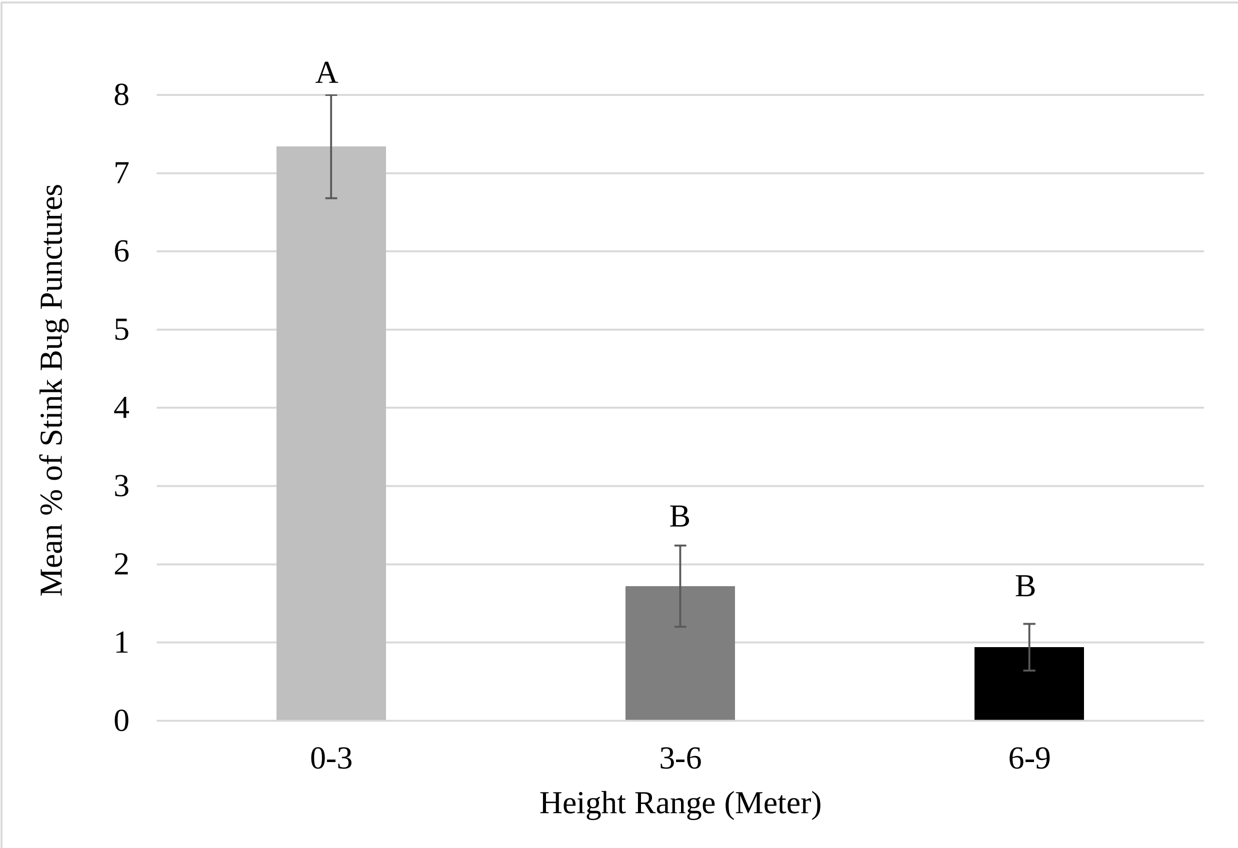


Figure 4. Mean percentage (± SE bars) of stink bug punctured pecans collected on 18 September 2014 from three height ranges in pecan trees with data pooled from four pecan groves in Atkins and Blackwell, AR. Bars with same letter are not statistically different (*P* > 0.05).

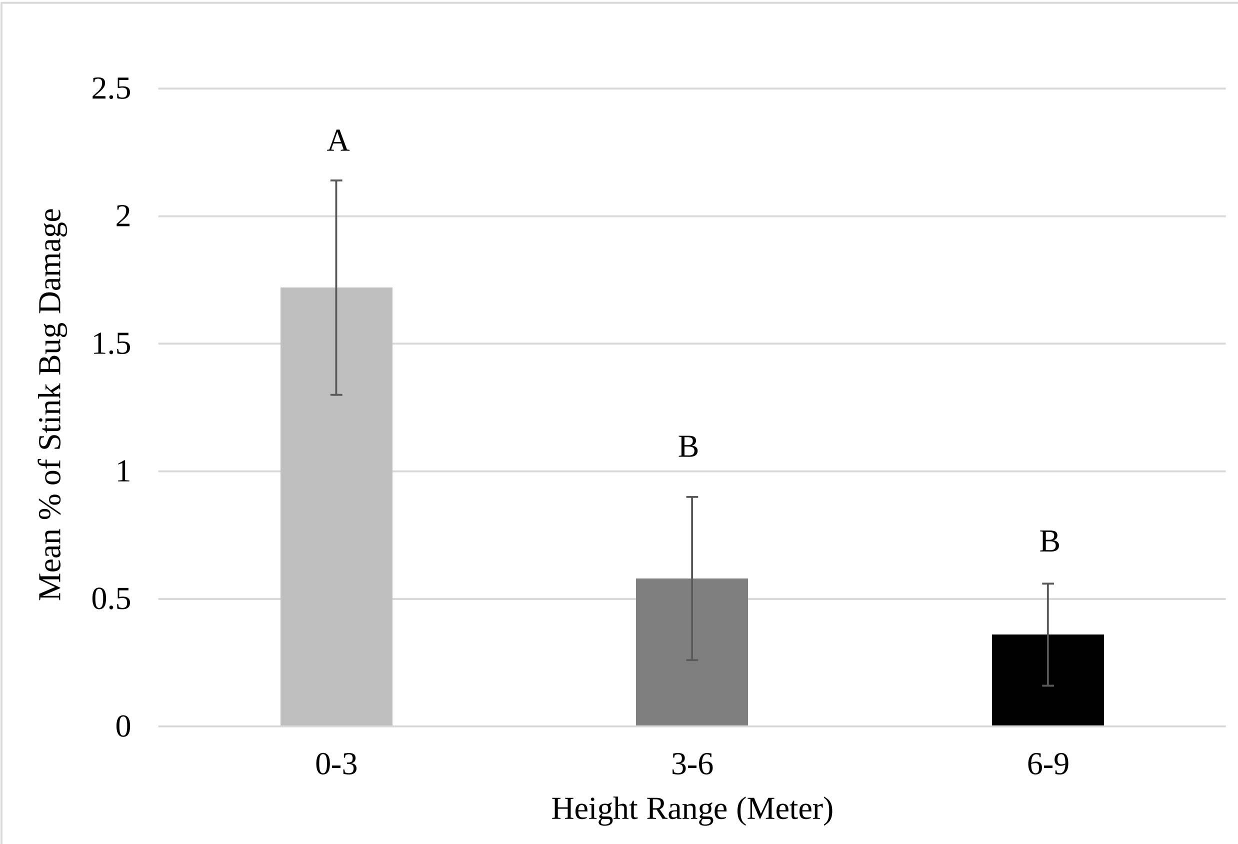


Figure 5. Mean percentage (± SE bars) of stink bug damaged pecans collected on 18 September 2014 from three height ranges in pecan trees with data pooled from four pecan groves in Atkins and Blackwell, AR. Bars with same letter are not statistically different ($P > 0.05$).

Chapter 5

Monitoring Methods for Stink Bug Complex (Heteroptera: Pentatomidae) in Arkansas Pecan Groves

ABSTRACT

I evaluated four recommended stink bug (SB) monitoring methods (baited yellow pyramid traps, black-light traps, visual surveys; and canopy knock down sprays). I determined which of the four methods best estimated the SB densities in pecan trees that directly relate to percentage of pecan nuts damaged by SBs. The baited yellow pyramid traps baited with a *Euschistus* (Brown SB) aggregation pheromone (E,Z,)-2,4-decadienoate caught the greatest number of SBs (mostly brown and dusky SBs with very few green SBs). The UV light traps captured very few brown SBs and dusky SBs but were much better than the other monitoring methods at capturing green SBs. The knock down sprays also captured very few SBs, but they did indicate what SBs species were present in the pecan trees at a given moment in time. The visual counts observed the fewest SBs, and would not be recommended in most of the Arkansas pecan groves. Only the yellow pyramid traps modified with baits with both the brown SB and green SB aggregation pheromones have any promise of being practical to be implemented by growers for monitoring SBs in pecan groves.

INTRODUCTION

Stink bugs (SB) (Hemiptera: Pentatomidae) are extremely mobile and polyphagous insects that are especially challenging to manage (McPherson and McPherson 2000). Mizell et al (1997) have demonstrated that the most prevalent SB species found in Florida and South Georgia pecan groves are mainly brown SB, *Euschistus servus* (Say), along with dusky SB, *Euschistus tristigmus* (Say), green SB, *Chinavia hilaris* (Say), and southern green SB, *Nezara viridula* (L.). Of these species, Dutcher and Todd (1983) reported that the brown SB is the most important species followed by the southern green SB. In Arkansas brown SBs are the most prevalent species trapped in pecan groves, whereas the southern green SB were not trapped (Cowell et al. 2015).

The brown, dusky, and green SB species have very similar life cycles and biology, and can be identified using the species key of McPherson and McPherson (2000) or Arnold and Drew (1988). All feed on similar plants including shrubs, vines, broadleaf weeds, corn, soybean, sorghum, okra, millet, snap beans, peas, cotton, and legumes which are the preferred host (Gomez and Mizell, 2008). Stink bugs will puncture and feed on pecan nuts throughout its several nut growth stages. Stink bug punctures cause a small visible mark on the shuck of the pecan that can extend all the way to the developing kernel, leaving an internal black path where the stylet penetrated. Fluid often oozes at the site of a puncture (Woodroof and Woodroof, 1928). When pecans are fed on during the water stage or liquid endosperm stage, the inside of the pecan will turn black, which is referred to as black pit, causing premature nut drop from the tree within five days after injury (Woodroof and Woodroof 1928; Polles 1979). Feeding on nuts from dough to mature stages causes darkened kernel spots (Hudson and Pettis, 2006), which lower the pecan nut quality and value and are undetectable until the pecans are shelled (Mizell and Tedders

1995). Hudson and Pettis (2006) also suggest that SBs have the ability to feed through the hard shells of fully developed pecans even after harvest.

Stink bugs have re-emerged as crop pests for a number of reasons, which include: the widespread use of *Bt* cotton, *Bt* soybean, and the successful eradication of the cotton boll weevil, *Anthonomus grandis* Boheman*.* All of these contributed to the significant decrease in insecticides, which were inadvertently controlling and reducing SBs numbers (Olson and Ruberson 2012). Compounding this problem is the fact that SBs have developed resistance to a number of insecticides along with the virtual elimination of broad spectrum insecticides (Roberson 2008, Olson and Ruberson 2012). In order to effectively manage SBs, insecticide application must be based on a monitoring program assessing their presence (Leskey and Hogmire 2005). Mizell and Tedders (1995) suggest that different monitoring methods should be used to relate trap catch to population density and damage in order to develop control thresholds.

Several sampling methods have been used to survey SB presence, in multiple different habitats. These include: D-Vac; malaise traps (Dutcher and Todd 1983); visual surveys (Pecan IPM PIPE 2011; Leskey et al. 2012; Hudson 2014); canopy knock down sprays (Hudson 2014); black light traps (Dutcher and Todd 1983; Lee 2007; Blinka et al. 2007); sweep net; limb jarring; black pyramid traps baited with pheromone lure (Leskey et al. 2012); and yellow pyramid traps baited with pheromone lure (Mizell and Tedders 1995). Of all of these sampling methods, four are recommended to monitor SBs in pecans, including: baited yellow pyramid traps (Mizell et al. 1997); black-light traps (Parker et al. 2005); visual surveys; and canopy knock down sprays (Hudson 2014).

The yellow pyramid trap described by Mizell and Tedders (1995) and Hogmire and Leskey (2006) was baited with a rubber septum charged with 40 µl of the *Euschistus* spp.

aggregation pheromone, methyl (2E, 4Z)-decadienoate (Aldrich et al. 1991). This trap was noted to capture three main SB species: brown SB, *E. servus*; dusky SB, *E. tristigmus*; and green SB, *C. hilaris* (Hogmire and Leskey 2006). Mizell et al. (1997) recommended placement of 3-5 pyramid traps along the border rows of the pecan grove and also in the interior. This monitoring method was directed toward *Euschistus* genus of SBs because of the use of the aggregation pheromone, but also captured a few green SBs due to the trap's attractive yellow color.

The UV black-light trap described by Lee (2007) and Blinka et al. (2007) was used to monitor green SB presence in soybeans and other agricultural crops. When monitoring for SB presence it was best to place traps right above the height of the expected ground vegetation (Mizell and Tedders 1995).

Both the yellow pyramid trap and the black-light trap attracted SBs from the area surrounding the traps but these counts did not correspond to the presence of SBs found in pecan trees. In comparison, visual surveys and canopy knock down sprays determined if stinkbugs were present in pecan trees.

Visual surveys involved inspecting 200 clusters of pecans and recording the number of clusters with SBs. Hudson (2014) suggested the non-science based threshold of if one pecan cluster in forty had a SB present, then an insecticide spray should be applied.

The canopy knock down spray method involved placing a ground cloth under 20% of a pecan tree canopy which was then sprayed with water (typically with insecticide). If five SBs were found per knock down spray then SB control was recommended (Hudson 2014).

Visual surveys and canopy knock down sprays have been recommended to assess need for SB control in pecans (Pecan IPM PIPE 2011; Hudson 2014). However, it has not been

determined if SB counts from any of these monitoring methods were correlated to the harvested percentage of pecan nuts damaged by SBs.

The objective of this study was to determine which of four SB monitoring methods (yellow pyramid trap method, knock down spray, UV black-light trap, and visual counts) best estimates the SB presence in pecan trees and if any method directly relates to percentage of pecan nuts damaged by SBs.

MATERIALS AND METHODS

In commercial pecan groves in Arkansas, I compared the biweekly numbers of each species of SB captured in each of four monitoring methods: yellow pyramid trap method; knock down spray; UV black-light trap, and visual counts. These biweekly counts of SBs from each monitoring method were then attempted to be related to the percentages of nuts punctured or kernels damaged by SBs.

Yellow Pyramid Trap Study

In 2013,traps were placed on June 12 in four Arkansas pecan groves numbered by city names (Blackwell 1, Blackwell 2, Mayflower, Humphrey).In 2014 traps were placed on June 18 in six Arkansas pecan groves (Blackwell 1, Blackwell 2, Blackwell 3, Blackwell 4, Mayflower, Humphrey).Traps were added on August 12 in two additional pecan groves (Blackwell 5, Atkins). Trap catches were recorded biweekly until the pecans were mature and ready to harvest on 30 Oct. 2013, and 24 Oct. 2014.

The pyramid part of this trap was made of 4 mm thick yellow corrugated plastic sheets (Corrugated Plastics, Hillsborough, New Jersey) cut in triangle measuring 121 cm tall with 53 cm base that tapers to a 5 cm tip. A funnel screen cage was fastened to the tip of the yellow plastic pyramid to act as a capture arena as described by Mizell and Tedders (1995) and Hogmire

and Leskey (2006). Wired inside each screen cage was an 8mm natural red rubber stopper (Sigma-Aldrich Corp., St. Louis, MO) charged with 40 µl of the *Euschistus* spp. (brown and dusky SB) aggregation pheromone, methyl (2E, 4Z)-decadienoate (Bedoukian Research, Inc., Danbury, CT) (Aldrich et al. 1991).

In 2013 and 2014, three baited yellow pyramid traps spaced at least 30 m apart were each staked to the ground in five locations, on each of four perimeters (north, east, south, and west) and the center of the Blackwell 1, Blackwell 2, Mayflower, and Humphrey pecan grove. In 2014, four pecan groves were added: Blackwell 3 had three traps each placed on both the north and the south perimeters; Blackwell 4 had three traps each placed on the east, south, west perimeters and the center; Blackwell 5 had three traps each placed on the east and west perimeters; and Atkins had three traps each placed on the east, west perimeters and center. Biweekly, all captured insects were transferred into a labeled zip lock bag (date, pecan grove and trap location), transported to the lab where insects were sorted in order to record numbers of each SB species. The SB species were placed back in the labeled zip lock and stored in a freezer at -18° C for future use.

Knock Down Spray

A 6 m x 6 m clear 6 mil plastic sheet was placed on the ground under a pecan tree and pressurized water used to knock down SBs from the lower canopy of the tree. The water was sprayed upward into the canopy from all available angles. In 2013 the knock down spray was conducted by using a 3.5 hp gas pressure washer water (Homelite pressure washer Model UT80522B, Homelite, Anderson, SC) which was gravity fed through a 3 m garden hose from a 57 liter water tank set on the truck bed 0.8 m above the ground. In 2014, the same pressure washer was rigged to receive water at 275 kpa from a 12 volt electric primer pump (High-Flo

Gold Series, FIMCO Industries, North Sioux City, SD) running off the truck battery (engine was running) and set in the hose line between a 189 liter water tank mounted in the truck bed and the pressure washer. The pressure washer instructions indicated that the pressure washer engine needed pressurized water entering the intake. In both years, this pressure washer was fitted with a 30^{o} flat fan nozzle and sprayed 19 liters of water into the lower canopy of each pecan tree in the study. In 2013, the knock down spray samples of three trees were collected biweekly in each of three different pecan groves (Blackwell 2, Mayflower, and Humphrey) from 9 July to 30 Oct. In 2014, the knock down water spray samples of five trees were collected biweekly in each of six pecan groves (Blackwell 1, Blackwell 2, Blackwell 3, Blackwell 4, Humphrey and Mayflower) from 16 July to 24 Oct. From 28 Aug. to 24 Oct., two additional pecan groves (Atkins, Blackwell 5) received these biweekly knock down water sprays until harvest. For both 2013 and 2014, all SBs knocked from the tree were immediately collected off the plastic ground sheet and placed in a plastic zip lock bag labeled with the date collected, grove, transported to the laboratory, insects sorted, and recorded numbers of each SB species. These SBs were placed back in the labeled zip lock and stored in a freezer kept at -18° C for later analysis if needed.

UV Traps

In 2013, two BioQuip universal UV black light bucket traps each with 22W black light Circline bulbs (BioQuip, Rancho Dominguez, California) were turned on for 24 h biweekly in each of three different pecan groves (Blackwell 2, Humphrey and Mayflower) from 9 Aug. to 30 Oct. In 2014, one UV trap was turned on for 24 h biweekly in each of seven pecan groves (Blackwell 1, Blackwell 2, Blackwell 3, Blackwell 4, Blackwell 5, Humphrey and Mayflower) from 2 July to 24 Oct. and an additional pecan grove in Atkins from 28 Aug. to 24 Oct. Each trap

was wired two meters off the ground on metal t-posts. After each 24 h capture period, the SBs were transferred to zip lock bags, labeled and record numbers of each SB species as above.

Visual Counts

In 2014, biweekly visual counts were made of the number of each SB species seen on each sample of 20 nut clusters on each of 10 pecan trees (200 nuts scanned per grove) (modified from Pecan IPM PIPE (2011) and Hudson (2014)). All SBs seen on pecan clusters were visually identified in the field and not captured. Counts were made at: Blackwell 1, Blackwell 2, Blackwell 3, Blackwell 4, Humphrey and Mayflower from 2 July to 24 Oct; and at Atkins and Blackwell 5 from 28 Aug. to 24 Oct.

Damage Assessment

Ten pecans were collected by hand from trees adjacent to each yellow pyramid trap on each date that the yellow pyramid traps were checked. This allowed for a comparison of trap catch to percentage of nuts with SB damage. Biweekly, a total of 150 pecans were collected per grove near each of 15 pyramid traps sampled that same day in Blackwell 1, Blackwell 2, Humphrey, and Mayflower. Smaller groves like Blackwell 4 had room for only 12 yellow pyramid traps so 120 pecans were collected. Atkins had only nine yellow pyramid traps whereas Blackwell 3 and Blackwell 5 both had six yellow pyramid traps so the respective nut collections were 90 pecans and 60 pecans. Each 10 nut pecan sample was placed in a zip lock bag, labeled and transported as noted above, stored in a refrigerator at 2^{o}C for less than 2 weeks to ensure visual detection of the SB puncture of nuts. The shuck surface of each pecan was visually examined for one or more small black punctures. Then layers of the shuck under each puncture were sliced away with a paring knife to determine and record if the puncture path penetrated to and through the nut shell. The nut growth stage was recorded and summarized by year, pecan

grove and sample date in Table 1. Then each punctured pecan nut was cut longitudinally, the embryo or kernel inspected for SB damage and recorded the type of damage or noted as healthy.

ANALYSIS

All data from the yellow pyramid traps were analyzed using PROC GLIMMIX assuming a Poisson distribution and repeated measures. Mean separations were done by LSMEANS (*SAS* Institute, Cary, NC). The many zero counts and low counts recorded from the other sampling methods (knock down spray, UV trap, visual counts, and percentages of SB puncture and damage) did not allow for a traditional analysis of variance of these data. Means were calculated and reported using PROC MEANS for data from the yellow pyramid trap, knock down spray, and the UV trap methods for 2013 and for the yellow pyramid trap, knock down spray, and visual counts methods for 2014 (*SAS*® 9.3, *SAS* Institute, Cary, NC). The UV trap method in 2014 only had one trap per pecan grove so the means could not be established and numbers reported are of SBs per trap. The mean percentages of each species present for each technique were reported. Preliminary findings on the knock down spray method in 2013 were reported previously in Cowell et al. (2015) (Chapter 2).

RESULTS

The combined means of the brown, dusky and green SBs captured in yellow pyramid trap significantly differed by year ($F = 10.59$; df = 1, 363; $P = 0.0012$) (Table. 2-3). In each of the two years, the combined means of the brown, dusky, and green SBs caught by the yellow pyramid traps were significantly different among pecan groves in 2013 ($F = 16.74$; df = 2, 447; $P < 0.0001$) (Table 2), and 2014 ($F = 26.03$; df = 8, 766; $P < 0.0001$) (Table. 3). The mean numbers of SBs per sampling method appeared to be different by year and between each pecan grove even

though traditional statistics could not be performed on the very low SB counts recorded by knock down spray, UV trap, and visual counts (Table. 2-6). Similarly, it can be seen in Table. 14-15 that the percentages SB punctured shucks and SB damaged kernels appeared different between years and pecan groves.

The seasonal totals and percentages of each SB species captured in yellow pyramid, UV light traps and knock down spray for 2013 can be found in Table. 2. While the seasonal totals and percentages of each SB species captured in yellow pyramid, UV light traps, knock down spray and visual inspections for 2014 can be found in Tables 3, 4, 5 and 6 respectively.

In 2013 and 2014, SB punctures occurred continually from the first sampling date until harvest in all pecan groves, but SB kernel damage (black pit or kernel spot) was not recorded until the pecans reached water stage across all pecan groves, except in 2014 in Blackwell 3 which had damage occur on 30 July when the pecans were finishing the nutlet stage (Table 1) (Table. 14 and 15).

DISCUSSION

My study documented that the combined means of the brown, dusky, and green SBs per yellow pyramid trap were significantly different by both the year and pecan grove in which samples were taken. Although no statistics could be conducted due to low counts per sample, there were large numeric differences observed between years and pecan groves in the numbers of SBs recorded by knock down spray, UV trap, and visual counts (Table. 2-6). McPherson et al. (1993) showed that the number of SBs along with the species collected varied by both the year and the location the SBs were collected from in soybeans.

Each of these different SB monitoring methods appeared to have different advantages or disadvantages for use in pecan SB pest management. The yellow pyramid traps baited with *Euschistus* aggregation pheromone estimated biweekly numbers of *Euschistus* spp. (often > 50 SBs/trap) present just above the ground in pecan groves but not in the pecan tree and did not capture green SBs. Cottrell et al. (2000) reported that yellow pyramid traps placed on the ground captured more brown SBs than any trap in the lower, middle and upper pecan canopy. In order to improve estimates of seasonal changes in the presence of *Euschistus* species and of green SBs in Arkansas pecan groves, the yellow pyramid trap should be baited with two lures: *Euschistus* aggregation pheromone methyl (E,Z,)-2,4-decadienoate (Aldrich et al. 1991) and green SB aggregation pheromone methyl (E,Z,Z)-2,4,6-decatrienoate (Aldrich et al. 2007) in order to optimize the traps ability to catch green SB. These traps should be fastened to the ground and the lower canopy of pecan trees in order to better monitor changes in the numbers of these SB species per trap.

The UV light traps captured very few brown SBs and dusky SBs ($\leq$ 3/trap) but was better than the other monitoring methods at capturing green SBs ($\leq$ 7/trap). The UV trap was an ineffective method for monitoring SBs in the pecan grove compared to the other methods. The UV trap may prove more useful if the grower ran it nightly and recorded daily numbers of SBs captured. Kennedy and Storer (2000) stated that weather conditions directly affected insect movement and dynamics.

The knock down sprays captured very few SBs ($\leq$ 14/spray), but this method did identify the SB species in the pecan trees at a given moment in time. In 2013, there were mostly brown SBs captured by knock down sprays in all the pecan groves, whereas in 2014, Blackwell 1, Blackwell 4, Humphrey, and Mayflower caught mostly brown SBs while Atkins, Blackwell 2,

and Blackwell 3 caught mostly green SBs. McPherson et al. (1993) reported that the proportion of SB species captured varied by both the year and the location in which the samples were taken by sweep net sampling soybeans. Monitoring SBs in pecan trees by knock down spray appeared to be an inadequate method for estimating the actual SB numbers in the pecan trees. Stink bug counts by knock down sprays were usually low and many samples had zero SBs compared to consistently higher counts in baited yellow pyramid traps.

The visual counts observed the least number of SBs (< 0.3 SBs/20 nut visual inspection) out of any of the above reported monitoring methods. Like the knock down spray, the visual counts determined the proportion of each SB species present in pecan trees in each sampled pecan grove. The SBs that were encountered differed by pecan grove, with Atkins and Blackwell 2 catching mostly green SBs, whereas Blackwell 1, Blackwell 3, Blackwell 4, and Humphrey caught mostly brown SBs. The SB species differences among groves were most likely due to the pecan groves surrounding habitats. The visual counts of SBs were so low and sporadic that this method would not be recommended in most of the Arkansas pecan groves.

I visually compared the mean numbers of SBs caught or observed by each SB monitoring method to the percentages of nuts punctured or damage by SBs in adjacent pecan trees (Table. 14, 15). In 2013, the mean number of SBs caught in the yellow pyramid traps did not adequately represent the percentage puncture, or damage, which would occur at any time during the season. Although it was observed that on any day which the yellow pyramid traps caught SBs, there would be SB punctures on the pecan shuck but not always kernel damage. The UV light traps caught so few SBs that the number of SBs caught had little to no relationship to either the punctures or damage. The number of SBs caught during the knock down spray method did not accurately represent the SB pecan punctures or SB kernel damage which would occur during the

pecan growing season, except for in the case of the Humphrey pecan grove which had greater amounts of SB kernel damage occurring in the later season than any other pecan grove in 2013 (Table. 7, 8, 9, 14).

Similarly, in 2014 the mean number of SBs caught in the yellow pyramid traps did not adequately represent either the percentage SB pecan puncture or SB kernel damage which would occur at any time during the season. However, on any day on which SBs were captured by the yellow pyramid traps, SB pecan punctures would occur, but not necessarily SB kernel damage. Both the UV light traps and visual counts either caught or observed so few SBs or counts were so sporadic, that there was little to no relationship to either the SB pecan punctures or SB kernel damage. The number of SBs caught from the knock down spray did not accurately represent the SB pecan punctures or SB kernel damage either, except for in pecan groves which received greater than 10% damage as seen in the Blackwell 3 and Humphrey pecan groves (Table. 10, 11, 12, 13, 15). Overall, kernel damage by SBs didn't begin until the water stage at the earliest in any of the pecan groves (Table 1, 14, 15).

Of these four main monitoring methods only one (yellow pyramid traps) has any promise of being practical enough to be implemented by pecan growers for monitoring SBs in pecan groves. However, the yellow pyramid traps need to be modified with baits of both the brown SB and green SB aggregation pheromones and then tethered in the lower tree canopy and tested. Each pecan cultivar should have the nut growth stage assessed weekly to identify when each cultivar begins the SB susceptible water stage. During this susceptible water stage the traps in the lower pecan canopy should be checked to determine if SBs are present. If present, then apply an insecticide reported as effective against SB in Extension spray guide (for now, that appears to be bifenthrin against brown SBs (Cottrell and Ree 2012). It would be recommended to reapply

insecticide every 10 days until nuts develop beyond the dough stage. There has yet to be an economic injury level (EIL) established for SBs in pecans but I have made the first steps by identifying a monitoring method.

REFERENCES CITED

Aldrich, J.R., A. Khrimian & M.J. Camp. 2007. Methyl 2,4,6-decatrienoates attract stink bugs and tachinid parasitoids. J. Chem. Ecol. 33: 801-815.

Aldrich, J.R., M.P. Hoffmann, J.P. Kochansky, W.R. Lusby, J.E. Eger, and J.A. Payne. 1991. Identification and attractiveness of a major pheromone component for Nearctic *Euschistus* spp. stink bugs (Heteroptera: Pentatomidae). Environ. Entomol. 20: 477-483.

Arnold, D. C. and W.A. Drew 1988. The Pentatomoidea (Hemiptera) of Oklahoma. Oklahoma state university, Tech. Bull. T-166.

Blinka, E.L., J.S. Bacheler, J.R. Bradley, and J.W. Van Duvn. 2007. Stink bug distribution based on black light trap captures across North Carolina in relation to surrounding agricultural host plant ratios, pp. 1711-1712. In Beltwide Cotton Conferences, New Orleans, Louisiana.

Cottrell, T.E., W. Ree. 2012. Managing black pecan aphids and stink bugs. Southeastern Pecan Growers Meeting Proceedings. sepga.com/presentations/2012-presentations/.

Cowell, B., D.T. Johnson, M.E. Garcia, and R. Mizell. 2015. Monitoring insect and pest damage in pecan in Arkansas. ISHS ActaHort. 1070:151-157.

Dutcher, J.D. and J.W. Todd 1983. Hemipteran kernel damage of pecan. Misc. Publ. Entomol. Soc. Amer. 13:1-11.

Gomez, C., and R.F. Mizell. 2008. Brown stink bug - *Euschistus servus* (Say). University of Florida. Dept. Entomol. and Nematol. Publ. EENY-433.

Hogmire, H.W., and T.C. Leskey. 2006. An improved trap for monitoring stink bugs (Heteroptera: Pentatomidae) in apple and peach orchards. J. Entomol. Sci. 41:9-21.

Hudson, W. 2014. Commercial Pecan Insect Control (Bearing Trees). University of Georgia Extension, spray guide.

Hudson, W.J., and Pettis G.V. 2006. Pest management strategic plan for pecans in the Southeastern U.S. 39pp. Southern Region Integrated Pest Management Center.

Kennedy, G. G., and N. P. Storer. 2000. Life systems of polyphagous arthropod pests in temporally unstable cropping systems. Annu. Rev. Entomol. 45: 467- 493.

Lee, D. 2007. Number of stink bugs growing in Missouri soybean fields. Univ. of Missouri Commercial Agricultural Program. http://agebb.missouri.edu/commag/news/archives/v16n1/news16.htm

Leskey, T. C., and H. W. Hogmire. 2005. Monitoring stink bugs (Hemiptera: Pentatomidae) in mid-Atlantic apple and peach orchards. J. Econ. Entomol. 98: 143-153.

Leskey, T.C., B.D. Short, B.R. Butler, and S.E. Wright. 2012. Impact of the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål), in Mid-Atlantic tree fruit orchards in the United States: case studies of commercial management. Psyche 2012: 1-14.

McPherson, R.M., G.K. Douce, and R.D. Hudson. 1993. Annual variation in stink bug (Heteroptera: Pentatomidae) seasonal abundance and species composition in Georgia soybean and its impact on yield and quality. J. Entomol. Sci. 28: 61-72.

McPherson, J.E., and R.M. McPherson. 2000. Stink bugs of economic importance in America north of Mexico. CRS Press, New York.

Mizell, R.F. III, and W.L. Tedders. 1995. A new monitoring method for detection of the stink bug complex in pecan orchards. Proc. Southeastern Pecan Growers Assoc. 88:36-40.

Mizell, R.F. III, and W.L. Tedders, and J.A. Aldrich. 1997. Stink bug monitoring - an update. Proceedings of the Southeastern Pecan Growers Association 90: 50-52.

Olson, D.M., and J.R. Ruberson. 2012. Crop-specific mortality of southern green stink bug eggs in Bt- and non-Bt cotton, soybean and peanut. Biocont. Sci. and Techn. 22:1417-1428.

Osburn, M.R., W.C. Pierce, A.M. Philips, J.R. Cole, and G.E. Kenbright. 1966. Controlling insects and diseases of pecans. USDA, Agricultural Handbook 240: Rev. 1–55.

Parker, M. L., W.E. Mitchem, K.A. Sorensen, B. Bunn, and S.J. Toth, Jr. (ed.). 2005. Crop Profile for Pecans in North Carolina. North Carolina Cooperative Extension Service 11 pp. Revised. http://content.ces.ncsu.edu/pecans.pdf

Pecan IPM PIPE. 2011. Pecan IPM toolbox – Insect monitoring and control. Retrieved on 20 Aug. 2015 from: http://pecan.ipmpipe.org/Toolbox/monitoring_control.pdf

Polles, S.G. 1977. Black pit and kernel spot of pecans: special emphasis on southern green stinkbug. Proc. Southeastern Pecan Growers Assn. 70:47-52.

Roberson, R. 2008. Cotton insect pressure has shifted. Mar 10, 2008 Southeast Farm Press. http://southeastfarmpress.com/cotton-insect-pressure-has-shifted

Woodroof, J.G., and N.C. Woodroof. 1928. The dropping of pecans. Natl. Pecan Growers' Assn. Bull. 2(28):30-34.

Table 1. The phenological growth stages of pecan nuts at each collection date by year and Arkansas pecan grove.

N = Nutlet	NE = Nuts expanding	WS = Water stage	W/G = Water / Gel stage	G = Gel stage	G/D = Gel / Dough stage	D = Dough stage	D/M = Dough stage / Mature	M = Mature	H = Harvesting

2013	26-Jun	9-Jul	23-Jul	9-Aug	20-Aug	4-Sep	18-Sep	3-Oct	16-Oct	30-Oct
Blackwell 2	N	N	NE	WS	W/G	G/D	D/M	M	H	H
Humphrey	N	N	N	NE	WS	G	G/D	D	M	M
Mayflower	N	N	N	NE	WS	G	G/D	D	M	M

2014	2-Jul	16-Jul	29-Jul	12-Aug	28-Aug	11-Sep	26-Sep	17-Oct	25-Oct
Adkins	.	.	.	WS	G	D	D/M	M	M
Blackwell 1	N	N	NE	WS	G	D	M	H	H
Blackwell 2	N	N	NE	WS	W/G	G/D	M	H	H
Blackwell 3	N	N	N	NE	WS	G	G/D	D	M
Blackwell 4	N	N	NE	WS	G	D	M	M	M
Blackwell 5	.	.	.	WS	W/G	G/D	M	H	H
Humphrey	N	N	N	NE	WS	G	G/D	D	M
Mayflower	N	N	N	NE	WS	G	G/D	D	M

Table 2. Season total number of stink bugs (SBs) per yellow pyramid trap, UV light trap and water knock down spray. Along with the percentages of brown, dusky, and green SBs sampled by each Arkansas pecan grove (2013).

	Grove	Total # of SBs	Mean % brown SBs	Mean % dusky SBs	Mean % green SBs
Pyramid trap					
	Blackwell 2	6,000	93.7	4.2	2.1
	Humphrey	4,039	93.9	5.6	0.5
	Mayflower	1,934	86.5	7.4	6.2
UV light trap					
	Blackwell 2	3	0.0	66.7	33.3
	Humphrey	1	100.0	0.0	0.0
	Mayflower	9	11.1	33.3	55.5
Knock down					
	Blackwell 2	4	75.0	25.0	0.0
	Humphrey	94	91.5	3.2	5.3
	Mayflower	7	85.7	0.0	14.3

Table 3. Season total number of stink bugs (SBs) per yellow pyramid trap. Along with the percentages of brown, dusky, and green SBs sampled by each Arkansas pecan grove (2014).

	Grove	Total # of SBs	Mean % brown SBs	Mean % dusky SBs	Mean % green SBs
Yellow pyramid trap					
	Atkins	549	67.2	6.0	26.8
	Blackwell 1	11,125	98.5	0.7	0.8
	Blackwell 2	5,658	96.4	2.1	1.5
	Blackwell 3	1,247	66.1	5.9	28.1
	Blackwell 4	2,595	90.0	2.9	7.1
	Blackwell 5	138	89.1	5.1	5.8
	Humphrey	5,603	78.5	20.2	1.3
	Mayflower	2,615	85.6	6.7	7.8

Table 4. Season total number of stink bugs (SBs) per UV light trap. Along with the percentages of brown, dusky, and green SBs sampled by each Arkansas pecan grove (2014).

	Grove	Total # of SBs	Mean % brown SBs	Mean % dusky SBs	Mean % green SBs
UV light trap					
	Atkins	3	0.0	0.0	100.0
	Blackwell 1	0	0.0	0.0	0.0
	Blackwell 2	10	20.0	0.0	80.0
	Blackwell 3	NA	NA	NA	NA
	Blackwell 4	8	75.0	25.0	0.0
	Blackwell 5	5	40.0	20.0	40.0
	Humphrey	3	66.7	33.7	0.0
	Mayflower	17	29.4	17.7	52.9

Table 5. Season total number of stink bugs (SBs) per water knock down spray. Along with the percentages of brown, dusky, and green SBs sampled by each Arkansas pecan grove (2014).

	Grove	Total # of SBs	Mean % brown SBs	Mean % dusky SBs	Mean % green SBs
Knock down spray					
	Atkins	181	28.2	5.0	66.9
	Blackwell 1	13	91.3	0.0	8.7
	Blackwell 2	23	41.0	7.7	51.3
	Blackwell 3	35	17.1	0.0	82.9
	Blackwell 4	7	57.1	0.0	42.9
	Blackwell 5	0	0.0	0.0	0.0
	Humphrey	46	85.4	12.4	2.2
	Mayflower	16	60.0	6.7	33.3

Table 6. Season total number of stink bugs (SBs) per visual inspection of 20 pecans in each of 10 trees. Along with the percentages of brown, dusky, and green SBs sampled by each Arkansas pecan grove (2014).

	Grove	Total # of SBs	Mean % brown SBs	Mean % dusky SBs	Mean % green SBs
Visual inspections					
	Atkins	7	42.9	0.0	57.1
	Blackwell 1	2	100.0	0.0	0.0
	Blackwell 2	1	0.0	0.0	100.0
	Blackwell 3	3	66.7	33.3	0.0
	Blackwell 4	4	100.0	0.0	0.0
	Blackwell 5	0	0.0	0.0	0.0
	Humphrey	1	100.0	0.0	0.0
	Mayflower	0	0.0	0.0	0.0

Table 7. Mean numbers of stink bugs (SBs) per yellow pyramid trap sampled after 26 June by date for each Arkansas pecan grove (2013). (B = Brown stink bug, D = Dusky stink bug, G = Green stink bug).

	Blackwell 2			**Humphrey**			**Mayflower**		
	B	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**
26-Jun	50.1	1.2	5.7	60.4	0.9	0.1	16.3	0.4	0.4
9-Jul	106.9	2.8	0.5	57.5	2.0	0.2	12.1	0.1	3.2
23-Jul	98.1	2.9	0.1	19.5	0.7	0.0	16.9	0.3	1.2
9-Aug	58.4	2.4	0.3	32.7	1.7	0.0	38.6	1.2	0.5
20-Aug	29.1	4.8	0.1	16.0	1.5	0.0	14.3	2.7	0.7
4-Sep	11.9	1.3	0.0	8.2	1.6	0.0	7.9	1.7	0.1
18-Sep	9.7	0.5	0.2	5.3	1.1	0.3	1.2	0.9	0.1
2-Oct	4.5	0.3	0.0	12.4	2.0	0.1	1.2	1.1	0.9
16-Oct	4.4	0.5	1.1	23.9	2.7	0.5	2.9	1.2	1.0
30-Oct	1.5	0.2	0.6	16.9	0.9	0.2	0.0	0.0	0.0

Table 8. Mean numbers of stink bugs (SBs) per pressurized knock down (KD) water spray sampled after 9 July by date for each Arkansas pecan grove (2013). (B = Brown stink bug, D = Dusky stink bug, G = Green stink bug).

	Blackwell 2			**Humphrey**			**Mayflower**		
	B	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**
26-Jun	.	.	.	.	.	.	.	.	.
9-Jul	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23-Jul	.	.	.	.	.	.	.	.	.
8-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0
20-Aug	0.0	0.0	0.0	0.7	0.0	0.0	1.0	0.0	0.0
4-Sep	0.7	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
18-Sep	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3-Oct	0.0	0.0	0.0	1.0	0.0	0.3	0.0	0.0	0.0
16-Oct	0.0	0.0	0.0	14.0	0.3	1.0	0.0	0.0	0.3
30-Oct	0.0	0.0	0.0	13.0	0.7	0.3	0.0	0.0	0.0

Table 9. Mean numbers of stink bugs (SBs) per UV black light trap sampled after 9 Aug by date for each Arkansas pecan grove (2013). (B = Brown stink bug, D = Dusky stink bug, G = Green stink bug).

	Blackwell 2			**Humphrey**			**Mayflower**		
	B	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**
26-Jun	.	.	.	.	.	.	.	.	.
9-Jul	.	.	.	.	.	.	.	.	.
23-Jul	.	.	.	.	.	.	.	.	.
9-Aug	0.0	1.0	0.5	0.0	0.0	0.0	0.0	1.5	1.5
20-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
4-Sep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
18-Sep	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
3-Oct	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16-Oct	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30-Oct	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0

Table 10. Mean numbers of stink bugs per yellow pyramid trap by sampling date for each Arkansas pecan grove. (2014) (B = Brown stink bug, D = Dusky stink bug, G = Green stink bug)

	Atkins			**Blackwell 1**			**Blackwell 2**			**Blackwell 3**		
	B	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**
2-Jul	.	.	.	101.9	0.5	0.2	61.5	0.5	0.5	32.3	1.2	0.0
16-Jul	.	.	.	253.3	0.7	0.4	159.5	2.1	0.5	38.5	3.2	0.3
30-Jul	.	.	.	121.7	0.6	0.1	38.9	0.7	0.5	17.2	2.2	1.0
12-Aug	.	.	.	107.5	0.5	0.2	37.7	0.9	0.3	19.2	2.2	5.0
28-Aug	12.7	0.7	0.7	49.3	0.0	0.1	21.6	0.3	0.4	4.8	1.3	1.5
12-Sep	4.7	0.9	0.8	34.4	0.5	0.3	19.5	1.1	0.4	4.2	1.0	2.0
26-Sep	6.4	0.4	1.4	31.1	0.8	0.3	10.9	0.9	0.4	2.7	0.2	8.0
18-Oct	14.1	1.4	12.3	24.2	1.2	3.6	10.6	1.1	1.3	12.8	1.0	26.8
24-Oct	3.1	0.2	1.1	7.7	0.3	1.0	3.4	0.1	1.5	5.7	0.0	13.7

Table 10. (Cont.) Mean numbers of stink bugs per yellow pyramid trap by sampling date for each Arkansas pecan grove. (2014). (B = Brown stink bug, D = Dusky stink bug, G = Green stink bug)

	Blackwell 4			Blackwell 5			Humphrey			Mayflower		
	B	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**
2-Jul	54.1	0.7	5.3	.	.	.	70.8	11.0	1.4	49.3	1.2	0.2
16-Jul	36.0	0.8	0.1	.	.	.	53.3	14.5	0.5	35.5	1.5	0.5
30-Jul	11.7	1.2	0.0	.	.	.	24.2	9.3	0.1	8.2	1.5	1.6
12-Aug	11.3	0.8	0.3	.	.	.	16.3	7.8	0.1	8.3	1.1	3.3
28-Aug	14.6	0.6	0.4	2.5	0.0	0.0	21.7	5.1	0.0	12.5	1.3	1.8
12-Sep	31.2	0.9	1.3	4.8	0.2	0.0	25.1	4.2	0.0	19.7	2.9	4.3
26-Sep	15.3	0.8	0.9	5.3	0.2	0.3	37.6	12.3	0.6	6.5	1.7	1.3
18-Oct	15.1	0.4	6.7	4.7	0.5	0.0	33.2	9.1	1.6	6.3	0.3	0.3
24-Oct	5.3	0.0	0.5	3.2	0.3	1.0	11.2	2.0	0.6	2.9	0.1	0.2

Table 11. Number of stink bugs (SBs) per UV light trap by sampling date for each Arkansas pecan grove. (2014). (B = Brown stink bug, D = Dusky stink bug, G = Green stink bug)

	Atkins			**Blackwell 1**			**Blackwell 2**			**Blackwell 3**		
	B	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**
2-Jul	.	.	.	0.0	0.0	0.0	1.0	0.0	8.0	.	.	.
16-Jul	.	.	.	0.0	0.0	0.0	0.0	0.0	0.0	.	.	.
30-Jul	.	.	.	0.0	0.0	0.0	1.0	0.0	0.0	.	.	.
12-Aug	.	.	.	0.0	0.0	0.0	0.0	0.0	0.0	.	.	.
28-Aug	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	.	.	.
12-Sep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.	.	.
26-Sep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.	.	.
18-Oct	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.	.	.
24-Oct	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.	.	.

Table 11. (Cont.) Number of stink bugs (SBs) per UV light trap by sampling date for each Arkansas pecan grove. (2014). (B = Brown stink bug, D = Dusky stink bug, G = Green stink bug)

	Blackwell 4			**Blackwell 5**			**Humphrey**			**Mayflower**		
	B	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**
2-Jul	3.0	1.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	3.0	1.0	6.0
16-Jul	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30-Jul	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	2.0	2.0	2.0
12-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0
28-Aug	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0	1.0
12-Sep	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26-Sep	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18-Oct	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
24-Oct	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0

Table 12. Mean numbers of stink bugs per pressurized knock down (KD) water spray by sampling date for each Arkansas pecan grove. (2014). (B = Brown stink bug, D = Dusky stink bug, G = Green stink bug)

	Atkins			**Blackwell 1**			**Blackwell 2**			**Blackwell 3**		
	B	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**
2-Jul	.	.	.	.	.	.	.	.	.	.	.	.
16-Jul	.	.	.	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
30-Jul	.	.	.	0.0	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0
12-Aug	.	.	.	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
28-Aug	0.4	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
12-Sep	0.0	0.0	9.4	0.4	0.0	0.2	0.0	0.0	0.2	0.0	0.0	0.4
26-Sep	2.4	0.8	11.2	0.4	0.0	0.0	0.6	0.0	1.8	0.2	0.0	1.6
18-Oct	2.6	0.4	2.2	0.2	0.0	0.0	0.2	0.0	0.0	0.8	0.0	3.4
24-Oct	4.8	0.6	1.2	0.4	0.0	0.0	0.2	0.0	0.0	0.2	0.0	0.2

Table 12. (Cont.) Mean numbers of stink bugs per pressurized knock down (KD) water spray by sampling date for each Arkansas pecan grove. (2014). (B = Brown stink bug, D = Dusky stink bug, G = Green stink bug)

	Blackwell 4			**Blackwell 5**			**Humphrey**			**Mayflower**		
	B	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**
2-Jul	.	.	.	.	.	.	.	.	.	.	.	.
16-Jul	0.0	0.0	0.0	.	.	.	0.2	0.1	0.0	0.0	0.0	0.0
30-Jul	0.0	0.0	0.0	.	.	.	0.0	0.0	0.0	0.0	0.2	0.0
12-Aug	0.0	0.0	0.0	.	.	.	0.4	0.0	0.0	0.2	0.0	0.0
28-Aug	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.2
12-Sep	0.6	0.0	0.2	0.0	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.2
26-Sep	0.0	0.0	0.4	0.0	0.0	0.0	1.2	0.2	0.2	1.4	0.0	0.6
18-Oct	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.2	0.0	0.2	0.0	0.0
24-Oct	0.0	0.0	0.0	0.0	0.0	0.0	4.6	0.4	0.0	0.0	0.0	0.0

Table 13. Mean number of stink bugs (SBs) per visual count of 20 pecan clusters by each pyramid trap on each collection date in each Arkansas pecan grove. The grove in Atkins had its first visual counts begin on 28 Aug. No stink bugs were visually detected in the Blackwell 5 and Mayflower pecan groves on any collection date (2014). (B = Brown stink bug, D = Dusky stink bug, G = Green stink bug)

	Atkins			**Blackwell 1**			**Blackwell 2**			**Blackwell 3**			**Blackwell 4**			**Humphrey**		
	B	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**	**B**	**D**	**G**
2-Jul	.	.	.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16-Jul	.	.	.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30-Jul	.	.	.	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12-Aug	.	.	.	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
28-Aug	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12-Sep	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
26-Sep	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
18-Oct	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24-Oct	0.2	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0

Table 14. Mean percentages of pecan nuts punctured and damaged by stink bugs on each sampling date by Arkansas pecan grove (2013) (N=15) (P = Puncture, D = Damage).

	Blackwell 2		**Humphrey**		**Mayflower**	
	% P	**% D**	**% P**	**% D**	**% P**	**% D**
9-Jul	5.3	0.0	7.3	0.0	3.3	0.0
23-Jul	9.3	0.0	7.3	0.0	8.0	0.0
9-Aug	6.7	0.0	4.0	0.0	6.0	0.0
20-Aug	5.3	0.0	4.7	0.0	8.0	4.0
4-Sep	2.7	0.0	5.3	0.0	4.7	2.0
18-Sep	2.0	0.7	6.7	0.7	4.0	0.7
2-Oct	2.7	0.0	10.0	4.7	6.7	1.3
16-Oct	2.7	0.0	16.7	5.3	6.0	1.3
30-Oct	2.0	0.0	16.7	8.7	2.7	0.0

Table 15. Mean percentages of pecan nuts punctured and damaged by stink bugs on each sampling date by Arkansas pecan grove (2014). Atkins (N=9), Blackwell 3 (N=6), Blackwell 1 and Blackwell 2 (N=15) (P = Puncture, D = Damage).

	Atkins		**Blackwell 1**		**Blackwell 2**		**Blackwell 3**	
	% P	**% D**	**% P**	**% D**	**% P**	**% D**	**% P**	**% D**
2-Jul	.	.	6.7	0.0	2.0	0.0	1.7	0.0
16-Jul	.	.	10.0	0.0	4.7	0.0	15.0	0.0
30-Jul	.	.	13.3	0.0	12.0	0.0	8.3	1.7
12-Aug	3.3	0.0	11.3	0.0	11.3	1.3	6.7	0.0
28-Aug	5.6	0.0	11.3	0.7	8.7	2.0	1.7	0.0
12-Sep	7.8	1.1	8.0	0.0	10.0	0.0	3.3	1.7
26-Sep	12.2	3.3	8.7	0.0	12.0	0.7	11.7	6.7
18-Oct	7.8	4.4	4.2	1.7	6.0	0.0	50.0	36.7
24-Oct	8.9	2.2	6.7	1.7	4.0	0.0	61.7	43.3

Table 15. (Cont.) Mean percentages of pecan nuts punctured and damaged by stink bugs on each sampling date by pecan grove (2014). Blackwell 4 (N=14), Blackwell 5 (N=6), Humphrey and Mayflower (N=15) (P = Puncture, D = Damage).

	Blackwell 4		**Blackwell 5**		**Humphrey**		**Mayflower**	
	% P	**% D**	**% P**	**% D**	**% P**	**% D**	**% P**	**% D**
2-Jul	5.0	0.0	.	.	2.0	0.0	.	.
16-Jul	7.5	0.0	.	.	3.3	0.0	2.7	0.0
30-Jul	8.3	0.0	.	.	4.7	0.0	1.3	0.0
12-Aug	5.0	0.0	0.0	0.0	4.0	0.0	1.3	0.0
28-Aug	4.2	0.0	0.0	0.0	6.0	2.0	3.3	0.0
12-Sep	3.3	0.0	0.0	0.0	9.3	2.0	2.0	0.0
26-Sep	7.5	1.7	1.7	1.7	16.0	4.7	4.7	0.7
18-Oct	4.2	4.2	0.0	0.0	22.0	14.0	9.3	7.3
24-Oct	10.8	5.0	0.0	0.0	24.7	15.3	10.7	4.7

Chapter 6

Effects of Adjacent Landscapes on Stink Bug Presents and Damage in Arkansas Pecan Groves

ABSTRACT

Stink bugs (SBs) are highly mobile polyphagous insects that disperse and feed on seeds of many host plant species throughout the season as the host plants enter into the preferred nutritional stage (milk stage). Since SBs prefer to feed on seeds of host plants during the milk stage, this causes SBs to continually disperse and aggregate from plant host to plant host throughout the season until they reach pecans. Once SBs enter pecan groves in later-summer or early-fall they will feed on maturing pecan nuts and locate overwintering sites. Yellow pyramid traps baited with *Euschistus* aggregation pheromone were used to monitor the movement of SBs from surrounding landscapes into pecan groves. In 2012 and 2013 there were significantly more brown SBs captured in the grass landscape at the pecan grove center than any other adjacent landscape in the Blackwell 2 (2012), Fayetteville and Humphrey (2013) pecan groves. This was due to Arkansas having a drought during the pecan growing season in both 2012 and 2013 which may have caused the brown SBs to move to the more shaded and humid interior of the pecan groves. In 2014, more SBs were caught in the pecan grove center traps and in the traps adjacent to forest tree line and soybean landscape. The 2014 pecan growing season was much cooler and wetter which may have affected the number of SBs captured. There were more SBs caught by baited yellow pyramid traps in each pecan grove in the early season than later season due to the large 1st summer generation and smaller 2nd summer generation of SBs. Stinkbugs punctured pecan nuts throughout the season in all pecan groves for each year. The percentages of SB punctured pecan nuts did not always equate to percentages of SB damaged pecan kernels. The chances of SBs damaging the pecan kernel remained relatively low until the pecan reached its water stage. The different management practices used in each pecan grove influenced the likelihood that pecan kernels were damaged by SBs.

INTRODUCTION

Stink bugs (SB) are extremely polyphagous hemipterans that feed on specific parts of plants, primarily the seeds during the milk stage. This milk stage only occurs during a short period of time which may help explain SBs aggregated distribution in fruiting crops (Mizell et al. 2008). Stink bugs benefit from selectively feeding on pods during the initial physiological maturity stage which has been associated with higher survival, fecundity, longevity, and body weight (Fehr and Caviness 1977).

According to Hudson and Pettis (2006) the SB complex in pecans in the southeastern U.S. included: Southern green SB, *Nezara viridula* (L.), brown SB, *Euschistus servus* (Say), dusky SB, *Euschistus tristigmus* (Say), green SB, *Chinavia hilaris* (Say), leaffooted bugs, *Leptoglossus phyllopus* (L.), and others. The main SB species found in Arkansas pecan groves were brown, dusky, and green SBs. There were very few leaffooted bugs and no southern green SBs found (Cowell et al. 2015). The geographical ranges of the brown SB, green SB and dusky SB were reported to span from Quebec to the southern United States. However, they cause more damage and injury in the southern United States (Carter et al. 1996). The brown, dusky, and green SB adults overwinter in fence rows, under boards, ditch banks, dead weeds, stones, ground cover, and under the bark of trees. These SBs begin to become active during the first warm days of spring (Polk et al. 1995). First spring emergence of SBs typically occur in late-March or April in Florida when temperatures rise above 21°C (Gomez and Mizell 2008). During mid-May to mid-June in North Carolina each female SB deposits up to several hundred eggs, in clusters averaging 36 eggs, on leaves, stems and occasionally on pods (Carter et al. 1996). The eggs typically hatch in 6-7 days with the nymphs remaining clustered until the third or fourth instar (Stewart et al. 2010). This clustering behavior of SB nymphs protects each nymph against

desiccation by increased the SBs uptake of atmospheric water (McPherson and McPherson 2000). It takes approximately five weeks for SBs to develop through five instars and molt to the adult stage (Carter et al. 1996).

The overwintered adults and first summer generation of nymphs feed on wild plants such as shrubs, vines, and many broadleaf weeds especially legumes producing early-season fruits (Gomez and Mizell 2008). The second generation of SBs regularly develop in field crops (Gomez and Mizell 2008) such as cotton, grain sorghum, peanut, soybean, and watermelon and later disperse to pecan (Toews 2010). Areas in the U.S. from Virginia to the north reported only one SB generation per year, whereas southern states like Arkansas have two generations per year (Carter et al. 1996). Brown and dusky SB have a first summer generation peak of activity from May through June with little adult activity in July and a second generation peak in August. The green SB on the other hand only has one generation, with peaks in activity in mid- to late-June and tapers off through July and August (Polk et al. 1995).

Stink bugs feed on many parts of a plant including the flowers, stem, foliage, vegetative parts, but most importantly feed on the more nutritious seed, nut and fruit. Stink bugs also have a large variety of host plants including but not limited to things such as shrubs, vines, broadleaf weeds, corn, soybean, sorghum, okra, millet, snap beans, peas and cotton. Legumes are preferred hosts (Gomez and Mizell 2008). A large number of adult SBs, but not immature, have been found on pecan trees during the late-summer and fall. This is an indicator that SBs do not breed or lay eggs on the pecan trees (Gill 1923, Hudson and Pettis 2006) but may reproduce earlier in the herbaceous weeds on the orchard floor or on other host plants in adjacent landscapes (Hudson and Pettis 2006). Good ground cover practices that eliminate SB host plants before seed heads appear were reported to help minimize local SB densities (Polk et al. 1995).

Stink bugs are polyphagous and can disperse during the season to feed on many host plant species, especially when those are in the preferred nutrition stage, e.g., seeds in the milk stage or ripening fruit (Hogmire and Leskey 2006, and Mizell et al. 2008). Velasco and Walter (1992) reported that SBs disperse to and feed on several host plant species during the season before reaching their preferred host, soybean, in late-summer. As the soybean crop senesces or is harvested in the later-summer or early-fall, SB move into pecan groves (Mizell et al. 1997) to feed on maturing pecan nuts and locate overwintering sites (Polles 1977). As SBs disperse to a new crop, they aggregate in higher numbers at the crop perimeter known as an edge effect (Tillman et al. 2009). This narrow temporal window of available high quality food for SBs may be responsible for this SB aggregation behavior (Tillman et al. 2009, Mizell et al. 2008). Similarly, Martinson et al. (2015) has demonstrated that brown marmorated SBs, *Halyomorpha halys* (Stal), have the ability to detect and disperse to food resources as they become available throughout the season. Other factors may also affect the movement of the SBs throughout the landscape. As Tillman et al. (2009) noted a tractor applying fungicide in one field caused the SBs to be flushed into an adjacent field.

Stink bugs high mobility with continual dispersal to different crops makes them difficult to control by insecticide applications alone (Polk et al. 1995). Currently, pyrethroid insecticides are being applied for stinkbug control (Hudson and Pettis 2006). Cottrell and Ree (2012) suggest that Brigade WSB (bifenthrin) is the most effective insecticide against the brown SB, which are more difficult to kill than the green SBs. The adult SBs are strong fliers and readily disperse between adjacent hosts (Polk et al. 1995). Stink bugs occurs both horizontally at the landscape level and vertically in the pecan tree canopy (Cottrell et al. 2000). Wright et al. (2007) found that nuts collected from the lower limbs had more SB damage than damage higher in the tree. This

suggests that by removing the lower limbs from the tree it will disrupt the movement of the SBs into the pecan canopy and may work as a control tactic. These brown and green SBs fly through the pecan groves at heights less than 1m or just above the height of ground vegetation (Mizell and Tedders 1995). Ground cover practices that eliminate seed heads and broadleaf weeds help minimize SB population (Polk et al. 1995). Tillman et al. (2009) stated that to improve SB management practices will require conducting more studies of spatiotemporal patterns and landscape ecology of SBs.

It is important to study the biology and behavior of the SBs, especially to describe seasonal movements between crops (Hudson and Pettis 2006). Baited yellow pyramid trap were used to monitor the movement of SBs within a landscape relative to pecan groves (Mizell and Tedders 1995, and Hogmire and Leskey 2006). These traps consisted of a yellow pyramid trap baited with a rubber septum charged with 40 μl of the *Euschistus* spp. aggregation pheromone, methyl (2E, 4Z)-decadienoate (Aldrich et al. 1991). Hogmire and Leskey (2006) used these baited yellow pyramid traps to capture three SB species including: brown; dusky; and green. Both the brown and dusky SBs were attracted to the traps by the *Euschistus* spp. aggregation pheromone and the yellow color of the traps while the green SB was only attracted by the yellow color.

According to Hudson et al. (2011), SBs are present in pecan groves all year long, but economic loss occurs only from late-August to late-September from shell hardening (dough stage) to early-maturity. It has been reported that SBs use amylase while feeding (Hori 2000). Amylase breaks down host plant sugars and starches so that these insects can feed. External SB damage can be diagnosed by looking for fluid oozing from shuck puncture site (Yates et al. 1991). Stink bugs feeding on a nut, from the liquid endosperm stage (water stage) through shell

hardening, will cause a black area around the puncture within one hour after feeding. By the second day the entire vascular tissue between the shuck and the shell will darken, and within four to five days the immature nut blackens (black pit) causing the nut to drop (Woodroof and Woodroof 1928). In contrast, SB feeding after shell hardening (dough stage) and later causes a bitter tasting dark spot called kernel spot to form on the edible kernel inside the pericarp of the pecan nut but these nuts will not drop (Osburn et al. 1966, Hudson and Pettis 2006). Kernel spot cannot be detected until the pecans are shelled (Hudson and Pettis 2006). Stink bugs also have the ability to feed on fully developed nuts through the hard shells even after harvest (Hudson and Pettis 2006), but it is unknown if this also results in kernel spot. The cage study (chapter 3) of this dissertation suggests that SBs cannot damage pecans once they are fully mature.

The objective of this study was to estimate the seasonal changes in the numbers of SBs captured in baited yellow pyramid traps, percentage of pecans with SB punctures, and percentage of pecans with SB damaged kernels in Arkansas pecan groves with different vegetative landscapes. This was done in order to determine if certain landscapes promote or inhibit SB movement into the adjacent pecan grove.

MATERIALS AND METHODS

Trapping

Due to grove to grove variability in different landscapes and weather conditions Mizell et al. (1997) suggested that 3-5 traps be placed on the border rows and the interior of the pecan groves from as early as June until harvest in order to monitor changes in SB density. In this study, yellow pyramid traps described by Mizell and Tedders (1995) and Hogmire and Leskey (2006) were used to monitor the movement of SBs from surrounding landscapes into pecan

groves. These pyramid traps were constructed out of 4 mm yellow corrugated plastic (Pack and Seal, Avenel, NJ) with the following dimensions; 1.2 m tall with a 0.5 m base that tapers to a 5 cm tip. On top of the pyramid was an inverted aluminum window screen funnel that measured 35 cm dia. x 30 cm height x 2 cm dia. opening. Stapled over the funnel was a capture screen cage that measured 38 cm height x 20 cm dia. The screen cage was held to the top of the yellow pyramid trap with ratchet-lock spring clamps and baited with a rubber septum lure charged with 40ul of the *Euschistus* spp. aggregation pheromone, methyl (2E, 4Z)-decadienoate (Aldrich et al. 1991). The base of each pyramid trap was covered with soil and the middle portion secured with bailing wire to three-0.5 m and one 1.3 m piece of 0.6 cm rebar hammered 0.25 m into the ground. In June 2012, 2013 and 2014, three of these traps were set out at least 22 m apart in each of five locations in each grove: center; and set along each perimeter quadrant (N, E, S, and W) between pecan trees parallel to each of the landscapes of interest. Biweekly, lures were replaced, and SBs emptied into labeled bags which were later identified to species and counts recorded of each SB species per trap.

Damage Assessment

Starting in mid-August in 2012 and early-July 2013 and 2014, biweekly samples of ten pecans were randomly collected from the pecan trees near each pyramid trap of each pecan grove. These pecan samples were stored in 3.79 liter storage bags at 2^{o}C until they were dissected for SB punctures, SB kernel damage and other insect damage. The nut shucks were visually inspected for SB punctures. Each suspected puncture was cut away exposing a small dark spot. This could be traced to a pin point dark spot on the pecan shell which confirmed the SB puncture. After shuck removal, the pecan samples were cracked open to note if the SB

punctures penetrated the shell of the nut and caused black pit in younger nuts or black kernel spot in more mature nuts where both were recorded as nut damage.

Groves and Adjacent Landscapes

In 2012 and 2013 these studies were conducted in five Arkansas pecan groves: Blackwell 1; Blackwell 2; Mayflower; Humphrey; and Fayetteville. There were eight pecan groves sampled in 2014: Blackwell 1; Blackwell 2; Blackwell 3; Blackwell 4; Blackwell 5; Mayflower; Humphrey; and Atkins. Landscapes adjacent to these pecan groves were fields of soybean, rice, pasture, mowed grass, levee, fallow field and woods. Some of the pecan groves did have different crops (landscapes) planted around them on during different years.

2012

In 2012, the landscapes adjacent to yellow pyramid traps in perimeter of each pecan grove were: Blackwell 1, the north, east and west were fallow fields, and the south was a levee covered with tall grass with more pecan grove on the other side; Blackwell 2, the north and east of the pecan grove were rice fields, the south was a late planted soybean field, and the west was a cow pasture; Mayflower, the north and west of the pecan grove were grass fields for hay, the east was a thick tree line and the south was a soybean field; Humphrey, the north of the pecan grove was a lake with some trees bordering it, the east and south were soybean fields, and the west a maintained grass lawn; Fayetteville, the north and south were grass fields for hay, the east was cow pasture, and the west was mostly highway with some grass and weed right of ways. The center of each of these pecan groves were grass that is occasionally mowed until late-August to early-September, at that time the grass was maintained at a shorter height in preparation for the upcoming pecan harvest. Soybean pod formation and fill began to occur during mid-August and full maturity was reached by the beginning of October.

2013

In 2013, the three yellow pyramid traps per side or center were placed in similar locations as in 2012. The grass drive rows in each pecan grove were mowed occasionally until late-August to early-September and then maintained at a shorter height in preparation for the upcoming pecan harvest. Soybean pod formation and fill began to occur during the beginning of August and full maturity was reached by the end of September.

2014

In 2014, three (Blackwell 1, Blackwell 2 and Mayflower) of the eight pecan groves each had three yellow pyramid traps placed in each of four sides and in center as set in the previous two years. The landscapes adjacent to the sides of the remaining five pecan groves were: Humphrey, north of the pecan grove was a lake with some trees bordering it, the east and south were rice fields, and the west a maintained grass lawn; Blackwell 3, the north had woods and the south was a soybean field; Blackwell 4, the east was a rice field, the south a maintained grass lawn and the west a soybean field; Blackwell 5, the east was a rice field and the west a levee covered with tall grass; Atkins, the east and west were soybean fields and the center a maintained grass lawn. The remaining pecan groves that did not have the grass centers of the groves mentioned (Blackwell 1, Blackwell 2, Blackwell 4, Blackwell 5, Mayflower, Humphrey) were occasionally mowed until late-August to early-September, when the grass was maintained at a shorter height in preparation for the upcoming pecan harvest. Soybean pod formation and fill began to occur during late-August and full maturity was reached by the middle of October (Fig. 4).

Grove management practices

The pecan grove management practices for 2012, 2013, and 2014 are found in Table A.1., A.2, and A.3

ANALYSIS

All SB data were analyzed using PROC GLIMMIX with a Poisson distribution and repeated measures. Mean separations were done by LSMEANS (*SAS* Institute, Cary, NC). The SB counts among years and among pecan groves were analyzed separately because these counts were significantly different. The relative numbers of dusky and green SBs along with the numbers of punctured pecans and/or damaged pecan kernels proved to have too many low and zero counts to use an ANOVA, so SB counts were reported as means (± SE) whereas punctured and damaged pecan nuts were reported as percentages.

Preliminary findings from 2012 on the mean pecans punctured by SBs and findings on the pecan grove surrounding landscapes influence on pecan groves were reported previously in Cowell et al. (2015) (Chapter 2).

RESULTS

Over 59,317 SBs from nine genera were collected from Arkansas pecan groves in baited yellow pyramid traps over the three years of this study. Traps monitored in 2012, 2013 and 2014, captured 12,520 SBs, 17,022 SBs and 29,775 SBs, respectively (Table 1). The predominant SB species trapped across all years were: brown SB (90.5%), dusky SB (4.6%), and green SB (2.5%). Over three years, these three species made up 96.6% (2012), 97.8% (2013) and 98.9% (2014) of the yellow pyramid trap catch. In each pecan grove there were numerically more

brown SBs caught in yellow pyramid traps than dusky and green SB in 2012, 2013, and 2014 (Table 2).

There were significant differences (F = 80.38; df = 2, 591; P = < 0.0001) in the annual mean numbers of SBs per trap of 38.0 (2014) > 22.2 (2013) > 18.0 (2012) (Table 3). The annual mean percentages of pecan nuts punctured by SB feeding were similar across years: 8.6% (2012), 8% (2014) and 6.1% (2013) (Table 3). The percentages of pecan nuts that had kernels damaged by SB were only recorded in 2013 (0.9%) and 2014 (2.1%) (Table 3).

The pecan groves had significantly different combined annual mean numbers of brown, dusky, and green SBs per trap in 2012 (F = 224.5; df = 4, 105; P = < 0.0001), 2013 (F = 587.7; df = 4, 266; P = < 0.0001), and 2014 (F = 252.2; df = 7, 209; P = < 0.0001) (Table 4). Annual mean trap counts of SBs in the pecan groves in Blackwell 1, Blackwell 2 and Humphrey were significantly more than those from the other pecan groves in 2012 and 2013. In 2014, pecan groves in Blackwell 3, Blackwell 4 and Mayflower all had moderate annual mean trap counts of SBs that were significantly more or less than those from all the other pecan groves. The significantly lowest annual mean trap captures occurred in pecan groves in Blackwell 5 (2014), Atkins (2014), and Mayflower and Fayetteville (2012 and 2013).

There were numeric differences between the pecan groves for all three years in the percentages of pecan nuts punctured by SBs and for the two years of recorded mean percentages of SB damaged pecan nuts (Table 4). The pecan grove in Humphrey had greater percentages of pecans punctured by SB in 2012 (22.4%) and 2013 (8.7%) than any other pecan grove. In 2014, three new pecan groves (Atkins, Blackwell 3, and Blackwell 4) were added to the study of which Blackwell 3 had the most SB punctured nuts (17.8%) followed by Humphrey (10.2%).

By pecan grove, the percentages of SB damaged nuts were usually at least two-fold less than corresponding mean percentages of nuts punctured by SBs. In 2013, the Humphrey pecan grove had the greatest percentage of SB damaged nuts (2.2%), whereas in 2014 the greatest percentage of damaged nuts occurred in pecan orchards in Blackwell 3 (10%) and Humphrey (4.2%).

Trap catches of the dusky SBs and green SBs were too low to analyze but some of the higher trap captures of brown SBs (Table 2) were significantly affected by landscapes adjacent or surrounding baited yellow pyramid traps. In 2012, only in the pecan grove in Blackwell 2 did the grass landscape surrounding the center traps capture significantly ($F = 4.88$; df = 4, 130; $P = < 0.0011$) more brown SBs than did perimeter traps adjacent to other landscapes (Table 5). In all other pecan groves, there was variation among the numbers of brown SBs per pyramid trap set along the perimeter or in the grove center, but no means were significantly different in: Blackwell 1 ($F = 0.79$; df = 4, 129; $P = 0.53$); Fayetteville ($F = 1.39$; df = 4, 145; $P = 0.24$); Humphrey ($F = 0.14$; df = 4, 129; $P = 0.97$); and Mayflower ($F = 0.25$; df = 4 , 130; $P = 0.91$) (Table 5). Note, the mean trap counts of brown SBs from all pecan grove centers (grass landscapes) in 2012 were numerically greater than the majority of other landscapes adjacent to the perimeter traps in all pecan groves.

When comparing the percentage of pecan nuts punctured by SBs near traps adjacent to or surrounded by various landscapes in each pecan grove more SB punctures occurred in the pecan trees adjacent to soybeans, a forest edge (trees), and the center of the pecan grove (center grass) (Table 5).

In 2013, the effects of landscape adjacent to perimeter traps or surrounding traps in the center of pecan grove significantly ($F = 3.11$; df = 4, 145; $P = < 0.012$) affected the season mean

numbers of brown SBs per yellow pyramid trap only in the pecan grove in Humphrey. This pecan grove caught significantly more brown SBs in traps in the center grass landscape than perimeter traps adjacent to the east soybean crop or north forest tree line which had similar numbers of brown SBs as caught in perimeter traps adjacent to a soybean landscape on the south and grass to the west. There were no significant differences found in the numbers of brown SBs per pyramid trap due to landscape adjacent or surrounding traps in Blackwell 1 ($F = 1.29$; df = 4, 145; $P = 0.28$), Blackwell 2 ($F = 0.58$; df = 4, 145; $P = 0.68$), and Mayflower ($F = 0.89$; df = 4, 145; $P = 0.47$) (Table 6). Similar to the 2012 findings, pecan groves in Blackwell 2, Humphrey, and Fayetteville had numerically more brown SBs caught in yellow pyramid traps in the center grass landscape than any other landscapes adjacent to perimeter traps. The grove in Blackwell 1 caught numerically more brown SBs in the perimeter adjacent to the south levee landscape which was similar to the center grass landscape. Mayflower had numerically more brown SBs caught in the perimeter traps adjacent to the south soybean landscape than any other landscape but this was not significantly different from traps in center grass. (Table 6).

When observing the percentage SB punctures by surrounding landscapes in each pecan grove there was a trend of more SB punctures occurring in the pecan trees adjacent to soybeans, a forest edge (trees), and the center of the pecan grove (center grass) (Table 6).

In 2014, the effect of landscapes adjacent to pecan grove or surrounding traps in center on the seasonal mean numbers of brown SBs per yellow pyramid trap was found to be significant in Atkins ($F = 4.74$; df = 2, 42; $P = 0.014$), Blackwell 3 ($F = 5.02$; df = 1, 52; $P = 0.03$), Blackwell 4 ($F = 10.1$; df = 3, 104; $P < 0.0001$), Humphrey ($F = 2.87$; df = 4, 127; $P = 0.03$), and Mayflower ($F = 6.74$; df = 4, 130; $P < 0.0001$) (Table 7). The Atkins pecan grove caught significantly more brown SBs in traps in the center grass than either the east or west perimeters

adjacent to soybeans. Blackwell 3 caught significantly more brown SBs in the south perimeter adjacent to soybeans than the north perimeter adjacent to a forest tree line (grove was too small to set center traps). The Blackwell 4 pecan grove caught significantly more brown SBs in traps surrounded by grass in the center than traps in perimeter adjacent on east to rice, south to grass, or west to soybean. The pecan grove in Humphrey had similarly the highest counts of brown SBs in the north perimeter adjacent to a forest tree line and the trap surrounded by grass in the center than the perimeter adjacent to rice to east or south or to grass to the west. The Mayflower pecan grove had significantly more brown SBs captured in traps set in the perimeter adjacent to soybeans and the trap surrounded by grass in the center than in traps in perimeters adjacent to the east forest tree line or grass to the north or west. Adjacent or surrounding landscape did not affect the seasonal mean numbers of brown SBs captured by yellow pyramid traps in pecan grove in Blackwell 1 ($F = 0.76$; df = 4, 130; $P = 0.55$), Blackwell 2 ($F = 1.49$; df = 4, 130; $P = 0.21$), and Blackwell 5 ($F =1.89$; df = 1, 28; $P = 0.18$) (Table 7). Just as the previous two years, there was a trend for traps in the perimeter adjacent to soybeans, a forest edge (trees), or surrounded by grass landscape in the center of each pecan grove to have pecan trees with more SB punctures than in pecan trees adjacent to other landscapes (Table 7). In 2014 the Humphrey pecan grove had more pecan nut punctures and damage occurring in the west grove perimeter adjacent to grass. In both 2013 and 2014, the percent damage found was similar to the percent punctures, with the greater percentage damage being found in the surrounding with soybeans (Soy), a forest tree line (trees), and the center of the pecan grove (center grass) (Tables 6 and 7).

In 2012, the mean numbers of brown SBs per yellow pyramid trap were significantly different among sampling dates in every sampled pecan grove: Blackwell 1 ($F = 124.7$; df = 8, 125; $P < 0.0001$), Blackwell 2 ($F = 59.3$; df = 8, 126; $P < 0.0001$), Fayetteville ($F = 20.8$; df = 8,

125; P < 0.0001), Humphrey (F = 34.42; df = 8, 125; P < 0.0001), and Mayflower (F = 27.29; df = 8, 126; P < 0.0001). In all pecan groves, there were more brown SBs caught in the early season from June 20 to Aug. 16 (Table 8) than in the late season from Aug. 29 to Oct. 25 (Table 9). The opposite was true in the pecan grove in Humphrey. In 2012, pecans were only checked for punctures in late season from Aug. 29 to Oct. 25 in four pecan groves (Blackwell 1, Blackwell 2, Humphrey, and Mayflower) (Table 9).

Similar to 2012, in 2013 there were significant differences among sampling dates in the mean numbers of brown SBs per yellow pyramid traps in every pecan grove: Blackwell 1 (F = 28.97; df = 9, 140; P < 0.0001), Blackwell 2 (F = 54.42; df = 9, 140; P < 0.0001), Fayetteville (F = 26.25; df = 9, 140; P < 0.0001), Humphrey (F = 22.21; df = 9, 140; P < 0.0001), and Mayflower (F = 24.14; df = 9, 140; P < 0.0001). In all groves, there were more brown SBs caught in the early season from June 26 to Aug. 20 (Table 10) than in the later season from Sept. 4 to Oct. 30 (Table 11). Numerically more SB punctures occurred in the early season when compared to the later season in Blackwell 1, Blackwell 2, and Mayflower. The pecan grove in Humphrey had more punctures occurring in the later season (Table 11) than in the early season (Table 10). The SB damage to the pecans did not begin to occur until Aug. 20 (Mayflower) at the earliest (Table 10 and 11).

In 2014, most pecan groves had more brown SBs caught per yellow pyramid trap in the early season from Jul. 2 to Aug. 12 (Table 12) than in the later season from Aug. 28 to Oct. 24 (Table 13) except Blackwell 5: Atkins (F = 7.57; df = 4, 40; P = 0.0001), Blackwell 1 (F = 49.73; df = 8, 126; P < 0.0001), Blackwell 2 (F = 40.36; df = 8, 126; P < 0.0001), Blackwell 3 (F = 10.82; df = 8, 45; P < 0.0001), Blackwell 4 (F = 12.89; df = 8, 99; P < 0.0001), Blackwell 5 (F = 1.34; df = 4, 25; P = 0.2817), Humphrey (F = 14.07; df = 8, 123; P < 0.0001), and Mayflower (F

= 19.6; df = 8, 126; $P < 0.0001$). Similarly, more SB punctures occurred in the early season than in the late season in pecan groves in Blackwell 1, Blackwell 2, Blackwell 3, and Blackwell 4. While in the Humphrey and Mayflower pecan groves more SB punctures occurred in the later season than in the early season and SB counts were also higher in late than early season. Similar to 2013, SB damage to pecan kernels did not begin to occur until Aug. 12 at the earliest.

DISCUSSION

My study demonstrated that SB numbers per pyramid trap differed by sampling date in a pecan grove and among pecan groves. It was also noted that the factors affecting SB trap catch included: landscape surrounding pyramid traps in the pecan grove center or the landscape adjacent to traps and pecan trees in the grove perimeter; pruning height of lower pecan tree limbs; ground cover management; and timing or use of insecticides. Although we found no relationship between the number of SBs and the percentages of pecans with SB punctures or SB damaged kernels the surrounding landscapes and management practices may be factors affecting the percentages of pecan nuts punctured and kernels damaged by SBs.

By pecan grove, the seasonal changes in the mean numbers of brown SBs per pyramid trap, percentages of pecan nuts punctured by SBs and kernels damaged by SB are illustrated in the Appendices noted by A.#: Fig. A.1-2, 4-5 (punctures only in 2012, no nuts on pecan trees in Fayetteville), Fig. A.6-7, 9-10 (2013 data, no nuts on pecan trees in Fayetteville), and Fig. A.11-18 (2014).

There were significant differences among pecan groves by year in the combined means of the brown, dusky, and green SBs caught per baited yellow pyramid trap. Leskey et al. (2012)

found similar results during their work on brown marmorated SBs, showing that the number of SBs varied both between the year and by the pecan orchard sampled.

Stink bug puncturing of pecan nuts was already occurring by the first inspections of nuts in the pecan grove in Humphrey on 29 Aug. 2012 (Cowell et al. 2015) (Fig. A.4) and peaked when the nut development ranged from water to gel stages (Table A.4). Nut inspections were begun earlier in 2013 and 2014. Those inspections detected SB punctures continuously from first sampling date on 9 Jul. 2013 or 2 Jul. 2014 (nutlet stage) to harvest in late-Oct. (Fig. A.6-18).

The highest mean numbers of SBs per trap occurred in the early season in traps surrounded by grass in the grove center in Blackwell 2, but that high trap catch did not equate to the greatest percentage of SB punctured nuts in that grove. Rather, the pecan trees adjacent to the soybean landscape had the most SB punctured nuts (Fig. A.2). In the Humphrey pecan grove the tree line landscape adjacent to the grove had both the greatest number of brown SBs and percentage SB punctured nuts. The Humphrey pecan grove did not have an insecticide applied against SB and pecan weevil in 2012, which consequently caused 50% SB punctured nuts on the north perimeter bordered by a tree line landscape (Fig. A.4). In contrast, pecan groves in Blackwell 1 (Fig. A.1) and Blackwell 2 (Fig. A.2) were treated with well-timed insecticide sprays against SBs during mid- and late-Aug. which resulted in less than 10% SB punctured nuts.

The SB damage of pecan nut kernels was often additive for a short time from the dough stage on from Aug. to 12 Sept. 2013 or from 11 to 26 Sept. 2014. The additive effect can be observed in the Humphrey pecan grove (Fig. A.9) which shows that damage did not begin to occur until 18 Sept. which was when some of the pecans were entering the dough stage (Table A.4). Any pecans that were SB damaged during the earlier water and gel stages through shell

hardening were darkened inside the pecan (black pit) and these nuts dropped from the tree (Osburn et al. 1966).

Stink bug feeding during the dough stage and later caused a bitter tasting dark spot called kernel spot to form on the edible kernel but these nuts did not drop (Osburn et al. 1966, Hudson and Pettis 2006). In my study, SB damage of nut kernels began during the water stage (black pit) and continued through nut maturity (kernel spot) (Table A.4): in 2013 started by 20 Aug. and increased until 30 Oct. (Fig. A.6-7, 9-10); or in 2014 started by 12 Aug. and increased until 24 Oct. (Fig. A.11-18).

Landscape and grove management practices affected percentage SB punctures and SB damaged pecan nuts. In 2012, the grassy center of the pecan grove in Mayflower had the greatest percentage of SB damaged pecan nuts (20%) (Fig. A.5) even though the mean number of brown SBs remained relatively low (< 25 SBs per trap after 16 Aug. 2012).

In 2013, the grove in Humphrey had aerial SB pyrethroid insecticide applications on Aug. 15 and Aug. 28. Since the Humphrey pecan grove had a pecan cultivar that matured later than other groves, these sprays should have been applied during the beginning of Sept. during the pecan gel stage. Those early sprays proved to be ineffective as the mean numbers of both the percentage SB punctured pecans (43.3% in center grass and 23.3% in trees adjacent to soybeans) and percentage SB damaged pecans (20% in center grass and 16.6% in pecan trees adjacent to soybeans) were higher in the Humphrey pecan grove (Fig. A.9) than the 10% SB punctures in later season and 3.3% percentage SB nut damage in groves in Blackwell 1(Fig. A.6) and Blackwell 2 (Fig. A.7). These last two pecan groves used several SB management methods: kept bare ground underneath the trees; kept grass mowed very short to prevent seed head formation; kept pecan grove free of pruning debris; and applied timely pyrethroid insecticidal sprays in mid-

and late-Aug. against SB and pecan weevil. The pecan grove in Mayflower (Fig. A.10) allowed grass underneath the trees; one mid-summer harvest of the grass for forage; and applied insecticide during mid-Aug., mid-Sept. and late-Sept. resulting in only slightly higher percentages of SB punctures (13.3%) but similar SB damage (3.3%) as groves in Blackwell 1 and Blackwell 2 (Fig. A.6-7).

In 2014, the surrounding or adjacent landscapes with the greatest mean numbers of brown SBs in any given pecan grove and/or sampling date did not necessarily relate to the reported percentage SB punctured and SB damaged pecans. Similar to 2013, the 2014 percentage SB damaged pecans didn't begin to occur until the water stage (Table A.4) or later in any of the pecan groves with the exception of Blackwell 3 (Fig. A.14) which had a small amount of SB damage occur on 30 Jul. when the pecans were completing the nutlet stage. The chance of finding SB damaged pecans during the nutlet, water and gel stages is rare due to the fact these damaged nuts eventually drop from tree. Any of the pecans that were SB damaged from dough stage on will stay and percentage SB damage often increases thereafter (Cowell SB cage study Chapter 3). This increase in SB damage over time was observed very clearly in the pecan groves in Blackwell 3 (Fig. A.14) and somewhat in Blackwell 4 (Fig. A.15) and Humphrey (Fig. A.17).

Again in 2014, the mean numbers of both percentage SB punctured pecans and percentage SB damaged pecans were much greater in pecan trees adjacent to certain landscapes in these pecan groves which did not use any SB management practices: 50% SB damaged nuts in pecans adjacent to the south soybean landscape in Blackwell 3 on Oct. 24 (Fig. A.14); 30% SB damaged nuts in pecans adjacent both to the north forest tree line and west grass landscape in Humphrey on Oct. 18 (Fig. A.17). The damage occurring in the west grass landscape was unexpected but may be due to a corridor the SB could travel down from a distant soybean field to

the west grass landscape of the pecan grove. In Blackwell 4 (Fig. A.15) there was no use of insecticide or any other SB management practices and no fungicide, which resulted in a high percentage of pecan scab. The high scab incidence caused many of these pecan nuts to drop off but those scab covered nuts that remained on the tree had low percentage SB punctures and SB damaged nuts. The pecan groves in Atkins (Fig. A.11), Blackwell 1 (Fig. A.12), Blackwell 2 (Fig. A.13), and Blackwell 5 (Fig. A.16) used several SB management practices: bare ground underneath the trees; grass mowed very short; grove free of debris; applied insecticide; and pecan groves in Blackwell 1 and Blackwell 5 trimmed the lower branches very high off the ground. It is reported that SBs tend to fly about 1 m above the ground (Mizell 1995) and tend to feed mostly in the lower pecan tree canopy (height study chapter by Cowell). Similarly, Wright et al. (2007) found that the nuts collected by hand off the ground and lower limbs had more SB damage than higher in the tree. Within each of these years, pecan groves that did not use any SB management practices had a greater percentage of nuts punctured and damaged than any of the pecan groves using one or more SB management practices

In agreement with Mizell and Tedders (1995), Hogmire and Leskey (2006) and Mizell and Tedders (1995), my three year study found that baited yellow pyramid trap monitoring the movement of SBs in pecan groves caught many species of SBs, but > 96% of those captured were brown, dusky, and green SB. My study found the number of SBs captured in yellow pyramid traps were significantly different between years. McPherson et al. (1993) found the number of SBs caught in soybeans by sweep net varied drastically between years. I found that the mean percentages of SB punctured and SB damaged pecan nuts varied numerically by each year but the mean numbers of SBs per pyramid trap did not necessarily relate to the percentage of SB punctured or SB damaged pecan nuts. The greatest season percentage SB punctured pecan

nuts was 8.6% in 2012 with a season mean of 18 SBs per trap, followed by 8% SB punctured nuts in 2014 with a season mean of 38 SBs per trap, and only 6.1% punctured nuts in 2013 with a season mean number of 22.2 SBs per trap. The pecan damage was only recorded in 2013 and 2014 where the overall season percentage SB damaged nuts was 2.1% in 2014 and 0.9% in 2013 (Table 2).

I found that the percentages of SB punctured and SB damaged nuts varied between years and the pecan grove in which the pecan samples were taken. Again Leskey et al. (2012) found similar results with the percentage of fruit injured by brown marmorated SB that varied by both year and orchard. Some of this variation between the years and pecan groves was explained by the individual pecan groves management techniques.

In 2012, only the Blackwell 2 pecan grove showed a significant difference in mean number of brown SBs captured by surrounding landscape, of which significantly more brown SBs were caught in the center grass landscape of this pecan grove than any other landscape. Again in 2013, only the Fayetteville and Humphrey pecan groves showed a significant difference in mean number of brown SBs captured by surrounding landscape where more brown SBs were caught in the center grass landscape than any other landscapes adjacent to the grove perimeter. In Arkansas there was a drought during the pecan growing season in both 2012 and 2013 which may have caused the brown SBs to move to the interior of the pecan groves, especially irrigated groves like Blackwell 1, Blackwell 2, Blackwell 3, Mayflower, and Humphrey (irrigated in 2013 only), which may have provided a shaded environment that was cooler with a higher relative humidity. Wood and Tedders (1996) stated that during a drought, irrigated pecan orchards became attractive to the SBs resulting in increased feeding damage which caused massive nut drop. These drought conditions caused SBs to look for new hosts as other hosts dried up (Mizell

et al. 1997). In comparison, the pecan growing season in 2014 was a much cooler and wetter season, which may have affected the number of SBs captured and their movement from adequate hosts toward pecans. In 2014, more brown SBs were caught in the pecan grove center traps surrounded by grass and in the perimeter traps adjacent to forest tree line and soybean landscape. The greater number of SBs captured in traps adjacent to forest tree line landscape in Humphrey and Mayflower may be explained by Venugopal et al. (2014) who stated that adjacent wooded landscapes constantly harbored higher densities of SBs than open landscapes. Herbert and Toews (2011) stated that a soybean planting harbored large number of brown SBs, which explains the high SB counts caught in traps adjacent to soybean landscape.

More SBs were caught in yellow pyramid traps in the early season than later season occurred in every pecan grove for every year, except for Humphrey in 2012 where more brown SBs were captured in the fall season dispersing from soybeans on two sides. Cottrell et al. (2000) showed that the brown SB had a large 1^{st} summer generation which peaked in June in Georgia and had a smaller 2^{nd} summer generation which peaked in Oct.

The percentage SB punctures of pecan nuts occurred throughout the season in all pecan groves for each year. These percentages of SB punctured nuts did not always equate to percentages of SB damaged nuts. The chances of SBs damaging the pecan remain relatively low until the pecan reaches its water stage. Pecans that are damaged during the water and gel stages of the pecan will abort and fall from the tree which will reduce the quantity of pecans on the tree but not the quality. Pecan nuts that are attacked by SBs during early development when the nut is in the water and gel stages causes the pecan centers to turn black (black pit) and the nut to drop (Woodroof and Woodroof 1928). This SB damage that causes the pecans to drop may actually act as a natural pecan thinning event. Wells et al. (2009) shows that by mechanically thinning

pecans, the number of the next year's fruiting shoots increases along with increasing the quality of the current year's pecans and reducing alternant bearing of the tree.

My studies suggest that the different management practices in each pecan grove have a large influence on the likelihood of pecan kernels being damaged by SBs. The pecan groves that had a pyrethroid insecticide spray applied during the gel stage of the pecans suffered much less pecan nut damage than the pecan groves that weren't sprayed. The pecan groves which had their limbs trimmed up high from the ground also seemed to have less pecan kernel damage than the unsprayed pecan groves. Wright et al. (2007) found that nuts collected from the lower limbs had more SB damage than damage higher in the tree. This suggests that by removing the lower limbs from the tree it will disrupt the movement of the SBs into the pecan canopy. The other SB management tactics recorded were: herbicide strip of bare ground underneath the trees; regularly mowed grass drive rows of pecan grove; and removal of all pruning debris and trash from the pecan grove. The herbicide strip and regular grass mowing removed the ground cover vegetation from the pecan grove that supported SBs feeding and reproduction. Toews (2010) showed that SBs were likely to be captured by sweep net in unmowed pecan groves but not mowed pecan groves. Nessler (2008) suggested that SBs could be managed by keeping adjacent field borders free of weeds and trash that supported SBs feeding and reproduction.

Recommendations for stink bugs in pecans:

In order to monitor for SBs in Arkansas pecan groves, four foot tall yellow pyramid traps baited with a rubber septum charged with 40 µl of the green and brown SB aggregation pheromone methyl (E,Z,Z)-2,4,6-decatrienoate (Aldrich et al. 2007) + methyl (E,Z,)-2,4-decadienoate (Aldrich et al. 1991) should be used. Monitoring for SBs should be started during the pecan nut gel stage which occurs between mid-Aug. and early Sept., depending on cultivar

nut development. Pecan nuts which are damaged by SB during the gel stage and before will drop from the pecan tree. If any SBs are caught in the yellow pyramid traps right before dough stage, an insecticide application may be recommended if historical SB damage exceeded 1% of harvested nut crop (> 1% SB damage to nut kernels occurred in all pecan groves sampled in this study). There is a great potential for SBs to disperse to a pecan grove and damage pecan nuts if the pecan grove is adjacent to a SB preferred host, or a preferred landscape, like a forest tree line. The percentages of SB punctured and damaged pecan nuts will be reduced (ideally < 1% SB nut damage) after applying an insecticide against SBs to an adjacent preferred SB host like soybean or to the adjacent edge of a SB preferred landscape like a forest tree line. Similarly Leskey et al. (2012) showed that an intense targeted insecticide spray program against brown marmorated SBs resulted in a decrease in the overall percent injury and lowered the number of brown marmorated SBs captured. If the source of the SBs is unknown then the pecan grove should be sprayed with insecticide. A forest tree line can act as a physical barrier causing SBs to be blocked and build up in that pecan perimeter. Tillman (2014) showed that the number of adult SBs entering a host crop can be significantly reduced by the presence of either a synthetic or plant-based physical barrier. If there is a preferred host crop such as soybeans separated from the pecans by a forested tree line, the tree line will act as a barrier and prevent SBs from entering the pecan grove (this occurred in the pecan grove in Mayflower). If the preferred host crop is on the opposite side of the pecan grove it will cause the SBs that are coming from the preferred host to buildup in the pecan grove along the thick forest line which would increase SB damage on the pecans. Keeping the lower pecan tree canopy treated with a bifenthrin insecticide from dough stage to mature nut will help prevent pecan nut damage by SBs. Brigade WSB (bifenthrin) should provide good SB control for at least seven days or longer without rain (Cottrell and Ree 2012). Insecticide

treatments can end when the pecan shucks have split (after late-Sept.) and the pecans are fully mature when SB feeding no longer causes kernel damage. Other management techniques that could greatly reduce the amount of SB damage inflicted on pecans are to trim the pecan trees branches up so that the lower limbs are > 3 m above the ground (Cowell SB stratification study Chapter 4) along with maintaining short cut grass throughout the pecan grove which reduces the number of SBs caught (Toews 2010), and removing trash and debris from in and around the pecan grove that support SB numbers (Nessler (2008).-Further studies need to be done comparing several combinations of these practices to determine which successfully prevents SB damage to pecan nuts.

REFERENCES CITED

Aldrich, J.R., A. Khrimian & M.J. Camp. 2007. Methyl 2,4,6-decatrienoates attract stink bugs and tachinid parasitoids. J. Chem. Ecol. 33: 801-815.

Aldrich, J.R., M.P. Hoffmann, J.P. Kochansky, W.R. Lusby, J.E. Eger, and J.A. Payne. 1991. Identification and attractiveness of a major pheromone component for Nearctic *Euschistus* spp. stink bugs (Heteroptera: Pentatomidae). Environ. Entomol. 20: 477-483.

Carter, C.C., T.N. Thomas, D.L. Kline, T.E. Reagan, W.P. Barney. 1996. Insect and related pests of field crops. North Carolina Cooperative Extension Service AG-271.

Cottrell, T.E., W. Ree. 2012. Managing black pecan aphids and stink bugs. Southeastern Pecan Growers Meeting Proceedings. sepga.com/presentations/2012-presentations/.

Cottrell, T.E., C.E. Yonce, and B. W. Wood. 2000. Seasonal occurrence and vertical distribution of *Euschistus servus* (Say) and *Euschistus tristigmus* (Say) (Hemiptera: Pentatomidae) in pecan orchards. J. Entomol. Sci. 35: 421-431.

Cowell, B., D.T. Johnson, M.E. Garcia, and R. Mizell. 2015. Monitoring insect and pest damage in pecan in Arkansas. ISHS ActaHort. 1070:151-157.

Fehr, W.R., and C.E. Caviness. 1977. *Stages of soybean development.* Coop. Ext. Service Agric. Home Economics Expt. Stn., Iowa State University Special report 80, p. 12.

Gill, J.B. 1923. Important pecan insects and their control. USDA Farmers' Bull. No. 1364.

Gomez, C., and R.F. Mizell. 2008. Brown stink bug - *Euschistus servus* (Say). University of Florida. Dept. Entomol. and Nematol. Publ. EENY-433.

Herbert, J. J., and M.D. Toews. 2011. Seasonal abundance and population structure of brown stink bug (Hemiptera: Pentatomidae) in farmscapes containing corn, cotton, peanut, and soybean. Ann. Entomol. Soc. Am. 104: 909-918.

Hogmire, H.W., and T.C. Leskey. 2006. An improved trap for monitoring stink bugs (Heteroptera: Pentatomidae) in apple and peach orchards. J. Entomol. Sci. 41:9-21.

Hori, K. 2000. Possible causes of disease symptoms resulting from the feeding of phytophagous Heteroptera, p. 11-35. *In* Schaefer CW, Panizzi AR (eds) Heteroptera of economic importance. CRC Press, Boca Raton.

Hudson, W.J., and Pettis G.V. 2006. Pest management strategic plan for pecans in the Southeastern U.S. 39pp. Southern Region Integrated Pest Management Center.

Hudson, W. J. Brock, S. Culpepper, W. Mitchem, and L. Wells. 2011. Georgia pecan pest management guide. Georgia Pecan Grower's Assoc. Bull. 841:1-16.

Leskey, T.C., B.D. Short, B.R. Butler, and S.E. Wright. 2012. Impact of the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål), in Mid-Atlantic tree fruit orchards in the United States: case studies of commercial management. Psyche 2012: 1-14.

Martinson, H.M., P.D. Venugopal, E.J. Bergmann, P.M. Shrewsbury, and M.J. Raupp. 2015. Fruit availability influences the seasonal abundance of invasive stink bugs in ornamental tree nurseries. Published on line 25 June 2015. http://link.springer.com/article/10.1007/s10340-015-0677-8

McPherson, R.M., G.K. Douce, and R.D. Hudson. 1993. Annual variation in stink bug (Heteroptera: Pentatomidae) seasonal abundance and species composition in Georgia soybean and its impact on yield and quality. J. Entomol. Sci. 28: 61-72.

McPherson, J.E., and R.M. McPherson. 2000. Stink bugs of economic importance in America north of Mexico. CRS Press, New York.

Mizell, R.F. III, and W.L. Tedders. 1995. Use of the modified Tedders trap to monitor stink bugs in pecan. Proc. Southeastern Pecan Growers Assoc. 88:36-40.

Mizell, R.F. III, and W.L. Tedders, and J.A. Aldrich. 1997. Stink bug monitoring - an update. Proceedings of the Southeastern Pecan Growers Association 90: 50-52.

Mizell, R.F., T.C. Riddle, and A.S. Blount. 2008. Trap cropping system to suppress stink bugs in the Southern Coastal Plain. Proc. Fla. State Hort. Soc. 121:377–382.

Nessler, S. 2008. Pest management strategic plan for snap beans in Virginia, North Carolina, and Delaware. Southern Region IPM Center. http://www.ipmcenters.org/pmsp/pdf/VA-NC-DEsnapbeanPMSP.pdf

Osburn, M.R., W.C. Pierce, A.M. Phillips, J.R. Cole, and G.E. Kenbright. 1966. Controlling insects and diseases of pecans. USDA Agric. Handbook 240: Rev. 1-55.

Polk, D.F., H.W. Hogmire, and C.M. Felland. 1995. Peach-direct pests: stink bugs, pp. 51-52. *In* H.W. Hogmire (ed.), The Mid-Atlantic Orchard Monitoring Guide (NRAES-75). NRAES, Ithaca, New York.

Polles, S.G. 1977. Black pit and kernel spot of pecans: special emphasis on southern green stinkbug. Proc. Southeastern Pecan Growers Assn. 70:47-52.

Stewart, S., A.T. McClure, and R. Patrick. 2010. Soybean insects: stink bugs. University of Tennessee Institute of Agriculture W200.

Tillman, P.G, T.D. Northfield, R.F. Mizell, and T.C. Riddle. 2009. Spatiotemporal patterns and dispersal of stink bugs (Heteroptera: Pentatomidae) in peanut-cotton farmscapes. Environ. Entomol. 38: 1038-1052.

Toews, M.D. 2010. Stink bug ecology in southeastern farmscapes, pp. 72-77. *In* K. Stevenson (ed.), Proc. 103rd Annual Convention of the Southeastern Pecan Growers Association.

Velasco, L.R.I., and G.H. Walter. 1992. Availability of different host plant species and changing abundance of the polyphagous bug *Nezara viridula* (Hemiptera: Pentatomidae). Environ. Entomol. 21:751-759.

Venugopal, P.D., P.L. Coffey, G.P. Dively, and W.O. Lamp. 2014. Adjacent habitat influence on stink bug (Hemiptera: Pentatomidae) densities and the associated damage at field corn and soybean edges. PLoS One 9:e109917.

Wells, M.L., D.S. Carlson, and R.P. Edwards. 2009. Profitability of Mechanical Fruit Thinning of 'Sumner' and 'Cape Fear' Pecan. HortTechnology 19(3):518-520.

Wood, B.W. and W.L. Tedders. 1996. Stink bug feeding costs massive nut dropping in orchards. The Pecan Grower 7 (2):14.

Woodroof, J.G., and N.C. Woodroof. 1928. The dropping of pecans. Natl. Pecan Growers' Assn. Bull. 2(28):30-34.

Wright, M.W., P.A. Follett, and M. Golden. 2007. Long-term patterns and feeding sites of southern green stink bug (Hemiptera: Pentatomidae) in Hawaii macadamia orchards, and sampling for management decisions. Bull. Entomol. Res. 97: 569-575.

Yates, I.E., W.L. Tedders and D. Sparks. 1991. Diagnostic evidence of damage on pecan shells by stink bugs and coreid bugs. J. Amer. Soc. Hort. Sci. 116:42-46

Table 1. Total numbers of twelve stink bug species caught in each year in yellow pyramid traps baited with *Euschistus* aggregation pheromone in Arkansas pecan groves.

	Year (number of pecan groves)		
Stink bug species	**2012 (5)**	**2013 (5)**	**2014 (8)**
Brochymena quadripustulata	2	1	1
Chinavia hilaris	65	328	1,142
Euschistus ictericus	108	110	155
Euschistus servus	11,624	15,676	26,630
Euschistus tristigmus	400	648	1,663
Euschistus variolarius	67	48	2
Hymenarcys nervosa	2	9	9
Mormidea lugens	2	2	0
Oebalus pugnax	194	173	155
Podisus maculiventris	4	4	0
Trichopepla semivittata	1	0	0
Thyanta accera	51	23	18
TOTAL	12,520	17,022	29,775

Table 2. Mean numbers (± SE) of three stink bug (SB) species captured per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) in 2012, 2013 and 2014 at pecan groves in Arkansas.

Year Grove	**No. of traps**	**Mean No. Stink bugs (± SE) per trap**		
		Brown	**Dusky**	**Green**
2012				
Blackwell 1	134	24.9 ± 2.77	0.1 ± 0.02	0.1 ± 0.03
Blackwell 2	135	28.7 ± 3.82	0.7 ± 0.15	0.1 ± 0.03
Fayetteville	150	2.1 ± 0.29	0.0 ± 0.00	0.0 ± 0.00
Humphrey	134	21.8 ±1.91	1.8 ± 0.36	0.2 ± 0.05
Mayflower	135	9.2 ± 1.12	0.4 ± 0.07	0.1 ± 0.05
2013				
Blackwell 1	150	26.7 ± 2.36	0.2 ± 0.04	0.2 ± 0.05
Blackwell 2	150	37.5 ± 3.61	1.7 ± 0.37	0.9 ± 0.56
Fayetteville	150	4.0 ± 0.49	0.01 ± 0.0	0.2 ± 0.04
Humphrey	150	25.3 ± 2.18	1.5 ± 0.22	0.1 ± 0.04
Mayflower	150	11.15 ± 1.23	1.0 ± 0.16	0.8 ± 0.30

Table 2. (Cont.) By year and Arkansas pecan grove location, mean numbers (± SE) of three stink bug (SB) species captured per yellow pyramid trap (baited with *Euschistus* aggregation pheromone).

Year	**No. of**	**Mean No. SB ± SE per trap**		
Grove	**Trap samples**	**Brown**	**Dusky**	**Green**
2014				
Atkins	45	8.2 ± 1.40	0.7 ± 0.18	3.3 ± 1.00
Blackwell 1	135	81.2 ± 7.23	0.6 ± 0.09	0.7 ± 0.12
Blackwell 2	135	40.4 ± 4.58	0.9 ± 0.12	0.6 ± 0.10
Blackwell 3	54	15.3 ± 2.43	1.4 ± 0.30	6.5 ± 1.62
Blackwell 4	108	21.6 ± 2.30	0.7 ± 0.10	1.7 ± 0.61
Blackwell 5	30	4.1 ± 0.63	0.2 ± 0.10	0.3 ± 0.11
Humphrey	132	32.7 ± 2.68	8.4 ± 1.08	0.5 ± 0.13
Mayflower	135	16.58 ± 2.14	1.3 ± 0.20	1.5 ± 0.36

Table 3. Yearly total number of yellow pyramid traps (baited with *Euschistus* aggregation pheromone) and 10 nuts sampled with corresponding mean numbers (± SE) of stink bugs (SBs) and percentages of pecan nuts punctured or damaged by SBs in Arkansas pecan groves.

Year	Total No. trap samples	Mean No. SBs ± SE	Total No. of 10 nut samples	% mean punctured	% mean damaged
2012	673	18.0 ± 1.14 a	269	8.6	.
2013	750	22.2 ± 1.14 b	540	6.1	0.9
2014	774	38.0 ± 1.89 c	768	8.0	2.1

Means in same column with different letters are significantly different ($P < 0.05$)

Table 4. By year and Arkansas pecan grove location, the combined means (±SE) of the total numbers of brown, dusky, and green stink bugs (SBs) caught per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) and percentage of pecan nuts punctured or damaged.

Year Grove	**Total No. pyramid trap samples**	**Mean No. SB ± SE per trap**	**Total No. 10 nuts sampled**	**% mean punctured nuts**	**% mean damaged nuts**
2012					
Blackwell 1	134	25.1 ± 2.76 b	60	2.2	.
Blackwell 2	135	29.4 ± 3.94 a	60	1.7	.
Fayetteville	135	2.3 ± 0.32 d	.	.	.
Humphrey	134	23.7 ± 2.04 b	74	22.4	.
Mayflower	135	9.8 ± 1.14 c	75	5.5	.
2013					
Blackwell 1	150	27.0 ± 2.36 c	135	6.1	0.3
Blackwell 2	150	40.0 ± 3.85 a	135	4.3	0.1
Fayetteville	150	4.2 ± 0.50 e	.	.	.
Humphrey	150	26.9 ± 2.23 b	135	8.7	2.2
Mayflower	150	12.9 ± 1.31 d	135	5.5	1.0

Table 4. (Cont.) By year and Arkansas pecan grove location, the combined means (±SE) of the total numbers of brown, dusky, and green stink bugs (SBs) caught per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) and percentage of pecan nuts punctured or damaged.

Year Grove	**Total No. pyramid trap samples**	**Mean No. SB ± SE per trap**	**Total No. 10 nuts sampled**	**% mean punctured nuts**	**% mean damaged nuts**
2014					
Atkins	45	12.2 ± 2.07 d	54	7.6	1.9
Blackwell 1	135	82.5 ± 7.21 a	129	9.1	0.4
Blackwell 2	135	41.9 ± 4.62 b	135	7.9	0.4
Blackwell 3	54	23.1 ± 2.90 c	54	17.8	10.0
Blackwell 4	108	24.0 ± 2.51 c	105	6.3	1.2
Blackwell 5	30	4.6 ± 0.67 e	36	0.3	0.3
Humphrey	132	41.7 ± 3.47 e	135	10.2	4.2
Mayflower	135	19.4 ± 2.23 c	120	4.4	1.6

Means in same column with different letters are significantly different ($P < 0.05$)

Table 5. By Arkansas pecan grove location and habitat adjacent to pyramid traps, mean numbers of BSBs (± SE) captured and percentages of pecan nuts punctured (2012)

Grove Landscape	**No. traps**	**Mean No. BSBs ± SE per trap**	**No. 10 nut samples**	**% punctured**
Blackwell 1				
Center Grass	27	28.8 ± 7.19 a	12	0.8
East Fallow	27	19.4 ± 5.25 a	12	1.7
North Fallow	27	25.6 ± 5.49 a	12	3.3
South Levee	27	28.9 ± 7.32 a	12	3.3
West Fallow	26	21.7 ± 5.54 a	12	1.7
Mean total		24.9		2.2
Blackwell 2				
Center Grass	27	57.0 ± 14.70 a	12	1.7
East Rice	27	24.4 ± 6.97 b	12	0.0
North Rice	27	20.4 ± 5.08 b	12	0.8
South Soybean	27	17.2 ± 2.69 b	12	5.0
West Pasture	27	24.4 ± 6.28 b	12	0.8
Mean total		28.7		1.5

Means in same column with different letters are significantly different ($P < 0.05$)

Table 5. (Cont.) By Arkansas pecan grove location and habitat adjacent to pyramid traps, mean numbers of BSBs (± SE) captured and percentages of pecan nuts punctured (2012)

Grove	**No.**	**Mean No.**	**No. 10 nut**	
Landscape	**traps**	**BSBs ± SE per trap**	**samples**	**% punctured**
Fayetteville				
Center Grass	30	2.5 ± 0.95 a	.	.
East Pasture	30	2.0 ± 0.44 a	.	.
North Grass	30	1.1 ± 0.31 a	.	.
South Grass	30	2.9 ± 0.84 a	.	.
West Fallow	30	1.9 ± 0.48 a	.	.
Mean total		2.1	.	.
Humphrey				
Center Grass	27	21.8 ± 4.37 a	14	27.9
East Soybean	26	19.5 ± 3.39 a	15	28.7
North Trees	27	28.3 ± 5.97 a	15	32.7
South Soybean	27	18.0 ± 2.84 a	15	16.0
West Grass	27	21.4 ± 4.12 a	15	7.3
Mean total		21.8		22.5

Means in same column with different letters are significantly different ($P < 0.05$)

Table 5. (Cont.) By Arkansas pecan grove location and habitat adjacent to pyramid traps, mean numbers of BSBs (± SE) captured and percentages of pecan nuts punctured (2012)

Grove Landscape	**No.** **traps**	**Mean No.** **BSBs ± SE per trap**	**No. 10 nut** **samples**	**% punctured**
Mayflower				
Center Grass	27	11.3 ± 3.72 a	15	10.7
East Trees	27	9.8 ± 2.65 a	15	4.7
North Grass	27	6.9 ± 1.26 a	15	4.7
South Soybean	27	10.5 ± 2.63 a	15	4.7
West Grass	27	7.7 ± 1.50 a	15	2.7
Mean total		9.2		5.5

Means in same column with different letters are significantly different ($P < 0.05$)

Table 6. By Arkansas pecan grove location and habitat adjacent to traps, mean numbers of BSBs (± SE) captured per yellow pyramid trap (baited with *Euschistus* aggregation pheromone), and percentages of pecan nuts punctured and damaged (2013)

Grove Landscape	**No. traps**	**Mean No. BSBs ± SE per trap**	**No. 10 nut samples**	**% Puncture**	**% Damage**
Blackwell 1					
Center Grass	30	24.5 ± 4.04 a	27	11.1	0.4
East Fallow	30	17.8 ± 3.55 a	27	3.7	0.4
North Fallow	30	22.3 ± 4.82 a	27	2.6	0.4
South Levee	30	40.3 ± 7.62 a	27	8.5	0.0
West Fallow	30	28.4 ± 4.74 a	27	4.4	0.4
Mean total		26.7		6.1	0.3
Blackwell 2					
Center Grass	30	52.1 ± 11.16 a	27	6.7	0.0
East Rice	30	35.5 ± 6.97 a	27	4.1	0.0
North Rice	30	29.4 ± 6.97 a	27	2.6	0.0
South Soybean	30	32.3 ± 6.38 a	27	6.7	0.4
West Pasture	30	38.0 ± 7.89 a	27	1.5	0.0
Mean total		37.5		4.3	0.1

Means in same column with different letters are significantly different ($P < 0.05$)

Table 6. (Cont.) By Arkansas pecan grove location and habitat adjacent to traps, mean numbers of BSBs (± SE) captured per yellow pyramid trap (baited with *Euschistus* aggregation pheromone), and percentages of pecan nuts punctured and damaged (2013)

Grove Landscape	**No. traps**	**Mean No. BSBs ± SE per trap**	**No. 10 nut samples**	**% punctured**	**% damaged**
Fayetteville					
Center Grass	30	6.4 ± 1.54 a	.	.	.
East Pasture	30	1.9 ± 0.46 a	.	.	.
North Grass	30	3.6 ± 1.10 ab	.	.	.
South Grass	30	5.4 ± 1.11 a	.	.	.
West Fallow	30	2.9 ± 0.75 ab	.	.	.
Mean total		4.0			
Humphrey					
Center Grass	30	33.4 ± 6.16 a	27	14.0	3.7
East Soybean	30	13.7 ± 1.75 c	27	7.8	3.0
North Trees	30	24.4 ± 5.82 bc	27	9.3	1.5
South Soybean	30	30.2 ± 5.02 ab	27	5.6	1.1
West Grass	30	24.8 ± 3.78 ab	27	6.7	1.5
Mean total		25.3		8.7	2.2

Means in same column with different letters are significantly different ($P < 0.05$)

Table 6. (Cont.) By Arkansas pecan grove location and habitat adjacent to traps, mean numbers of BSBs (± SE) captured per yellow pyramid trap (baited with *Euschistus* aggregation pheromone), and percentages of pecan nuts punctured and damaged (2013)

Grove Landscape	**No. traps**	**Mean No. BSBs ± SE per trap**	**No. 10 nut samples**	**% punctured**	**% damaged**
Mayflower					
Center Grass	30	11.6 ± 2.71 a	27	5.9	0.4
East Trees	30	8.2 ± 1.78 a	27	10.0	1.5
North Grass	30	12.2 ± 3.08 a	27	3.3	0.4
South Soybean	30	16.4 ± 3.74 a	27	5.2	1.9
West Grass	30	7.3 ± 1.81 a	27	3.0	1.1
Mean total		11.1		5.5	1.1

Means in same column with different letters are significantly different (P < 0.05)

Table 7. By Arkansas pecan grove location and habitat adjacent to traps, mean numbers of BSBs (± SE) captured per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured and damaged (2014)

Grove Landscape	**No.** **traps**	**Mean No. BSBs ±** **SE per trap**	**No. 10 nut** **samples**	**% punctured**	**% damaged**
Atkins					
Center Grass	15	13.1 ± 2.73 a	18	3.9	1.1
East Soybean	15	4.7 ± 1.32 b	18	11.7	3.3
West Soybean	15	6.8 ± 2.54 b	18	7.2	1.1
Mean total		8.2		7.6	1.8
Blackwell 1					
Center Grass	27	92.4 ± 19.70 a	27	16.3	1.1
East Soybean	27	74.1 ± 16.50 a	27	7.4	0.4
North Fallow	27	63.8 ± 14.58 a	27	5.9	0.4
South Levee	27	83.1 ± 14.39 a	27	7.8	0.0
West Fallow	27	92.8 ± 15.53 a	21	7.6	0.0
Mean total		81.2		9.0	0.4

Means in same column with different letters are significantly different ($P < 0.05$)

Table 7. (Cont.) By Arkansas pecan grove location and habitat adjacent to traps, mean numbers of BSBs (± SE) captured per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured and damaged (2014)

Grove Landscape	**No.** **traps**	**Mean No. BSBs ±** **SE per trap**	**No. 10 nut** **samples**	**% punctured**	**% damaged**
Blackwell 2					
Center Grass	27	39.6 ± 11.57 a	27	17.8	1.1
East Rice	27	51.1 ± 11.13 a	27	4.4	0.0
North Rice	27	38.2 ± 10.98 a	27	3.3	0.0
South Soybean	27	30.5 ± 7.74 a	27	11.5	0.7
West Pasture	27	42.7 ± 9.69 a	27	2.2	0.4
Mean total		40.4		7.8	0.4
Blackwell 3					
North Trees	27	8.0 ± 1.81 b	27	14.4	7.4
South Soybean	27	22.6 ± 4.08 a	27	21.1	12.6
Mean total		15.3		17.8	10.0

Table 7. (Cont.) By Arkansas pecan grove location and habitat adjacent to traps, mean numbers of BSBs (± SE) captured per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured and damaged (2014)

Grove Landscape	**No. traps**	**Mean No. BSBs ± SE per trap**	**No. 10 nut samples**	**% punctured**	**% damaged**
Blackwell 4					
Center Grass	27	38.6 ± 5.32 a	27	8.2	1.5
East Rice	27	16.7 ± 3.67 b	24	3.8	0.4
South Grass	27	15.5 ± 3.16 b	27	7.0	2.6
West Soybean	27	15.6 ± 4.52 b	27	5.9	0.4
Mean total		21.6		6.2	1.2
Blackwell 5					
East Rice	15	5.1 ± 1.03 a	18	0.6	0.6
West Levee	15	3.1 ± 0.67 a	18	0.0	0.0
Mean total		4.1		0.3	0.3

Means in same column with different letters are significantly different (P < 0.05)

Table 7. (Cont.) By Arkansas pecan grove location and habitat adjacent to traps, mean numbers of BSBs (± SE) captured per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured and damaged (2014)

Grove Landscape	**No. traps**	**Mean No. BSBs ± SE per trap**	**No. 10 nut samples**	**% punctured**	**% damaged**
Humphrey					
Center Grass	27	36.5 ± 4.26 ab	27	7.0	1.1
East Rice	24	25.2 ± 4.02 bc	27	13.7	4.8
North Trees	27	49.2 ± 9.48 a	27	19.6	7.8
South Rice	27	24.6 ± 4.48 c	27	0.4	0.0
West Grass	27	27.3 ± 4.45 bc	27	10.4	7.4
Mean total		32.6		10.2	4.2
Mayflower					
Center Grass	27	16.6 ± 3.38 ab	24	2.5	0.8
East Trees	27	11.2 ± 4.92 b	24	5.4	0.8
North Grass	27	11.4 ± 1.87 b	24	1.3	0.0
South Soybean	27	36.3 ± 7.44 a	24	12.5	6.3
West Grass	27	7.4 ± 1.89 c	24	0.4	0.0
Mean total		16.6		4.4	1.6

Means in same column with different letters are significantly different ($P < 0.05$)

Table 8. Early season sample dates by pecan grove location of mean numbers of brown stink bugs ± SE per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) (2012) (N=15)

	20-Jun	**5-Jul**	**30-Jul**	**16-Aug**	**Early season mean total**
Blackwell 1	97.1 ± 7.72 a	49.4 ± 4.77 b	10.7 ± 2.04 d	12.8 ± 1.04 d	**42.5**
Blackwell 2	109.7 ± 19.54 a	61.5 ± 11.18 b	19.2 ± 5.93 cd	12.9 ± 3.41 de	**50.8**
Fayetteville	9.5 ± 1.62 a	3.4 ± 0.75 b	2.5 ± 0.4 b	2.7 ± 0.57 b	**4.5**
Humphrey	16.7 ± 2.74 c	7.5 ± 1.54 d	0.6 ± 0.24 f	2.0 ± 0.4 e	**6.7**
Mayflower	26.9 ± 6.59 a	19.1 ± 3.03 a	3.3 ± 0.80 c	3.1 ± 0.54 c	**13.1**

Means in same column with different letters are significantly different ($P < 0.05$)

Table 9. Late season sample dates by pecan grove location of mean numbers of brown stink bugs ± SE per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured (2012) (N=15)

	29-Aug	**13-Sep**	**27-Sep**	**10-Oct**	**25-Oct**	**Late season mean total**
Blackwell 1						
Stink bug	32.3 ± 2.31 c	10.7 ± 1.55 d	4.5 ± 0.82 e	3.7 ± 0.68 e	3.3 ± 0.49 e	**10.9**
% Punctured	0.0	0.2	0.4	0.3	.	**0.2**
Blackwell 2						
Stink bug	20.1 ± 2.6 c	8.1 ± 0.62 e	14.3 ± 2.0 cd	4.7 ± 0.75 f	7.7 ± 1.09 e	**11.0**
% Punctured	0.0	0.2	0.3	0.2	.	**0.2**
Fayetteville						
Stink bug	0.8 ± 0.24 cd	1.0 ± 0.28 c	0.3 ± 0.12 de	0.3 ± 0.15 de	0.4 ± 0.16 cde	**0.6**
% Punctured	.	.	.	.	.	

Means in same row with different letters are significantly different (P < 0.05)

Table 9. (Cont.) Late season sample dates by pecan grove location of mean numbers of brown stink bugs ± SE per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured (2012) (N=15)

	29-Aug	**13-Sep**	**27-Sep**	**10-Oct**	**25-Oct**	**Late season mean total**
Humphrey						
Stink bug	48.5 ± 6.56 a	38.4 ± 8.25 b	29.3 ± 2.95 b	24.3 ± 2.16 b	29.5 ± 4.61 b	**34.0**
% Punctured	1.9	2.3	2.1	2.1	2.9	**2.1**
Mayflower						
Stink bug	14.5 ± 1.88 ab	10.1 ± 1.45 b	1.4 ± 0.27 d	1.3 ± 0.41 d	3.7 ± 0.87 c	**6.2**
% Punctured	0.4	0.5	0.7	0.7	0.4	**0.54**

Means in same row with different letters are significantly different ($P < 0.05$)

Table 10. Early season sample dates by pecan grove location of mean numbers of brown stink bugs ± SE per (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured and damaged (2013) (N=15)

	26-Jun	**9-Jul**	**23-Jul**	**9-Aug**	**20-Aug**	**Early season mean total**
Blackwell 1						
Stink bug	46.8 ± 5.76 a	43.5 ± 5.24 a	63.2 ± 12.2 a	46.3 ± 6.87 a	25.7 ± 4.72 b	**45.1**
% Puncture	.	6.7	12.7	8.0	7.3	**8.7**
% Damage	.	0.0	0.0	0.0	0.0	**0.0**
Blackwell 2						
Stink bug	50.1 ± 6.26 b	106.9 ± 11.98 a	98.1 ± 11.58 a	58.4 ± 6.97 b	29.1 ± 3.31 c	**68.5**
% Puncture	.	5.3	9.3	6.7	5.3	**6.7**
% Damage	.	0.0	0.0	0.0	0.0	**0.0**

Means in same row with different letters are significantly different ($P < 0.05$)

Table 10. (Cont.) Early season sample dates by pecan grove location of mean numbers of brown stink bugs ± SE per (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured and damaged (2013) (N=15)

	26-Jun	**9-Jul**	**23-Jul**	**9-Aug**	**20-Aug**	**Early season mean total**
Fayetteville						
Stink bug	0.9 ± 0.27 f	4.3 ± 1.26 c	15.1 ± 2.21 a	9.6 ± 1.52 b	4.3 ± 0.79 c	**6.8**
% Puncture	.	.	.	.	.	**.**
% Damage	.	.	.	.	.	**.**
Humphrey						
Stink bug	60.4 ± 7.61 a	57.5 ± 11.99 ab	19.5 ± 3.07 de	32.7 ± 4.17 bc	16.0 ± 2.51 e	**37.2**
% Puncture	.	7.3	7.3	4.0	4.7	**5.8**
% Damage	.	0.0	0.0	0.0	0.0	**0.0**
Mayflower						
Stink bug	16.3 ± 3.83 b	12.1 ± 3.88 bc	16.9 ± 1.72 b	38.6 ± 5.72 a	14.3 ± 2.56 b	**19.6**
% Puncture	.	3.3	8.0	6.0	8.0	**6.3**
% Damage	.	0.0	0.0	0.0	4.0	**1.0**

Means in same row with different letters are significantly different ($P < 0.05$)

Table 11. Late season sample dates by pecan grove location of mean numbers of brown stink bugs ± SE per (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured and damaged (2013) (N=15) (2013) (N=15)

Grove						**Late season**
Counts	**4-Sep**	**18-Sep**	**2-Oct**	**16-Oct**	**30-Oct**	**mean total**
Blackwell 1						
Stink bug	14.1 ± 2.57 c	6.1 ± 1.36 d	9.9 ± 1.73 c	5.7 ± 1.13 d	5.6 ± 1.46 d	**8.3**
% Puncture	4.7	4.7	2.7	2.7	5.3	**4.0**
% Damage	1.3	0.0	0.0	1.3	0.0	**0.5**
Blackwell 2						
Stink bug	11.9 ± 2.27 d	9.7 ± 1.50 d	4.5 ± 0.79 e	4.4 ± 0.56 e	1.5 ± 0.39 f	**6.4**
% Puncture	2.7	2.0	2.7	2.7	2.0	**2.4**
% Damage	0.0	0.7	0.0	0.0	0.0	**0.1**
Fayetteville						
Stink bug	1.3 ± 0.41 f	2.3 ± 0.50 d	1.9 ± 0.55 e	0.4 ± 0.21 f	0.0 ± 0.00 g	**1.2**
% Puncture	.	.	.	.	.	**.**
% Damage	.	.	.	.	.	**.**

Means in same row with different letters are significantly different ($P < 0.05$)

Table 11. (Cont.) Late season sample dates by pecan grove location of mean numbers of brown stink bugs ± SE per (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured and damaged (2013) (N=15) (2013) (N=15)

	4-Sep	**18-Sep**	**2-Oct**	**16-Oct**	**30-Oct**	**Late season mean total**
Humphrey						
Stink bug	8.2 ± 1.35fg	5.3 ± 0.50g	12.4 ± 1.71ef	23.9 ± 2.32cd	16.9 ± 4.43e	**13.3**
% Puncture	5.3	6.7	10.0	16.7	16.7	**11.0**
% Damage	0.0	0.7	4.7	5.3	8.7	**3.9**
Mayflower						
Stink bug	7.9 ± 1.35c	1.2 ± 0.37e	1.2 ± 0.33e	2.9 ± 0.61d	0.0 ± 0.00e	**2.6**
% Puncture	4.7	4.0	6.7	6.0	2.7	**4.8**
% Damage	2.0	0.7	1.3	1.3	0.0	**1.1**

Means in same row with different letters are significantly different ($P < 0.05$)

Table 12. Early season sample dates by pecan grove location of mean numbers of brown stink bugs ± SE per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured and damaged (2014)

Grove Count	**No. samples**	**2-Jul**	**16-Jul**	**30-Jul**	**12-Aug**	**Early season mean total**
Atkins	(N=9)					
Stinkbug		.	.	.	.	**N/A**
% Puncture		.	.	.	3.3	**N/A**
% Damage		.	.	.	0.0	**N/A**
Blackwell 1	(N=15; 12 after 9/26)					
Stinkbug		101.9 ± 13.06b	253.3 ± 23.12a	121.7 ± 12.89b	107.5 ± 11.02b	**146.1**
% Puncture		6.7	10.0	13.3	11.3	**10.3**
% Damage		0.0	0.0	0.0	0.0	**0.0**
Blackwell 2	(N=15)					
Stinkbug		61.5 ± 10.15b	159.5 ± 16.81a	38.9 ± 5.17c	37.7 ± 5.92c	**74.4**
% Puncture		2.0	4.7	12.0	11.3	**7.5**
% Damage		0.0	0.0	0.0	1.3	**0.3**

Means in same row with different letters are significantly different ($P < 0.05$)

Table 12. (Cont.) Early season sample dates by pecan grove location of mean numbers of brown stink bugs ± SE per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured and damaged (2014)

Grove Count	**No. samples**	**2-Jul**	**16-Jul**	**30-Jul**	**12-Aug**	**Early season mean total**
Blackwell3	(N=6)					
Stinkbug		32.3 ± 10.25ab	38.5 ± 10.00a	17.2 ± 4.79c	19.2 ± 6.18bc	**26.8**
% Puncture		1.7	15.0	8.3	6.7	**7.9**
% Damage		0.0	0.0	1.7	0.0	**0.4**
Blackwell4	(N=12)					
Stinkbug		54.1 ± 10.95a	36.0 ± 8.22a	11.7 ± 3.28bc	11.3 ± 2.09b	**28.3**
% Puncture		5.0	7.5	8.3	5.0	**6.5**
% Damage		0.0	0.0	0.0	0.0	**0.0**
Blackwell5	(N=6)					
Stinkbug		.	.	.	.	**.**
% Puncture		.	.	.	0.0	**N/A**
% Damage		.	.	.	0.0	**N/A**

Means in same row with different letters are significantly different (P < 0.05)

Table 12. (Cont.) Early season sample dates by pecan grove location of mean numbers of brown stink bugs ± SE per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured and damaged (2014)

Grove Count	**No.** **samples**	**2-Jul**	**16-Jul**	**30-Jul**	**12-Aug**	**Early season** **mean total**
Humphrey	(N=15)					
Stinkbug		70.8 ± 13.83a	53.3 ± 8.01ab	24.2 ± 5.16de	16.3 ± 3.00ef	**41.2**
%Puncture		2.0	3.3	4.7	4.0	**3.5**
%Damage		0.0	0.0	0.0	0.0	**0.0**
Mayflower	(N=15)					
Stinkbug		49.3 ± 11.55a	35.5 ± 8.64ab	8.2 ± 2.84cd	8.3 ± 2.78cd	**25.3**
%Puncture		.	2.7	1.3	1.3	**1.8**
%Damage		.	0.0	0.0	0.0	**0.0**

Means in same row with different letters are significantly different (P < 0.05)

Table 13. Late season sample dates by pecan grove location of mean numbers of brown stink bugs ± SE per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured and damaged (2014)

Grove Counts	**No. samples**	**28-Aug**	**12-Sep**	**26-Sep**	**18-Oct**	**24-Oct**	**Late season mean total**
Atkins	(N=9)						
Stink bug		12.7 ± 4.69a	4.7 ± 1.55b	6.4 ± 1.82ab	14.1 ± 3.68a	3.1 ± 0.61b	**8.2**
% Puncture		5.6	7.8	12.2	7.8	8.9	**8.4**
% Damage		0.0	1.1	3.3	4.4	2.2	**2.2**
Blackwell 1	(N=15; 12 after 9/26)						
Stink bug		49.3 ± 6.10c	34.4 ± 7.88d	31.1 ± 7.51d	24.2 ± 2.85d	7.7 ± 0.65e	**29.3**
% Puncture		11.3	8.0	8.7	4.2	6.7	**7.7**
% Damage		0.7	0.0	0.0	1.7	1.7	**0.8**
Blackwell 2	(N=15)						
Stink bug		21.6 ± 3.41d	19.5 ± 3.65d	10.9 ± 2.52e	10.6 ± 1.64e	3.4 ± 0.5e	**13.2**
% Puncture		8.7	10.0	12.0	6.0	4.0	**8.3**
% Damage		2.0	0.0	0.7	0.0	0.0	**0.5**

Means in same row with different letters are significantly different ($P < 0.05$)

Table 13. (Cont.) Late season sample dates by pecan grove location of mean numbers of brown stink bugs ± SE per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured and damaged (2014)

Grove Counts	**No.** **samples**	**28-Aug**	**12-Sep**	**26-Sep**	**18-Oct**	**24-Oct**	**Late season** **mean total**
Blackwell 3	(N=6)						
Stink bug		4.8 ± 0.87d	4.2 ± 1.42d	2.7 ± 1.38d	12.8 ± 4.49c	5.7 ± 1.50d	**6.1**
% Puncture		1.7	3.3	11.7	50.0	61.7	**25.6**
% Damage		0.0	1.7	6.7	36.7	43.3	**17.7**
Blackwell 4	(N=12)						
Stink bug		14.6 ± 2.58b	31.2 ± 7.13a	15.3 ± 3.62b	15.1 ± 3.34b	5.3 ± 1.04c	**16.3**
% Puncture		4.2	3.3	7.5	4.2	13.3	**6.5**
% Damage		0.0	0.0	1.7	4.2	6.7	**2.5**
Blackwell 5	(N=6)						
Stink bug		2.5 ± 1.15a	4.8 ± 2.30a	5.3 ± 1.59a	4.7 ± 0.99a	3.2 ± 0.60a	**4.1**
% Puncture		0.0	0.0	1.7	0.0	0.0	**0.3**
% Damage		0.0	0.0	1.7	0.0	0.0	**0.3**

Means in same row with different letters are significantly different ($P < 0.05$)

Table 13. (Cont.) Late season sample dates by pecan grove location of mean numbers of brown stink bugs ± SE per yellow pyramid trap (baited with *Euschistus* aggregation pheromone) and percentages of pecan nuts punctured and damaged (2014)

Grove Counts	**No. samples**	**28-Aug**	**12-Sep**	**26-Sep**	**18-Oct**	**24-Oct**	**Late season mean total**
Humphrey	(N=15)						
Stink bug		21.7 ± 3.80de	25.1 ± 4.82de	37.6 ± 5.71bc	33.2 ± 5.90cd	11.2 ± 1.52f	**25.7**
% Puncture		6.0	9.3	16.0	22.0	24.7	**17.6**
% Damage		2.0	2.0	4.7	14.0	15.3	**7.6**
Mayflower	(N=15)						
Stink bug		12.5 ± 2.78c	19.7 ± 3.71b	6.5 ± 1.5d	6.3 ± 2.16cd	2.9 ± 0.69d	**9.6**
% Puncture		3.3	2.0	4.7	9.3	10.7	**6.0**
% Damage		0.0	0.0	0.7	7.3	4.7	**2.5**

Means in same row with different letters are significantly different ($P < 0.05$)

APPENDICES

Table A.1. Pecan grove management tactics used by pecan grove (2012)

Grove	**Herbicide under trees**	**Mowed**	**Debris removed**	**Trimmed**	**Date (insecticide applied)**
Blackwell 1	Yes	regularly	yes	slightly	8-15 & 8-25 (pyrethroid)
Blackwell 2	Yes	regularly	yes	slightly	8-20 & 9-1 (pyrethroid)
Fayetteville	no	rarely	no	rarely	none
Mayflower	no	occasionally	occasionally	no	8-22, 9-5 & 9-19 (pyrethroid)
Humphrey	no	regularly	yes	no	none

Table A.2. Pecan grove management tactics used by pecan grove (2013)

Grove	**Herbicide under trees**	**Mowed**	**Debris removed**	**Trimmed**	**Date (insecticide applied)**
Blackwell 1	Yes	regularly	yes	slightly	8-15 & 8-25 (pyrethroid)
Blackwell 2	Yes	regularly	yes	high (> 3 m)	none
Fayetteville	no	rarely	no	rarely	none
Mayflower	no	occasionally	occasionally	no	8-22, 9-5 & 9-19 (pyrethroid)
Humphrey	no	regularly	yes	no	8-15 & 8-28 (pyrethroid)

Table A.3. Pecan grove management tactics used by pecan grove (2014)

2014

Grove	Herbicide under trees	Mowed	Debris removed	Trimmed	Date (insecticide applied)
Atkins	Yes	regularly	yes	no (branches on ground)	5-8, 6-14, 7-12, 8-1 & 8-19 (chlorpyrifos)
Blackwell 1	Yes	regularly	yes	slightly	8-15 & 8-25 (pyrethroid)
Blackwell 2	Yes	regularly	yes	high (> 4 m)	none
Blackwell 3	no	very rarely	no	no	none
Blackwell 4	no	occasionally	occasionally	no	none
Blackwell 5	Yes	regularly	yes	high (> 4 m)	none
Mayflower	no	regularly	occasionally	high (> 3 m)	none
Humphrey	no	regularly	yes	no	none

Table A.4. The phenological stages of pecan nuts for each year and pecan grove location by collection date (legend at top).

N = Nutlet	NE = Nuts Expanding	WS = Water stage	W/G = Water / Gel stage	G = Gel stage	G/D = Gel / Dough stage	D = Dough stage	D/M = Dough stage / Mature	M = Mature	H = Harvest

2012	**20-Jun**	**5-Jul**		**30-Jul**		**16-Aug**	**29-Aug**	**12-Sep**	**26-Sep**	**10-Oct**	**24-Oct**
Blackwell 1	N	N		NE		WS	G/D	D	M	M	H
Blackwell 2	N	N		NE		WS	G/D	G/D	D/M	M	H
Fayetteville	N	NE		WS		G	G	D	D/M	M	M
Humphrey	N	N		N		NE	WS	G	G/D	D	M
Mayflower	N	N		N		NE	WS	G	G/D	D/M	M
2013	**26-Jun**	**9-Jul**	**23-Jul**		**9-Aug**	**20-Aug**	**4-Sep**	**18-Sep**	**3-Oct**	**16-Oct**	**30-Oct**
Blackwell 1	N	N	NE		WS	G	D	M	M	H	H
Blackwell 2	N	N	NE		WS	W/G	G/D	D/M	M	H	H
Fayetteville	N	NE	WS		WS	G	G	D	D/M	M	M
Humphrey	N	N	N		NE	WS	G	G/D	D	M	M
Mayflower	N	N	N		NE	WS	G	G/D	D	M	M

Table A.4. (Cont.) The phenological stages of pecan nuts for each year and pecan grove location by collection date (legend at top).

N = Nutlet	NE = Nuts Expanding	WS = Water stage	W/G = Water / Gel stage	G = Gel stage	G/D = Gel / Dough stage	D = Dough stage	D/M = Dough stage / Mature	M = Mature	H = Harvest

2014	2-Jul	16-Jul	29-Jul	12-Aug	28-Aug	11-Sep	26-Sep	17-Oct	25-Oct
Adkins	.	.	.	WS	G	D	D/M	M	M
Blackwell 1	N	N	NE	WS	G	D	M	H	H
Blackwell 2	N	N	NE	WS	W/G	G/D	M	H	H
Blackwell 3	N	N	N	NE	WS	G	G/D	D	M
Blackwell 4	N	N	NE	WS	G	D	M	M	M
Blackwell 5	.	.	.	WS	W/G	G/D	M	H	H
Humphrey	N	N	N	NE	WS	G	G/D	D	M
Mayflower	N	N	N	NE	WS	G	G/D	D	M

Figure A.1. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured by stink bugs (SBs) in Blackwell 1 pecan grove (2012). Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south and W = west)

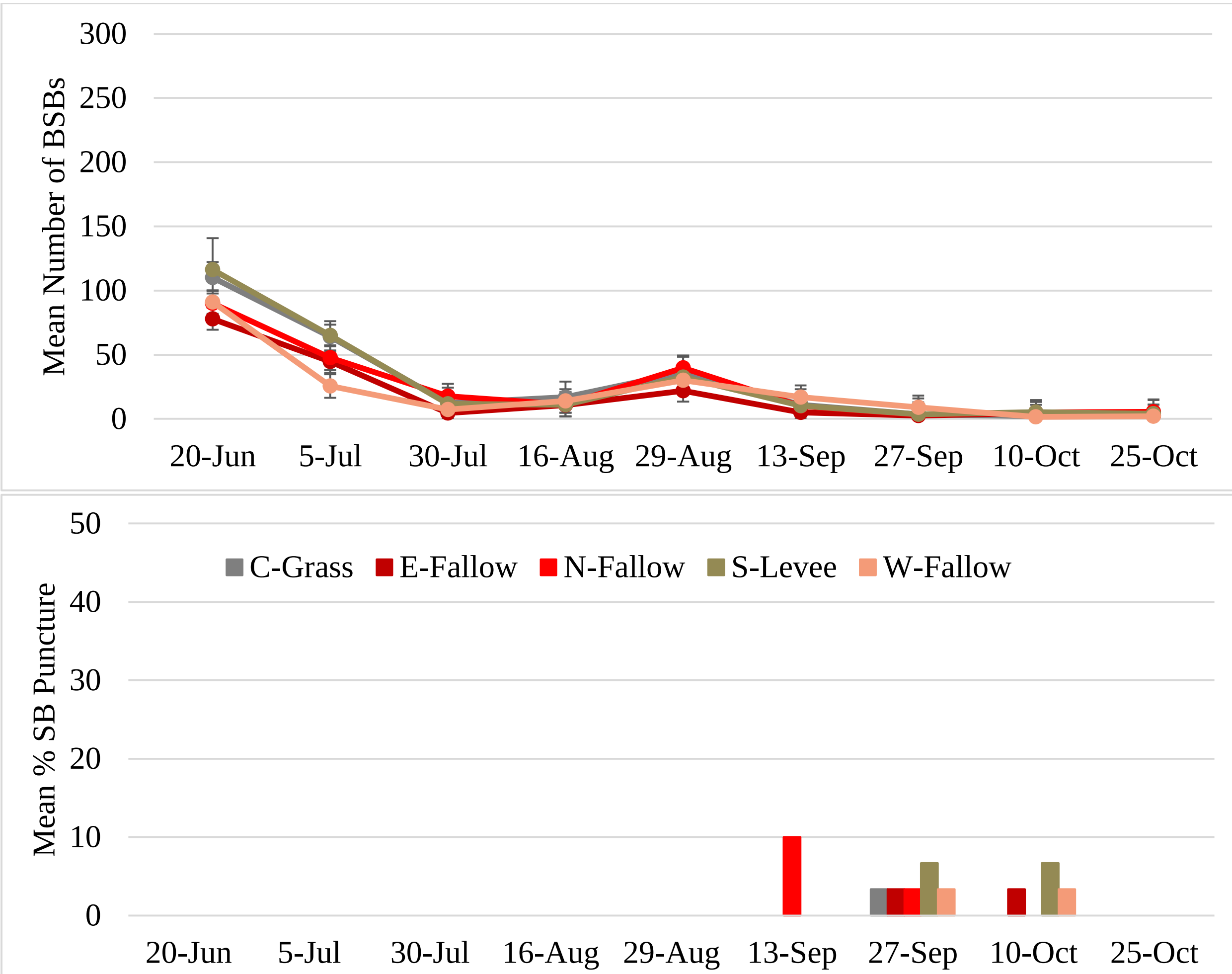


Figure A.2. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured by stink bugs (SBs) in Blackwell 2 pecan grove (2012). Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south and W = west; Soy = soybean)

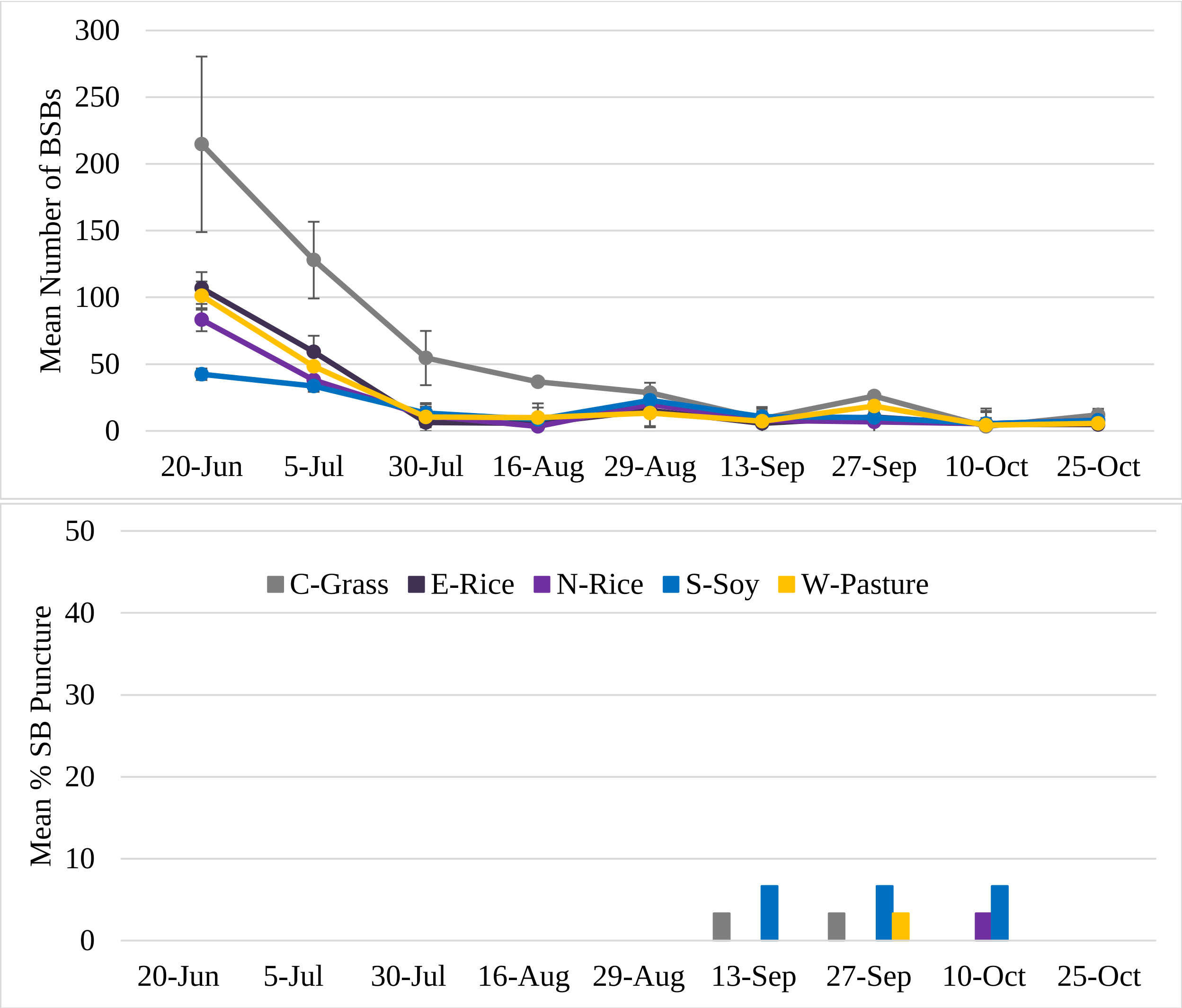


Figure A.3. Mean numbers (± SE) of brown stink bugs (BSBs) in Fayetteville pecan grove (2012). Not enough pecans were present to estimate the mean % nut puncture. Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south and W = west)

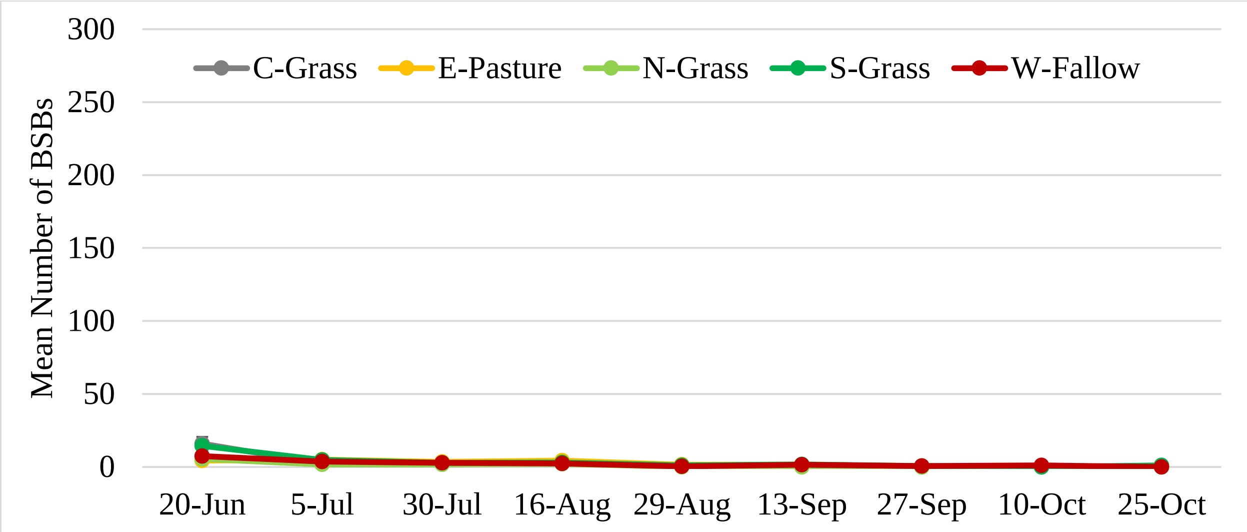


Figure A.4. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured by stink bugs (SBs) in Humphrey pecan grove (2012). Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south and W = west; Soy = soybean, Trees = forest tree line)

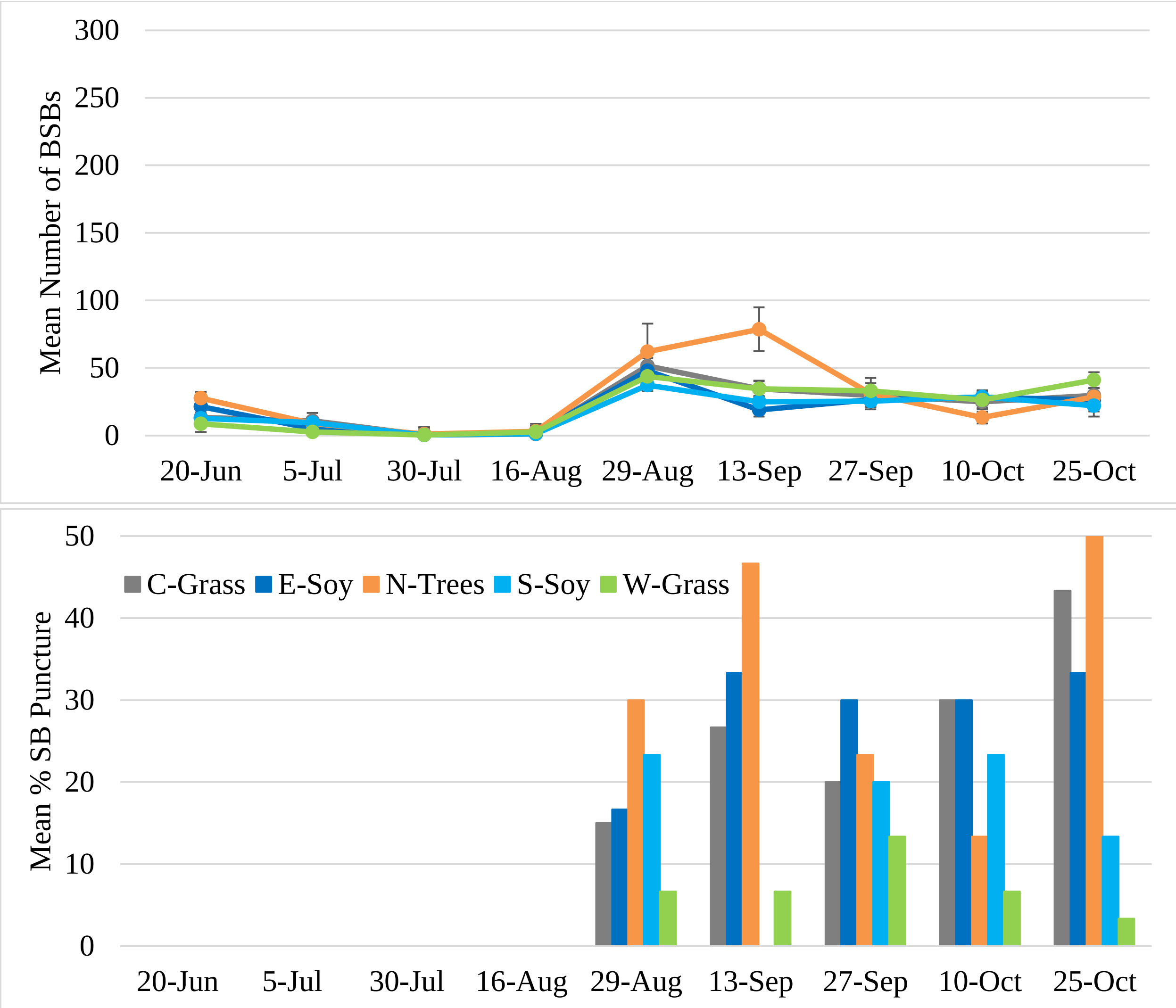


Figure A.5. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured by stink bugs (SBs) in Mayflower pecan grove (2012). Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south and W = west; Soy = soybean, Trees = forest tree line)

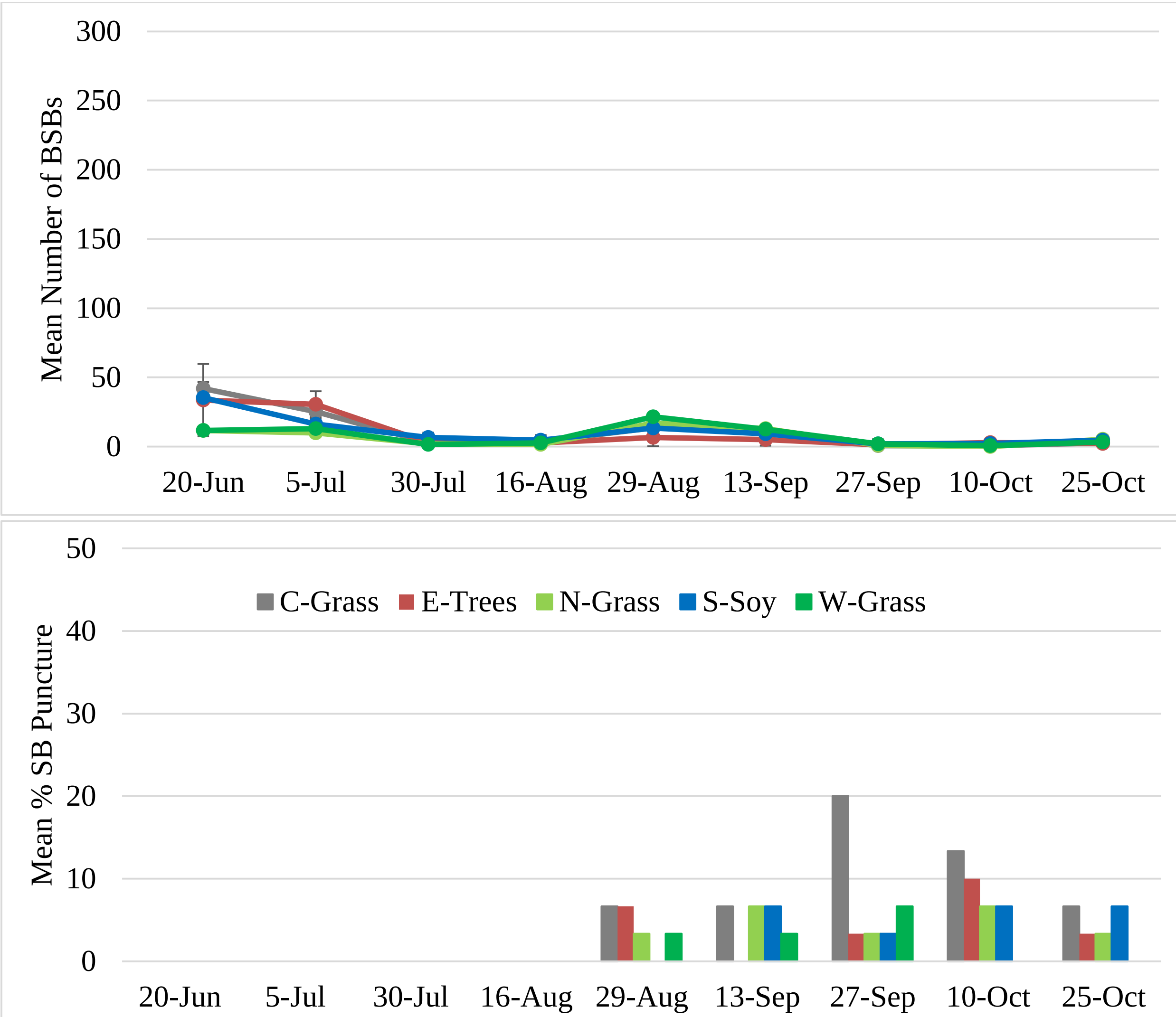


Figure A.6. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured or damaged by stink bugs (SBs) in Blackwell 1 pecan grove (2013). Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south and W = west)

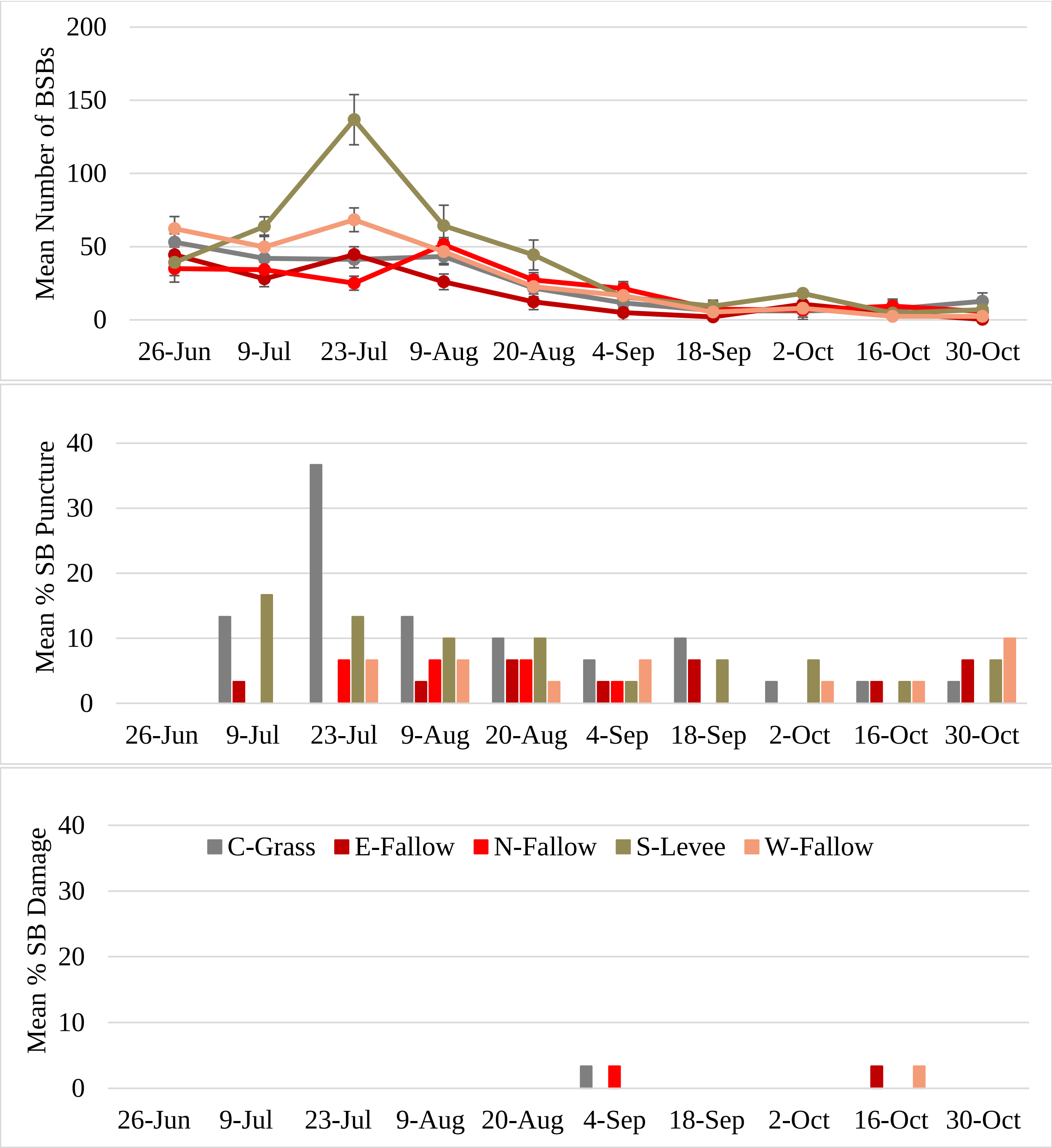


Figure A.7. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured or damaged by stink bugs (SBs) in Blackwell 2 pecan grove (2013). Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south and W = west; Soy = soybean)

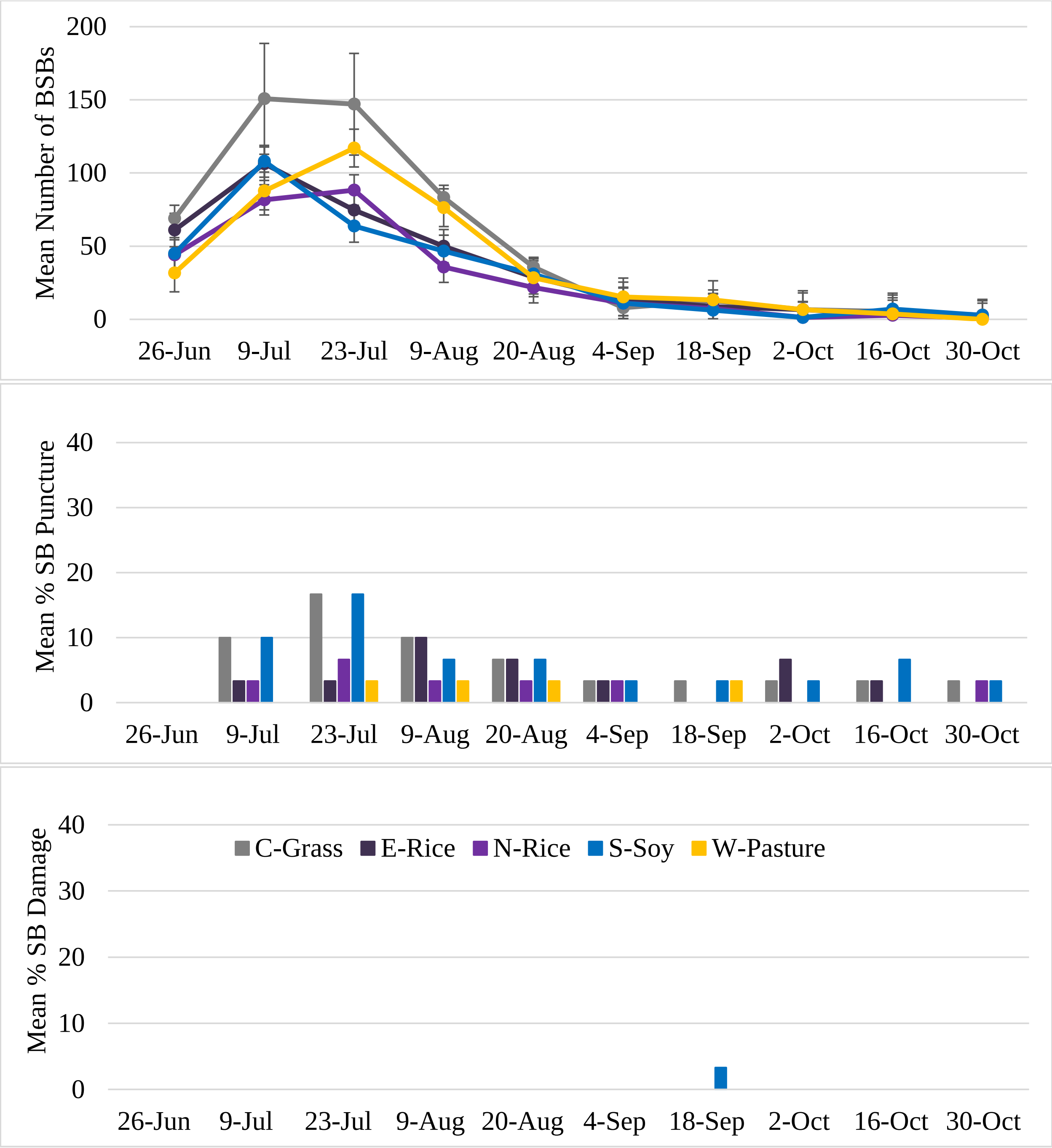


Figure A.8. Mean numbers (± SE) of brown stink bugs (BSBs) in Fayetteville pecan grove (2013). Not enough pecans were present to estimate the mean % nut puncture and damage. Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south and W = west)

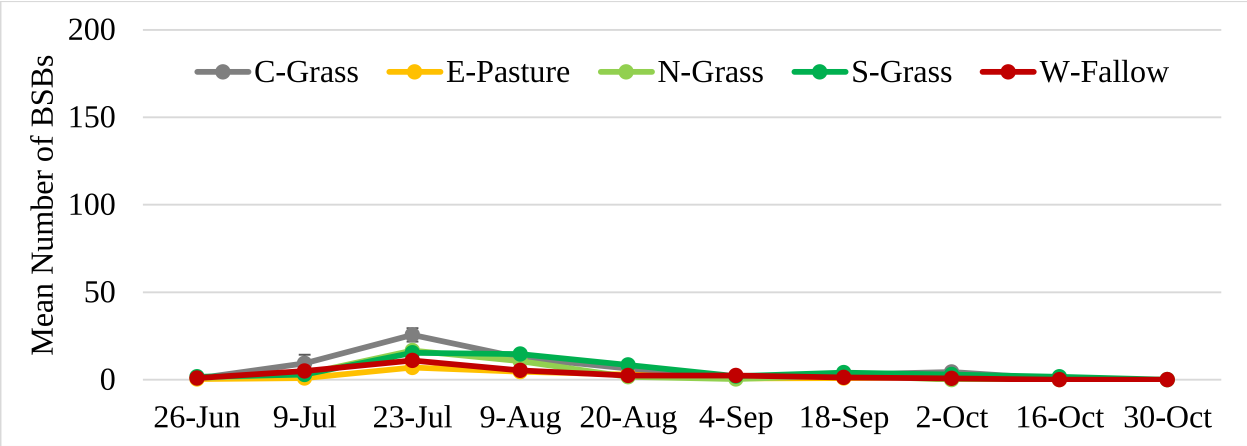


Figure A.9. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured or damaged by stink bugs (SBs) in Humphrey pecan grove (2013). Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south W = west; Soy = soybean, Trees = forest tree line)

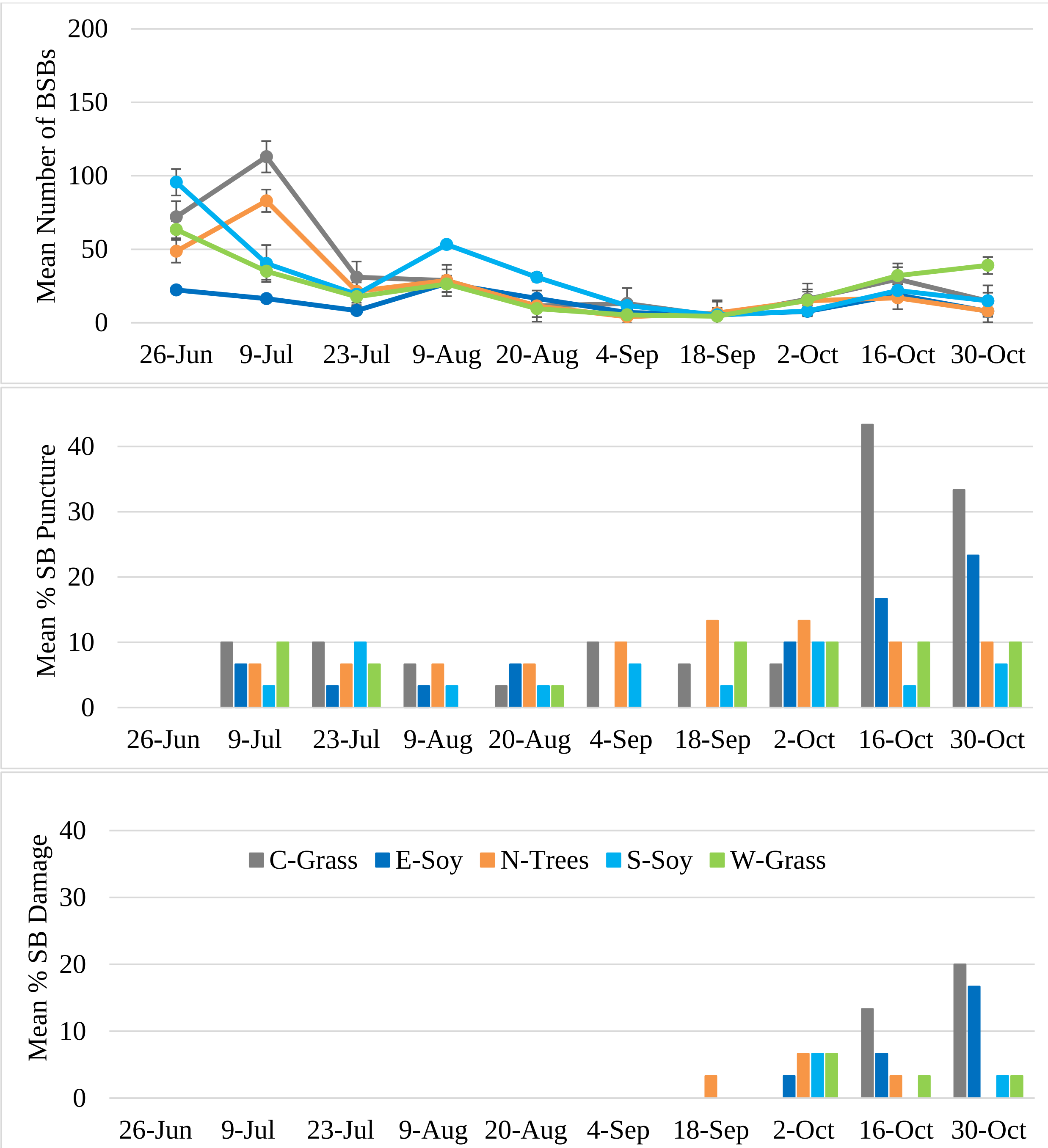


Figure A.10. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured or damaged by stink bugs (SBs) in Mayflower pecan grove (2013). Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south W = west; Soy = soybean, Trees = forest tree line)

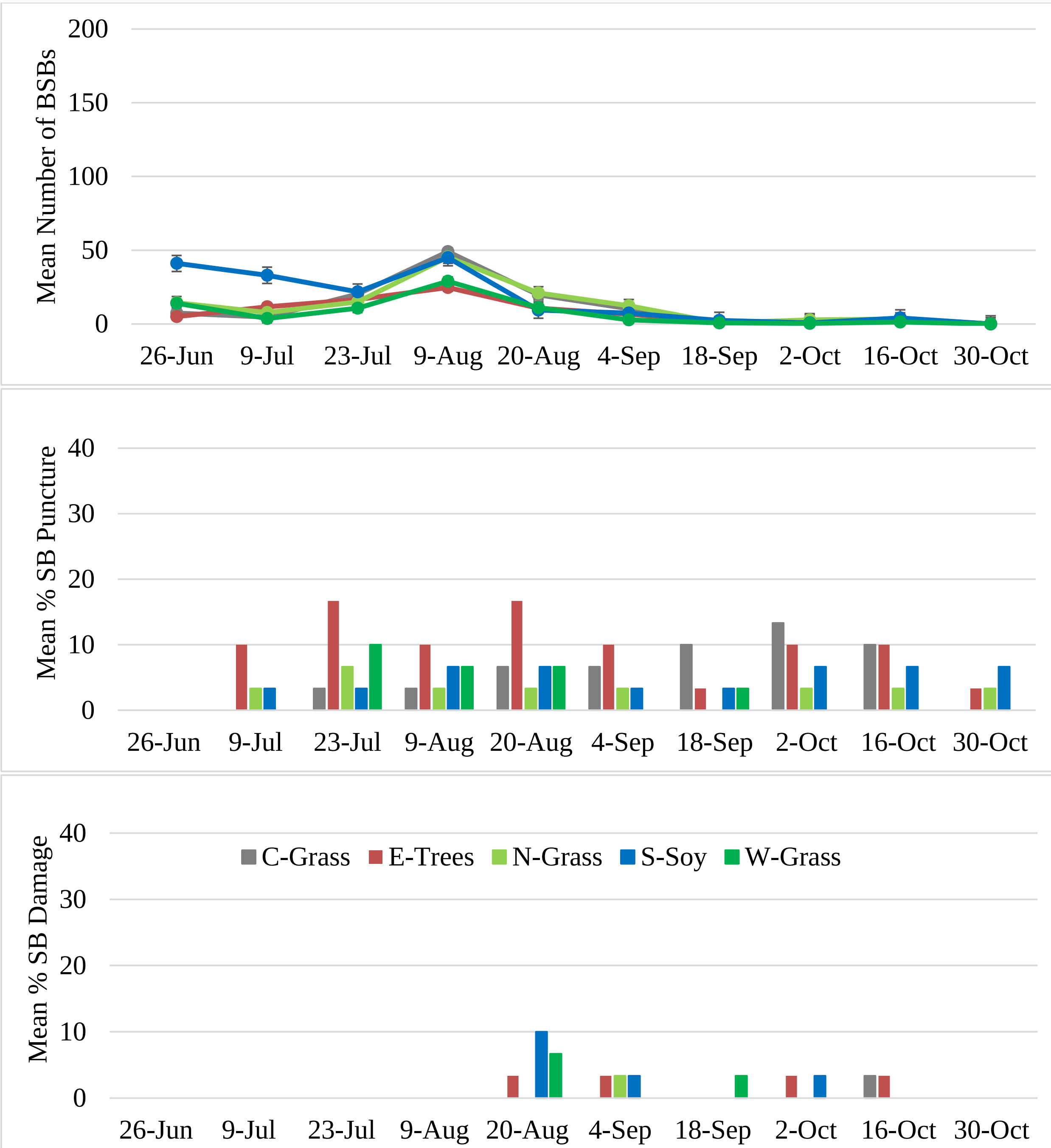


Figure A.11. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured or damaged by stink bugs (SBs) in Atkins pecan grove (2014). . Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south W = west; Soy = soybean)

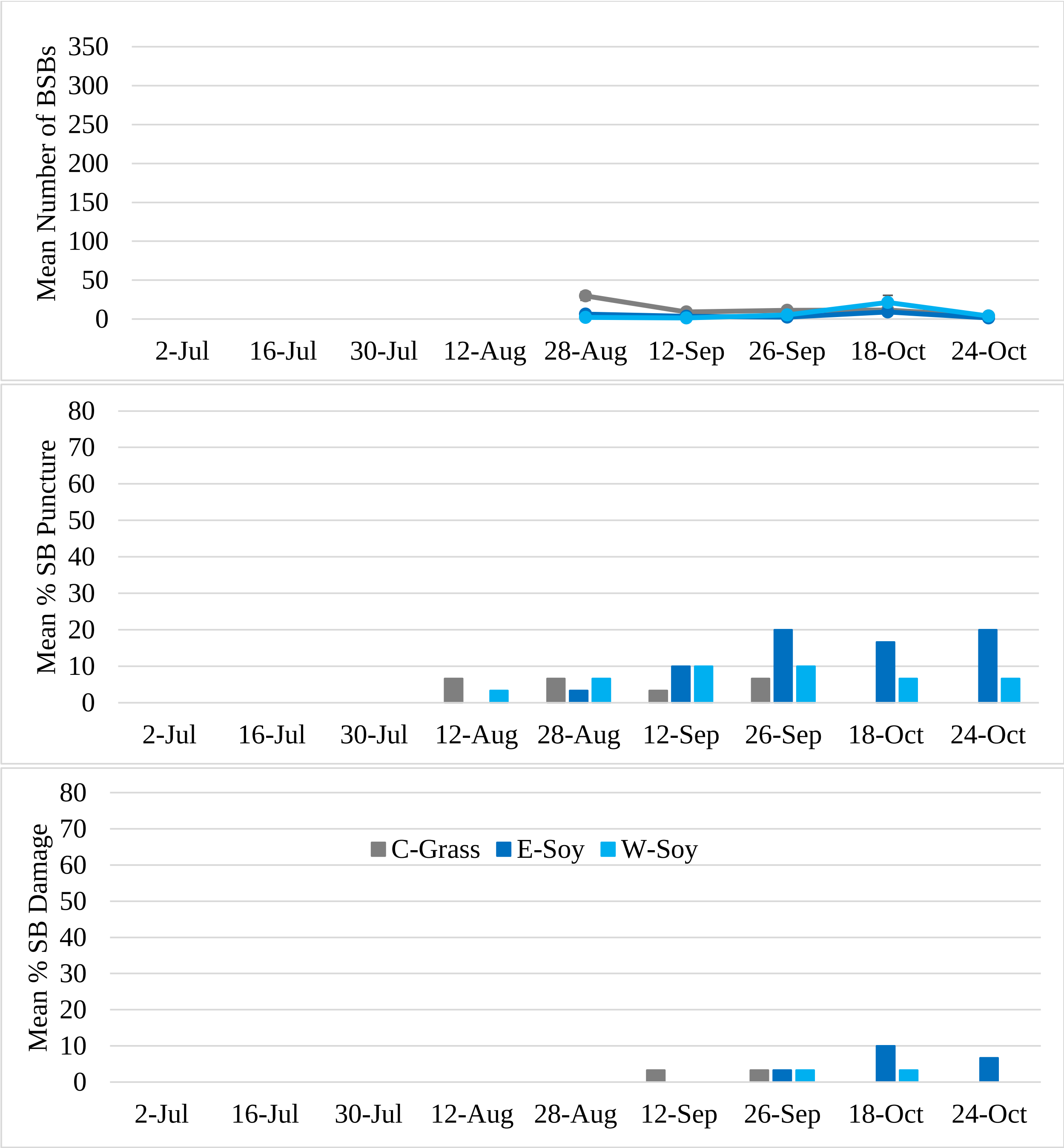


Figure A.12. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured or damaged by stink bugs (SBs) in Blackwell 1 pecan grove (2014). Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south W = west; Soy = soybean)

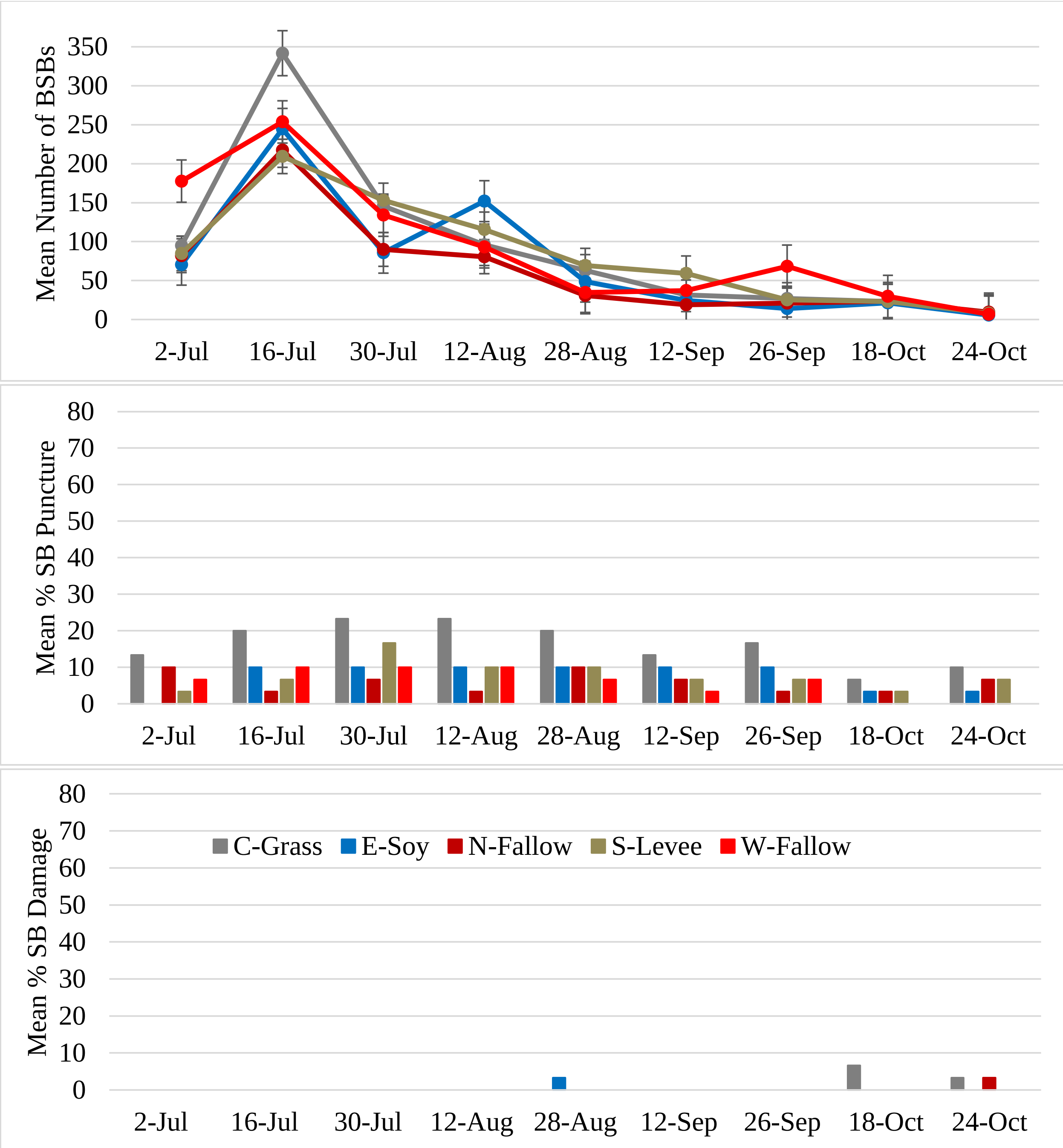


Figure A.13. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured or damaged by stink bugs (SBs) in Blackwell 2 pecan grove (2014). Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south W = west; Soy = soybean)

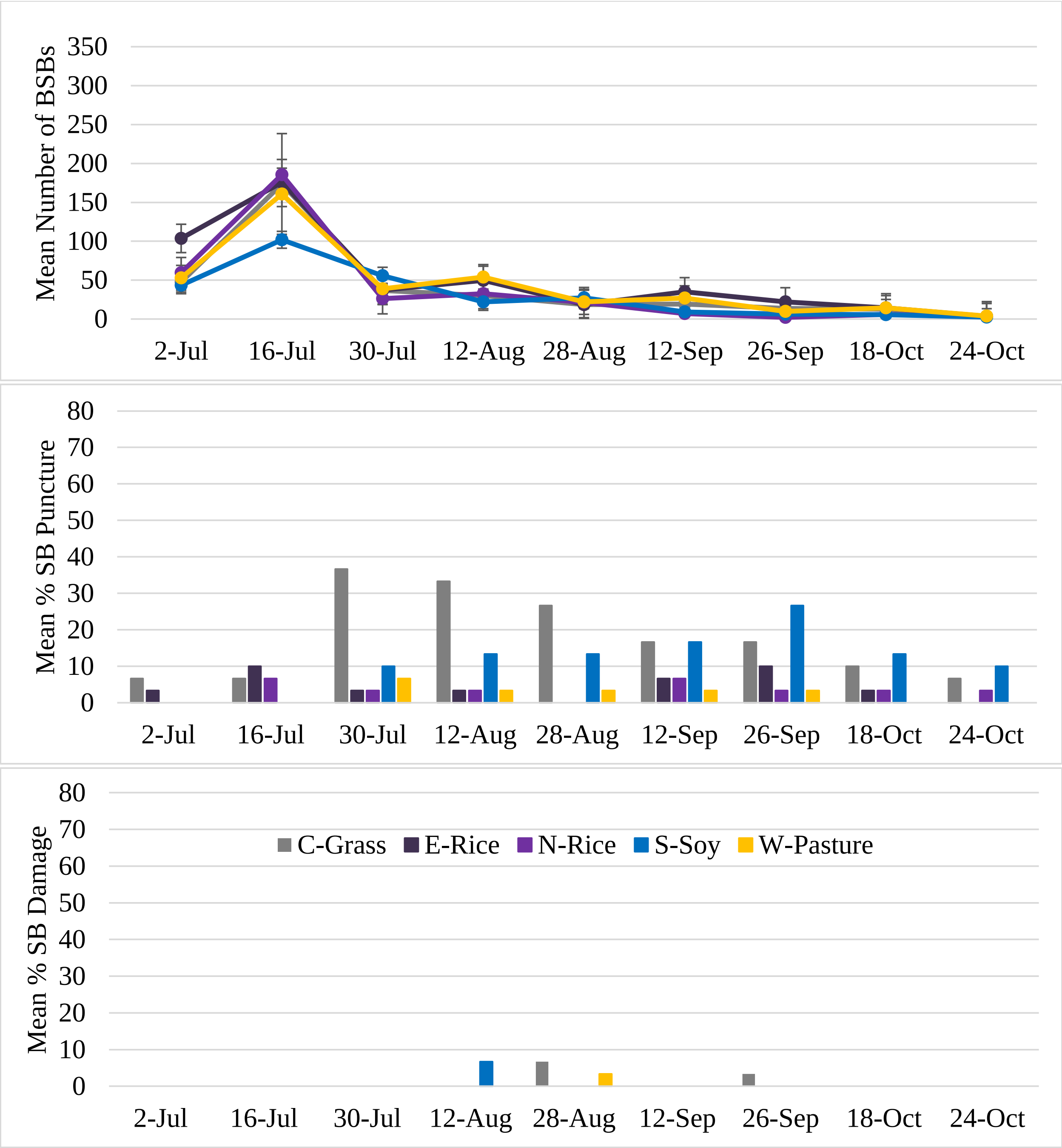


Figure A.14. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured or damaged by stink bugs (SBs) in Blackwell 3 pecan grove (2014). Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south W = west; Soy = soybean, Trees = forest tree line)

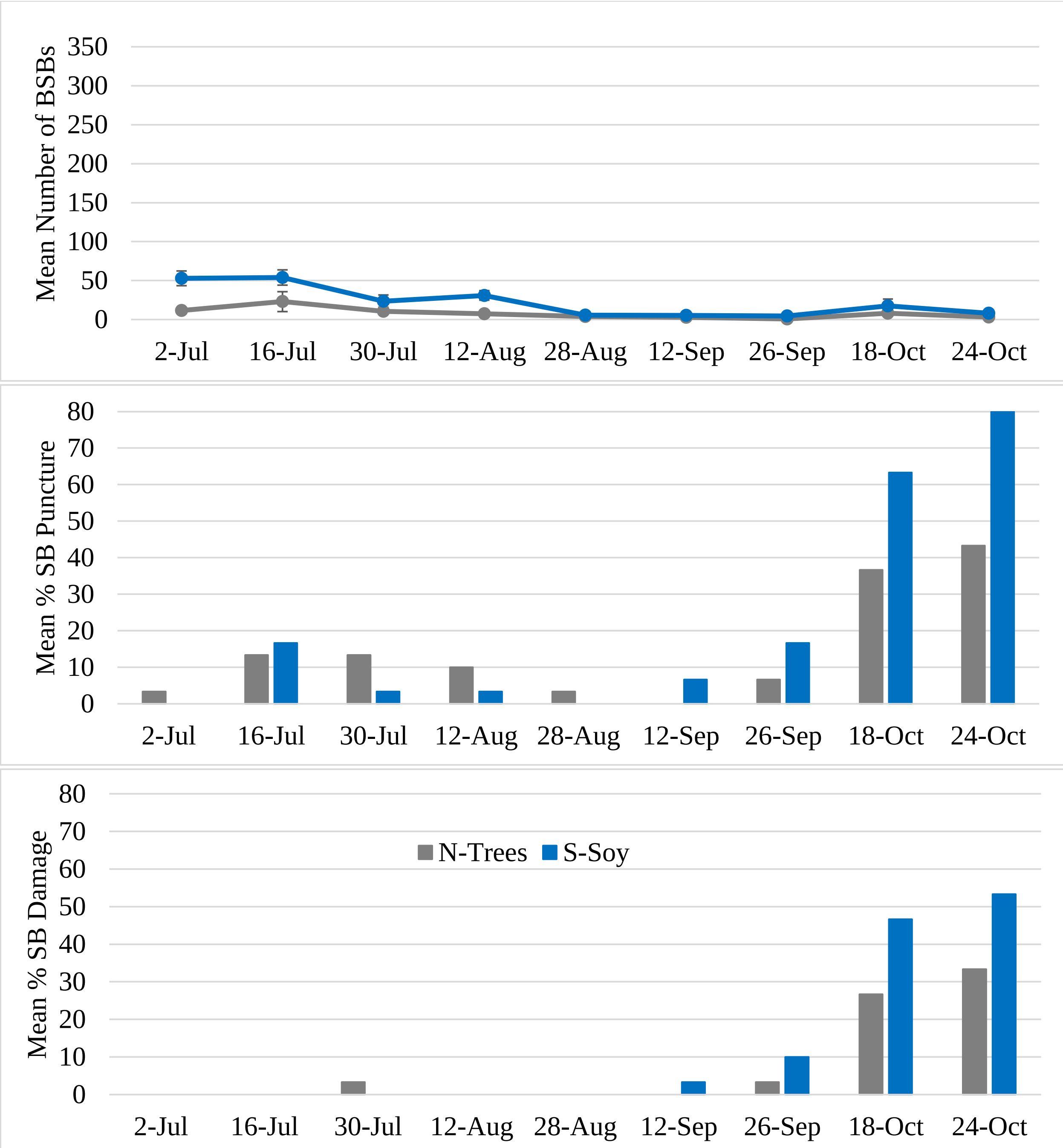


Figure A.15. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured or damaged by stink bugs (SBs) in Blackwell 4 pecan grove (2014). Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south W = west; Soy = soybean)

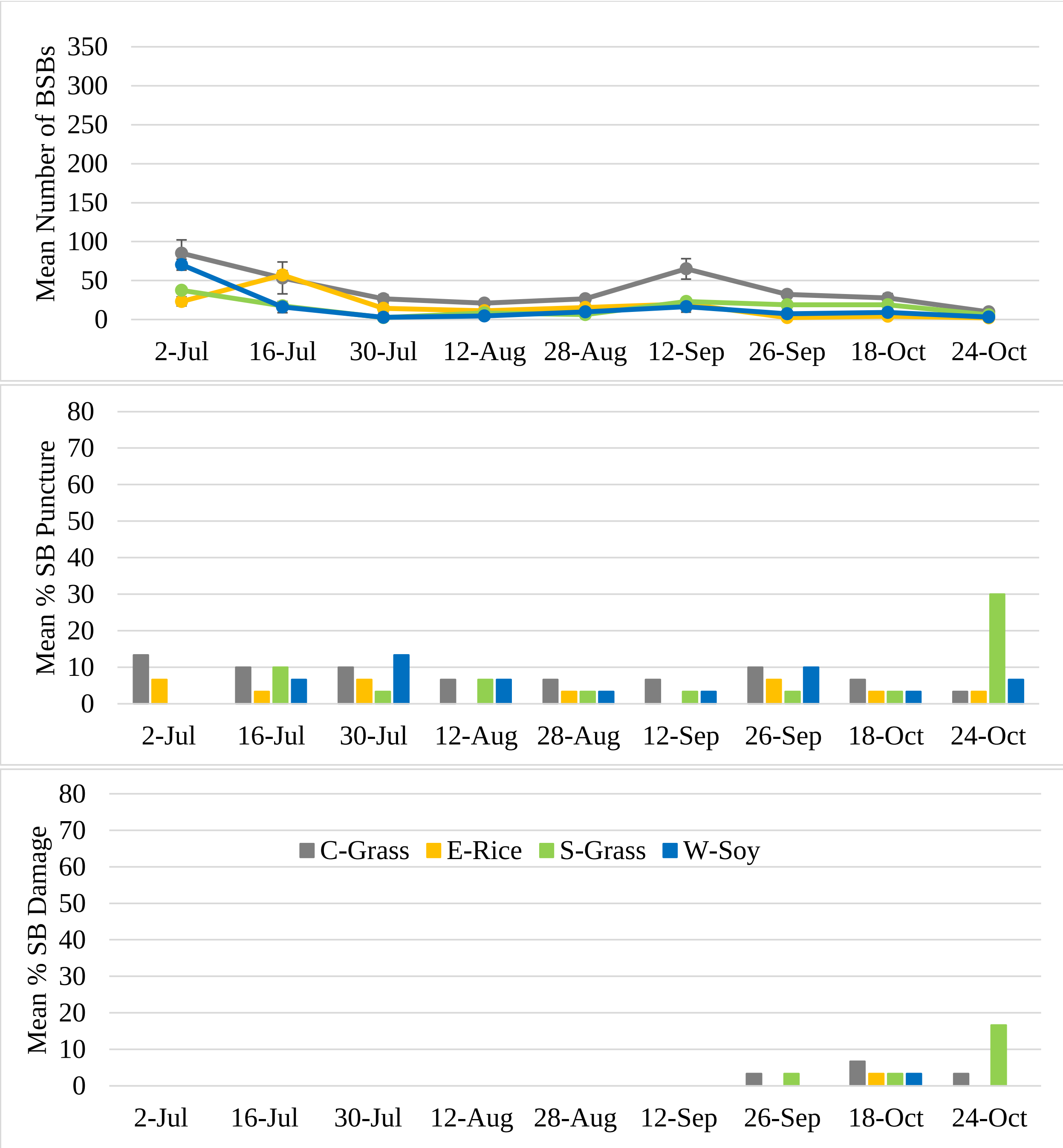


Figure A.16. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured or damaged by stink bugs (SBs) in Blackwell 5 pecan grove (2014). Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south W = west)

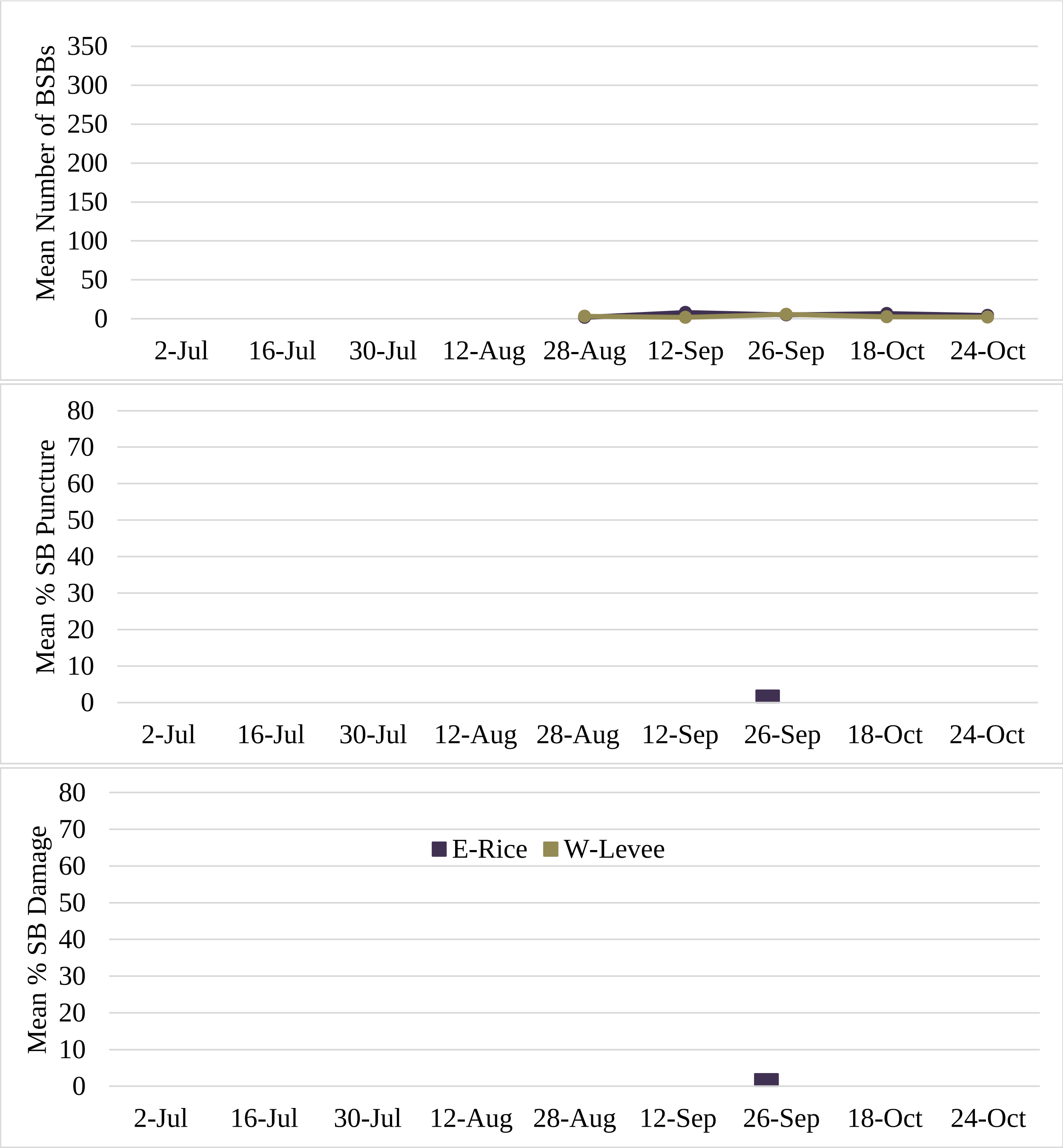


Figure A.17. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured or damaged by stink bugs (SBs) in Humphrey pecan grove (2014). Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south W = west; Trees = forest tree line)

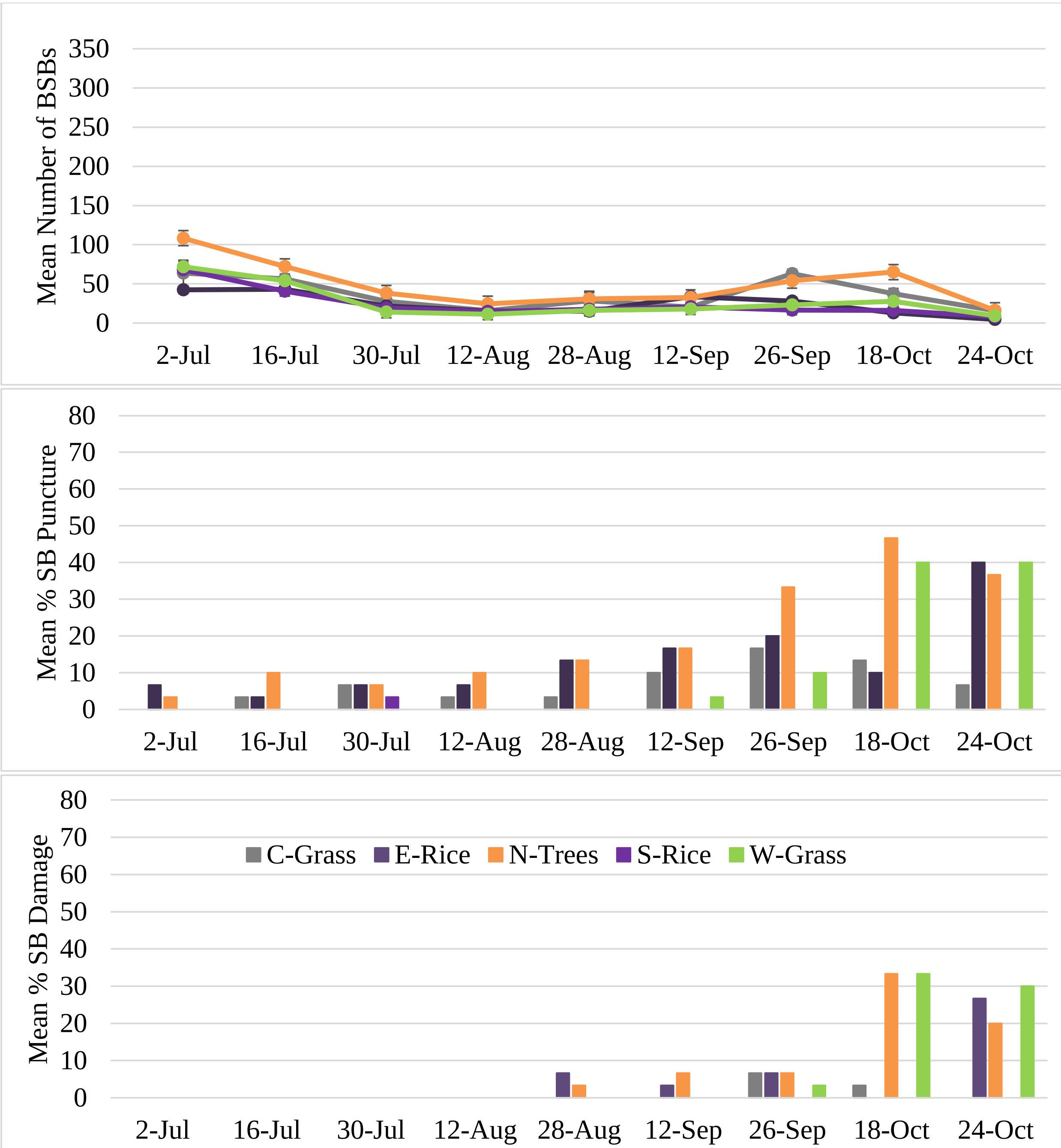
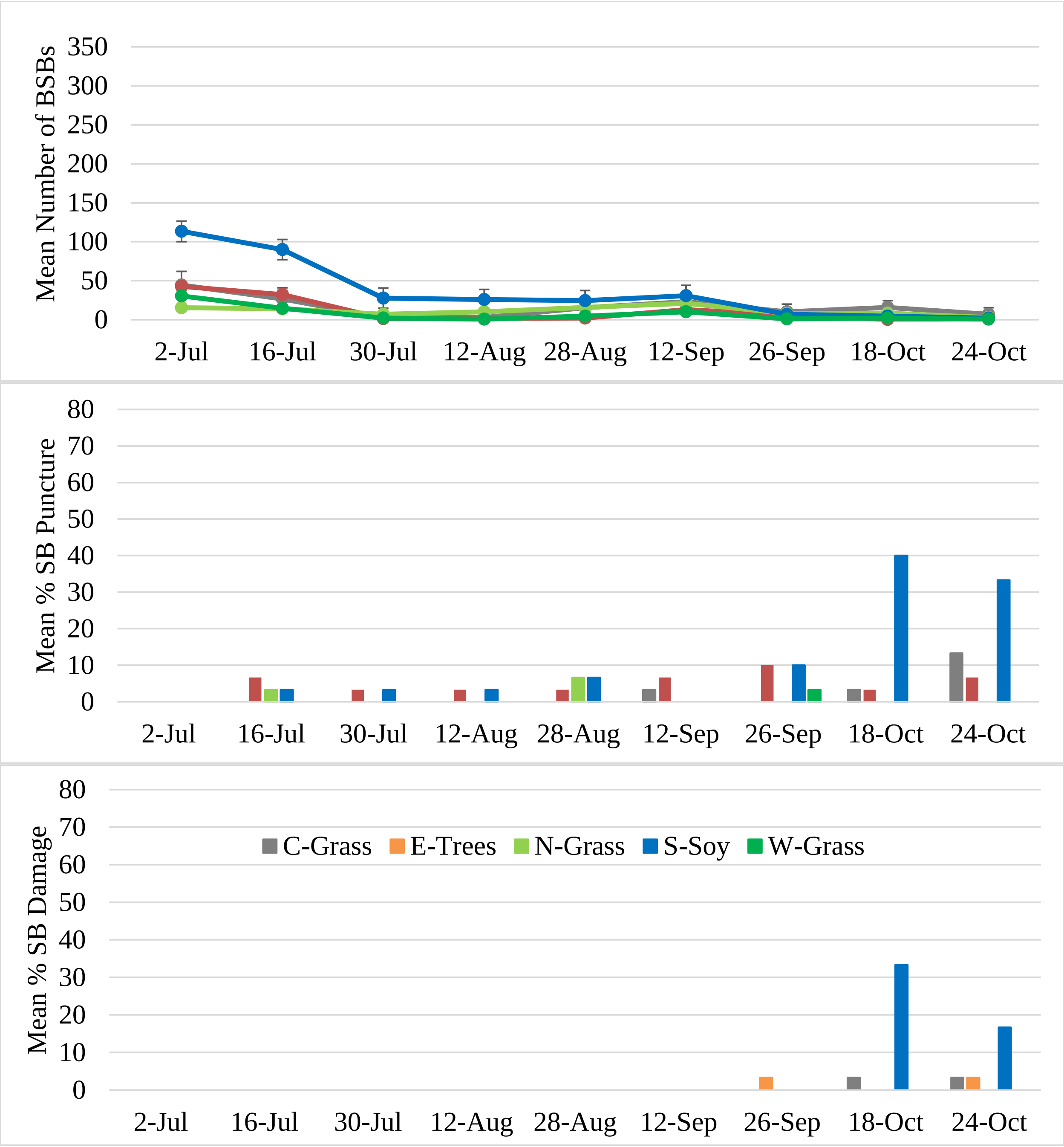


Figure A.18. Mean numbers (± SE) of brown stink bugs (BSBs) and percentage pecan nuts punctured or damaged by stink bugs (SBs) in Mayflower pecan grove (2014). Legend notes five sampling locations with habitat descriptors (C = center, E = east, N = north, S = west, S = south W = west; Soy = soybean, Trees = forest tree line)



Chapter 7

Conclusions and Future Work

INTRODUCTION

The quality and efficiency of pecan production in Arkansas could be greatly increased by implementing a SB pest management program. Four main things must be identified before an effective IPM program can be developed to control stink bugs: (1) SB susceptible phenological stages of pecans; (2) where in the tree are the SBs causing nut damage; (3) which monitoring method will be helpful in predicting SB damage to pecans; and (4) what surrounding landscapes contribute SBs in the pecan grove.

Brown stink bug damage of pecans at different phenological stages

The cage study was conducted by enclosing a brown stink bug, *Euschistus servus* (Say) in a screened cup cage with a pecan nut in different phenological growth stages from nutlet to mature. The SB punctured pecans regardless their phenological stages. These punctures induced pecan drop and kernel damage within five days of SB feeding on caged pecans but not all SB punctured shucks had kernel damage. The pecans which dropped due to SB feeding during the nutlet expansion to early-water stage were not significantly different from pecans which naturally dropped. Pecans in the water and gel nut stages had significantly greater kernel damage and pecan drop than any other pecan stages. . This is due to the fact there are sugars present in the pecan from the water stage through the early dough stage. The SB digestive enzyme (amylase) can break down these sugars and cause black spot (dough stage) and pecans to drop from the trees (pre dough stage) reducing overall pecan yield but not quality. Stink bug feeding damage to pecan kernels occurred during the early-water to gel / dough stages with greatest nut loss during the water and gel stages and the greatest quality reduction during the dough stage. As the pecans reach the dough stage and the shell hardens SB feeding will no longer cause the pecans to drop. As the pecans mature, the sugars are converted into fats so there is little sugar left

for the amylase to act on so no black spot form on kernels. No kernel damage was found on either mature or harvested pecans.

Using this information I can conclude that there is no need to protect the pecans during the nutlet to early-water stage because the pecan loss attributed to SBs was found to be no different from the natural loss that occurs during the same time in the absence of SBs. There is a need to protect pecans from stink bug feeding from the water to gel through dough nut stages. Stink bug feeding during both the water and gel stages will cause the center of the nuts to turn black and nuts drop from the tree reducing the crop yield. During a heavy crop years the SB induced drop could be acting as a natural thinning event, which has been shown to reduce biennial bearing and increase crop quality. Any pecans which are injured by SBs from dough stage through early mature stage will cause bitter black kernel spots on the pecans and reduce nut quality. No SB damage occurred once the pecans nuts were mature indicating that the dough and early mature stage should be protected against SBs in order to prevent quality loss.

Pecan nut feeding cage studies need to be conducted with other species of SBs known to feed on pecans, besides BSBs, to determine for each species the types and percentages of feeding damage during each nut development stage. Mizell and Tedders (1995) mentioned that the southern green SB causes 34-53% pecan drop while the brown SB causes 73% drop. These facts need to be verified along with determining relative likelihood of each species causing black kernel spots to form on the pecans.

Stink bug feeding damage by pecan canopy strata

Stink bug punctures and damage were assessed in the pecan tree canopy by collecting nuts by three sampling methods: by hand from the lower canopy; by pecan trunk shaker; and an Orbit lift sampling the lower (0 – 3 m), middle (3 – 6 m) and upper (6 – 9 m) pecan canopy. My

studies suggest that more SB punctures were found in the lower strata of the pecan canopy than from the canopy as a whole. In order to verify this finding, an Orbit lift was used to collect nut samples from three strata of pecan trees in several commercial orchards. Again, these samples had significantly more SB punctures and SB damage in the lower strata than either the middle or upper strata. Both of these studies show that more SB feeding on pecan nuts occurs below 3 m than above the 3 m pecan tree canopy. The fact that more SB feeding occurred below 3 m in the pecan canopy indicates that the current SB monitoring techniques may not accurately estimate the SB damage of pecans in the canopy. The pyramid trap monitors for SBs just above the ground level. Since most the SB damage is occurring in the lower canopy this suggest that it would be more effective for growers to apply insecticide against SBs by ground airblast sprayer to the lower pecan canopy than by an aerial spray coating mostly the upper canopy. Ground applications of insecticide for the pecan weevil (Harris et al. 1980) and fungicides for pecan scab (Sanderlin 2008) have proven to be more effective than applications applied by airplane.

Additional studies need to be conducted to determine if by removing the lower limbs of the pecan tree up to 3 m that it would disrupt the movement of SBs into the pecan tree and reduce the SB damage to the pecans. If pruning off the lower limbs of the trees in fact does reduce SB damage it could be recommended and used as a cultural method to control SBs.

Monitoring methods

To date, there have been several methods recommended for monitoring SBs in different crops. The four methods that have been recommended for monitoring SBs in pecans were baited yellow pyramid traps, black-light traps, visual surveys, and canopy knock down sprays. My goal was to determine which of these four SB monitoring methods gave the best estimate of SB

densities, was most related to percentage of SB pecan damage in pecan trees and note advantages (practicality) and disadvantages of each.

Out of the four monitoring methods the yellow pyramid trap captured the most brown SBs all season (very few green SBs captured) and was the most practical monitoring method but it was not without its faults. This is due to the fact that the yellow pyramid traps were baited with the brown SB aggregation pheromone which attracted mainly brown SBs and not Green SBs. The number of SBs per trap did not predict either the percentage SB punctures or percentage SB damage throughout the season. On any day that the yellow pyramid traps did catch SBs, SB punctures occurred but not necessarily SB damage of kernels.

The UV light trap method ran for one night biweekly and caught very few SBs compared to cumulative biweekly SB catches in baited yellow traps. There were several problems: rainy nights drastically reduced the number of SBs captured per UV light trap; UV light traps caught very few brown and dusky SBs but more green SBs but these numbers were still very low; and these traps must be powered by electricity or batteries which limits trap placement. The low SB catch per UV light trap resulted in no relationship between the number of SBs and the percentages of pecans with SB punctures or SB damaged kernels. The UV light trap method would not be a recommended method for monitoring SBs in pecan groves.

The knock down spray method did determine the main SB species and respective numbers present in pecan trees at a given moment in time. The problem with this is that if the SBs are already in the tree the damage could already be occurring. Given the half hour to complete a knock down spray again there were very few SBs captured with the most prevalent species being brown SBs and dusky SBs which varied by pecan grove and year. Again, the numbers of SBs captured per knock down sprayed tree resulted in no relationship to percentages

of pecans with SB punctures or SB damaged kernels except for in a few cases where pecan groves had high percentage of SB damage (> 10%). The knock down spray method would not be a recommended method for monitoring SBs in pecan groves in most cases, especially in trees with pecan canopy pruned to above 3 m.

Visual inspection of the pecan canopy indicated lower numbers of SBs in the pecan canopy than were detected by the knock down spray method. Visual counts were often zero and sporadic so these numbers were not related to either pecan punctures or kernel damage caused by SBs. One benefit of the visual count method is that the particular species is in the tree can be observed at the exact moment it is there. The major problem with this method is that if the SBs are already in the pecan tree then the damage is most likely already occurring, making this a poor method for monitoring to prevent damage.

From my current information I can recommend that the yellow pyramid traps baited with the brown SB aggregation pheromone coupled with knowledge of when pecan tree has nuts in entering dough stage could be used to determine whether to spray insecticides for SBs. If a SB is caught in yellow pyramid traps directly before or during dough stage then an insecticide application is recommended to protect the nut crop.

There is room for improvement on these recommendations though. Future studies need to be conducted on the yellow pyramid traps baited with both the brown SB aggregation pheromone methyl (E,Z,)-2,4-decadienoate (Aldrich et al. 1991) and green SB aggregation pheromones methyl (E,Z,Z)-2,4,6-decatrienoate (Aldrich et al. 2007) with an insecticide ear tag. In order to determine how effective these traps can be for both the brown SBs and green SBs, trap capture of double-baited yellow pyramid traps need to compare the traps tethered in the lower pecan canopy

to traps on the ground to determine if either gives a better prediction of SB feeding damage in pecan trees.

In addition, a regional SB risk map needs to be developed and made available to pecan growers via online Pecan ipmPIPE (similar to pecan nut casebearer Risk Map). After being developed and validated by entomologist across the pecan growing region. This could be a growing degree day map by cultivar initiated by date of pollination (biofix) uploaded by county agents and/or growers. This would create a risk map for each major pecan cultivar group (early, mid and late maturing) to note seasonal changes in pecan nut phenological stage and indicate decision windows: imminent for SB damage; active period for checking for presence of SB and applying insecticide; and note when the threat of SB damage prevention period has passed.

Effects of adjacent landscapes on stink bugs

The landscapes adjacent to pecan groves seem to have an effect on SB dispersal into pecan groves, but this dispersal is also affected by weather patterns. Stink bugs are highly mobile and extremely polyphagous hemipterans that feed primarily on the seeds of plants during their water stage. The maturation and drying of host seeds causes SBs to disperse from that food source to another throughout the season. Thus, SBs disperse to pecans in late-summer to early-fall as pecans enter dough stage and then locate overwintering sites like woodlots. Yellow pyramid traps baited with the *Euschistus* aggregation pheromone were used in this study to monitor the dispersal of stink bugs from surrounding landscapes into several commercial pecan groves. During years with summer droughts like 2012 and 2013 in Arkansas, SBs were more likely found in the center of the pecan grove than in perimeter of the grove. This suggests that the center of the pecan grove provided a shaded environment which may have been cooler and more humid refuge for the SBs. In 2014, the sampled pecan groves had a cooler and wetter July

and August so greater numbers of SBs were trapped overall with more SBs trapped in three locations (grove center, adjacent tree line or soybean field) than the rest of the landscapes. The soybeans appeared to be a source of the SBs entering pecan groves while the forest tree lines acted as a barrier blocking SB dispersal from soybean field through the forest tree line to the pecan grove on the other side or to concentrate SBs within a pecan grove perimeter from soybean field adjacent to pecan grove.

The different management practices in each pecan grove influenced risk of SB damage to pecans. The pecan growers that either applied a pyrethroid insecticide during the pecan gel stage or trimmed pecan trees limbs up high off the ground (> 3 m) seemed to have fewer SB damage pecans than unsprayed pecan groves. The other SB management tactics that appeared to contribute to reduced SB damage of pecans included: herbicide strip of bare ground underneath the trees; keep drive row grass in pecan grove mowed short; and remove all trash and pruning debris from the pecan grove to lessen overwintering sites. These different management practices should be utilized by pecan growers to reduce the risk of SB damage to pecans.

In most cases more SBs were caught by yellow pyramid trap in the early season when compared to the later season. This is due to the fact that SBs have a large 1st summer generation which peaked in June and a smaller 2nd summer generation which peaked in Oct in Georgia (Cottrell et al. 2000). Stink bugs continually punctured pecans throughout the season in all pecan groves. The percentage of pecans punctured by stink bugs did not always equal the percentage of damage the SBs caused to the pecans. The chances of SBs damaging the pecan kernel remained relatively low until the pecan reached its water stage or later. Thus the high trap captures of SBs in early season inside the pecan grove will not equate to pecan nut damage because pecans are

too immature to be damaged by SBs. In the later season when the pecans are in the stages that can be damaged by the SBs the smaller numbers of SBs trapped caused much greater damage.

Further work needs to be done on the effects of adjacent landscapes on SBs dispersal into pecan groves. Multiple pecan groves of the same age and size with the same adjacent landscapes need to be monitored over time so that the number of SBs captured near each landscape can be compared to each other and confirm or refute my findings of which landscape(s) promote SB dispersal into pecans. Also more studies need to be done on the effectiveness of each of the different management practices in order establish better pest management practices.

REFERENCES CITED

Aldrich, J.R., A. Khrimian & M.J. Camp. 2007. Methyl 2,4,6-decatrienoates attract stink bugs and tachinid parasitoids. J. Chem. Ecol. 33: 801-815.

Aldrich, J.R., M.P. Hoffmann, J.P. Kochansky, W.R. Lusby, J.E. Eger, and J.A. Payne. 1991. Identification and attractiveness of a major pheromone component for Nearctic *Euschistus* spp. stink bugs (Heteroptera: Pentatomidae). Environ. Entomol. 20: 477-483.

Cottrell, T.E., C.E. Yonce, and B. W. Wood. 2000. Seasonal occurrence and vertical distribution of *Euschistus servus* (Say) and *Euschistus tristigmus* (Say) (Hemiptera: Pentatomidae) in pecan orchards. J. Entomol. Sci. 35: 421-431.

Deuce, G.K., and E.F. Suber. 1986. Summary of losses from insect damage and costs of control in Georgia, 1985. Univ. of Georgia Spec. Publ. 55.

Harris, M.K., D.R. Ring, B.L. Cutler, C.W. Neeb and J.A. Jackman. 1980. Pecan weevil management in Texas. The Pecan Quarterly. Vol. 14. No. 2

Mizell, R.F. III, and W.L. Tedders. 1995. Use of the modified Tedders trap to monitor stink bugs in pecan. Proc. Southeastern Pecan Growers Assoc. 88:36-40.

Reisig, D.D. 2011. Insecticidal management and movement of the brown stink bug, *Euschistus servus*, in corn. J. Insect Sci. 11:168.

Sanderlin, R.S. 2008. Fungicide application recommendations for pecan disease control. LSU AgCenter Pecan Research-Extension Station. http://www.agrisk.umn.edu/cache/arl02807.pdf