Stink Bugs (Hemiptera: Pentatomidae) in Pheromone-Baited Traps Near Crop Field Edges in Georgia, USA

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Stink bugs (Hemiptera: Pentatomidae) in pheromone-baited traps near crop field edges in Georgia, USA

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Abstract

Stink bugs (Hemiptera: Pentatomidae) are economic pests of cotton. Our specific objective for this 3 yr study was to use traps baited with *Euschistus* pheromone to monitor stink bugs in habitats near cotton and peanut field edges in Georgia, USA, before, during, and after crop growth and development. Plant-feeding stink bugs captured in traps included *Euschistus servus* (Say), *E. tristigmus* (Say), *Chinavia hilaris* (Say), *Nezara viridula* (L.), *Hymenarchys nervosa* (Say), *E. ictericus* (L.), *Thyanta custator custator* (F.), *E. quadrator* Rolston, *Brochymena quadripustulata* F., *Proxys punctulatus* (Palisot), and *Oebalus pugnax* (F.). Two predatory stink bug species, *Podisus maculiventris* (Say) and *Euthyrhynchus floridanus* (L.), also were captured. *Euschistus servus* was the predominant species captured, followed by *E. tristigmus*. In both cotton and peanut, traps with a pyramid-shaped base captured significantly more *E. servus* and *E. tristigmus* nymphs and adults than traps with a bamboo pole base, suggesting that the pyramid base provides a broader platform for nymphs to crawl into the insect-collecting device at the top of the trap and for adults to land. *Euschistus servus*, *E. tristigmus*, *C. hilaris*, and *N. viridula* were captured in traps before crop production, during the time stink bugs were detected in peanut and/or cotton, and after crop senescence or harvest at which time some overwintering *E. servus* and *E. tristigmus* adults were captured. Sustainable management strategies, including using pheromone-baited traps to capture and kill stink bugs, have the potential to disrupt the cycle of stink bug population growth and dispersal in farmscapes.

Key Words: *Euschistus*; *Nezara*; *Chinavia*; overwintering stink bug; nymph

Resumen

Las chinches (Hemiptera: Pentatomidae) son plagas económicas de algodón. Nuestro objetivo específico para este estudio de 3 años fue utilizar trampas cebadas con feromonas de especies de *Euschistus* para controlar las chinches en los hábitats cercanos a los bordes de algodón y de campo de maní en Georgia, EE.UU., antes, durante y despūés del crecimiento y desarrollo del cultivo. Las chinches capturadas en trampas que se alimentan de plantas incluyen *Euschistus servus* (Say), *E. tristigmus* (Say), *Chinavia hilaris* (Say), *Nezara viridula* (L.), *Hymenarchys nervosa* (Say), *E. ictericus* (L.), *Thyanta custator custator* (F.), *E. quadrator* Rolston, *Brochymena quadripustulata* F., *Proxys punctulatus* (Palisot) y *Oebalus pugnax* (F.). Dos especies de las chinches depredadoras, *Podisus maculiventris* (Say) y *Euthyrhynchus floridanus* (L.), también fueron capturadas. *Euschistus servus* fue la especie predominante capturada, seguido por *E. tristigmus*. Tanto en algodón y maní, trampas con una base en forma de pirámide capturaron significativamente más ninfas y adultos de *E. servus* y *E. tristigmus* que las trampas con una base de caña de bambú, lo que sugiere que la base de la pirámide provee una plataforma más amplia para que las ninfas entren el recipiente en la parte superior de la trampa y para que los adultos pueden aterrizar. *Euschistus servus, E. tristigmus, C. hilaris* y *N. viridula* fueron capturados en trampas antes de la producción de cultivos, durante el tiempo que las chinches fueron detectadas sobre maní y/o algodón, y después de la senescencia del cultivo o cosecha al momento en el que algunos de los adutos de *E. servus* y *E. tristigmus* invernando fueron capturados. Las estrategias de manejo sostenible, incluyendo el uso de trampas cebadas con feromonas para capturar y matar chinches, tienen el potencial de interrumpir el ciclo de crecimiento de la población y la dispersión de chinches en las fincas.

Palabras Clave: *Euschistus*; *Nezara*; *Chinavia*; chinche hedionda invernando; ninfa

Stink bugs (Hemiptera: Pentatomidae) are primary pests responsible for millions of dollars in losses and cost of control in fruit, vegetable, grain, and row crops (McPherson & McPherson 2000). For example, 130,905 bales of cotton nationwide were lost due to stink bug pest species in 2014 (Williams 2015). The 3 main stink bug pests in cotton in the coastal plain of the southeastern United States are the brown stink bug, *Euschistus servus* (Say), the southern green stink bug, *Nezara viridula* (L.), and the green stink bug, *Chinavia hilaris* (Say). Other species include *Euschistus quadrator* Rolston, *E. tristigmus* (Say), and *Thyanta custator accerra* McAtee (Bundy & McPherson 2000; McPherson & McPherson 2000). In cotton, stink bugs feed on developing seeds and lint, causing shedding of young bolls, yellowing of lint, yield reduction, and transmission of a bacterial pathogen (Barbour et al. 1990; Medrano et al. 2009). In peanut, stink bugs feed on plant vegetation (Tillman 2008), and thus they are not considered to be economic pests of this crop. However, stink bugs in peanut in peanut–cotton farmscapes can negatively impact cotton, for *N. viridula* and *E. servus* develop in peanut and then disperse to feed on cotton (Tillman et al. 2009).

A pyramid insect trap (Tedders & Wood 1994) was modified by Mizell & Tedders (1995) to facilitate stink bug capture. Aldrich et al. (1991) identified the major component of the male-specific

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pheromone of *Euschistus* species as methyl (*E*,*Z*)-2,4-decadienoate. This pheromone attracts adults and nymphs of *E. servus* and other *Euschistus* species. The major pheromone components of the male-produced *N. viridula* pheromone were identified as *trans*-(*Z*)-α-bisabolene epoxide and the corresponding *cis*-(*Z*)-(1*R*,2*S*,4*S*)-epoxybisabolene (*cis*-(*Z*)-α-bisabolene epoxide (Aldrich et al. 1987; Baker et al. 1987). The pheromone of this stink bug attracts conspecific adults and nymphs (Harris & Todd 1980). In the field, *C. hilaris* is cross-attracted to the pheromone (methyl [*E*,*E*,*Z*]-2,4,6-decatrienoate) produced by males of *Plautia stali* Scott (Tillman et al. 2010). When pyramid traps are baited with lures containing pheromones attractive to *E. servus*, *N. viridula*, and *C. hilaris*, they effectively capture these stink bug species in the field (Aldrich et al. 1991; Mizell & Tedders 1995; Cottrell et al. 2000; Johnson et al. 2002; Leskey & Hogmire 2005; Tillman et al. 2010).

Stink bugs, including *E. servus*, *E. tristigmus*, *C. hilaris*, and *N. viridula*, feed not only on crops but also on non-crop host plants in habitats bordering crops (Jones 1918; Hoffmann 1935; Jones & Sullivan 1982; Panizzi 1997). Non-crop hosts can play a significant role in the early-season buildup of stink bugs as reported for *C. hilaris* in South Carolina (Jones & Sullivan 1982). Stink bug species also overwinter as adults in grass clumps, leaf litter, and under tree bark (Borden et al. 1952; Rolston & Kendrick 1961; Jones & Sullivan 1981; Mizell & Schiffhauer 1987). Therefore, our objective for this paper was to use traps baited with *Euschistus* pheromone to monitor stink bugs in habitats near cotton and peanut field edges before, during, and after crop growth and development.

Materials and Methods

SITE DESCRIPTION AND PHEROMONE-BAITED STINK BUG TRAPS

The 3 yr study was conducted in 2 to 5 farmscapes per year near Ocilla, Georgia. Sites and locations (GPS coordinates) of farmscapes along with varieties, planting dates, and field sizes for crops in each farmscape are listed in Table 1. Pheromone-baited stink bug traps were positioned around a farmscape in woodland–shrub field borders ~6 m from crop field edges. Trees, including pine (*Pinus* spp.; Pinaceae), black cherry (*Prunus serotina* Ehrh.; Rosaceae), oak (*Quercus* spp.; Fagaceae), and uncultivated pecan [*Carya illinoinensis* (Wangenh.) K. Koch.; Juglandaceae], and shrubs, especially elderberry (*Sambucus nigra* subsp. *canadensis* [L.] R. Bolli; Adoxaceae), grew in these field borders. There were 12 traps at the Starr and Dogwood farmscapes, 9 traps at the Laurel farmscape, 10 traps at the Oak farmscape, and 4 traps at the Evergreen farmscape.

A stink bug pheromone–baited trap with a yellow pyramid base (Mizell & Tedders 1995) was used to capture stink bugs (Fig. 1A). The insect-collecting device was modified from that used by Mizell & Tedders (1995) in that it was made from a 2.8 L clear plastic PET® jar (United States Plastic Corp., Lima, Ohio) with a screw-cap lid (10.2 mm in diameter) and seated atop the 1.22-m-tall yellow pyramid base (Cottrell et al. 2000). A lure with the *Euschistus* pheromone, methyl [*E*,*Z*]-2,4-decadienoate (Degussa AG Fine Chemicals, Marl, Germany), was placed in the collecting device. In the field, stink bug species can be cross-attracted to the pheromone produced by another stink bug species so traps baited with *Euschistus* pheromone capture *N. viridula* and *C. hilaris* (Tillman et al. 2010). At the time of the study, the pheromones attractive to *N. viridula* and *C. hilaris* were not commercially available. An insecticidal ear tag (10% λ-cyhalothrin and 13% piperonyl butoxide) (Saber extra insecticide ear tags, Sagebrush Tags, De Smet, South Dakota) was placed in this device to decrease stink bug escape (Cottrell 2001). Lures were produced by pipetting 40 µL of the *Euschistus* pheromone into the opening of rubber septa (11 mm natural, rubber sleeve stoppers, Wheaton, Millville, New Jersey), holding the septa upright in a laboratory rack, and allowing septa to absorb the pheromone at room temperature (Cottrell & Horton 2011). In the field, lures were changed and insects collected on a weekly basis from mid-Jul through mid-Dec in 2007, from early May through early Nov in 2008, and from early Jul though mid-Dec in 2009. Because color change in *E. servus* from green to reddish brown is an indicator of reproductive diapause (Borges et al. 2001), reddish brown *E. servus* and *E. tristigmus* adults captured in traps were considered to be overwintering adults.

TRAP BASE TEST

To test the efficacy of a pyramid base with a pheromone-baited stink bug trap in capturing stink bug nymphs and adults, trap capture was examined for 2 types of trap bases: a pyramid base (as described above) and a bamboo pole base. The test was conducted in a peanut–cotton farmscape (31.55752°N, 83.28583°W) for 8 wk, from early Sep to mid-Oct 2013. For the bamboo pole base, the pyramid base was replaced with a natural bamboo pole (1.3 cm in diameter at the bottom and 1.5 m high) (A. M. Leonard Horticultural Tool & Supply Co., Piqua, Ohio) (Fig. 1B). Approximately 0.3 m

Table 1. Site, year, and location (GPS coordinate) and variety, planting date (PD), and field size (ha) for peanut and cotton in study farmscapes.

			Peanut			Cotton		
Site	Year	Location	Variety	PD	ha	Variety	PD	ha
Starr	2007	31.5696944°N, 83.2982222°W	GA Green[a]	5/29	9.7	DP 555[b]	6/7	18.6
Dogwood	2007	31.5485833°N, 83.2873889°W	GA Green	5/21	17.4	DP 555	6/11	18.2
Laurel	2007	31.5554167°N, 83.3361944°W	GA Green	5/21	9.7	DP 555	5/9	8.9
Oak	2007	31.6311389°N, 83.1904722°W	GA 02-C	5/29	10.9	DP 555	5/11	19.0
Evergreen	2007	31.6340278°N, 83.1885556°W	—	—	—	DP 555	5/11	25.5
Starr	2008	—	GA Green	5/17	18.6	DP 555	5/8	9.7
Dogwood	2008	—	GA Green	5/13	17.8	DP 555	6/6	17.8
Starr	2009	—	GA Green	5/19	9.7	DP 555	5/5	18.6
Dogwood	2009	—	—	—	—	DP 555	5/14	35.6
Laurel	2009	—	—	—	—	DP 555	5/14	18.6

[a]GA, Georgia
[b]DP, Deltapine

Fig. 1. Stink bug pheromone–baited trap with a pyramid base (A) and a bamboo pole base (B) in peanut row. Distance between each trap treatment was 9 m.

of the bamboo pole was inserted into the ground to support the insect-collecting device (as described above). The 2 treatments were set up as a randomized complete block design using 7 blocks (i.e., replicates). The traps were located approximately 18 m from the crop field edge. They were lined along a crop row, and the distance between each trap treatment was 9 m (Fig. 1). Lures were changed and insects collected on a weekly basis. The test was duplicated in cotton and peanut.

INSECT SAMPLING PROCEDURES IN CROPS

In each farmscape, crops were examined weekly for the presence of stink bugs during the growing season. Peanut sampling started at the initiation of pegging (i.e., when budding ovaries or "pegs" grow down into the soil) and continued until harvest. The peanut canopy within a 7.31 m length of row was swept (38-cm-diameter sweep net) to capture stink bugs. Stink bugs collected from peanut were identified to species in the laboratory. In cotton, sampling began with the onset of flowering and continued until defoliation. For each cotton sample, all plants within a 1.83 m length of row were shaken over a drop cloth, identified, and recorded. Stink bug species were identified using the keys in McPherson & McPherson (2000). Voucher specimens were stored in the United States Department of Agriculture, Agricultural Research Services, Crop Protection and Management Research Laboratory, Tifton, Georgia.

Within a farmscape of peanut and cotton, a crop field was partitioned into 3 sampling locations: 1) the crop-to-crop interface; 2) the 3 field edges excluding the interface; and 3) the interior of the field. In farmscapes with only cotton, the 4 field edges and the field interior were sampled. At the interface in cotton, samples were obtained at rows 1, 2, 5, and 9 from the field edge. At the interface in peanut, samples were taken at rows 1, 6, and 10 from the field edge. For field edges, samples were obtained at rows 1, 5, and 9 in cotton and rows 1, 6, and 10 in peanut. In cotton, there were 9 to 18 interface samples and 6 to 9 field edge samples each year. In peanut, there were 9 to 18 interface samples and 3 to 9 field edge samples each year. For the 6 interior field transects in both crops, samples were obtained 16 and/or 33 rows distant from the interface and then approximately every 33 rows beyond row 33 from the interface, depending on field width.

DATA ANALYSES

All data were analyzed using SAS statistical software (SAS Institute 2010). Chi-squared analyses were used to compare overall frequencies of stink bug species in traps (PROC FREQ). Yearly means for *E. servus*, *E. tristigmus*, *N. viridula*, and *C. hilaris* combined were calculated for the number of stink bugs per trap (PROC MEANS). Weekly means for *E. servus*, *E. tristigmus*, *N. viridula*, and *C. hilaris* were calculated for trap capture and the number of stink bugs per sample in cotton and peanut (PROC MEANS). For the trap base test, the count data (number of *E. servus* and *E. tristigmus* nymphs and adults) were modeled by a Poisson distribution. The analyses were done using PROC GLIMMIX. The KENWARD-ROGER option and the LINK=LOGIT function were used in the model statement. Model fit was evaluated by use of the chi-squared and df statistic provided by PROC GLIMMIX (Littell et al. 2006). Fixed effects were treatment, week, and treatment by week. Random effects were replicate and residual error. The treatment by week interaction was not significant for all trap data; the interaction was therefore dropped from the model, and the model was rerun. Means were back transformed using the ILINK option in the LSMEANS statement and compared using Tukey's honestly significant difference (HSD).

Results

Eleven plant-feeding stink bug species, *E. servus*, *E. tristigmus*, *C. hilaris*, *N. viridula*, *Hymenarchys nervosa* (Say), *E. ictericus* (L.), *T. c. custator*, *E. quadrator*, *Brochymena quadripustulata* F., *Proxys punctulatus* (Palisot), and *Oebalus pugnax* (F.), were captured in pheromone-baited traps (Table 2). Two predatory stink bug species,

Table 2. Frequency of occurrence of stink bug species in pheromone-baited traps.

Stink bug species	Frequency of occurrence	χ²	df	*P*
E. servus	74.34			
E. tristigmus	20.91			
C. hilaris	1.23			
N. viridula	1.06			
P. maculiventris	0.52			
H. nervosa	0.51			
E. ictericus	0.37			
T. c. custator	0.31			
E. quadrator	0.24			
B. quadripustulata	0.21			
E. floridanus	0.15			
P. punctulatus	0.10			
O. pugnax	0.05			
Frequency comparisons				
All stink bug species		130,085.6	12	0.0001
E. servus vs. *E. tristigmus*		5,767.7	1	0.0001
C. hilaris and *N. viridula*		2.5	1	0.1161
E. tristigmus vs. Greens[a]		2,877.1	1	0.0001
Greens vs. Remaining species[a]		11.9	1	0.0005

[a] Greens, *C. hilaris* and *N. viridula*; Remaining species, all species except *E. servus*, *E. tristigmus*, *C. hilaris*, and *N. viridula*.

Podisus maculiventris (Say) and *Euthyrhynchus floridanus* (L.), also were captured. The frequency of occurrence for stink bug species in traps was highest for *E. servus* followed by *E. tristigmus* (Table 2). Together, *C. hilaris* and *N. viridula* were more commonly collected in traps than the remaining 9 stink bug species.

The total number of combined *E. servus*, *E. tristigmus*, *C. hilaris*, and *N. viridula* nymphs and adults captured in pheromone-baited stink bugs traps in the Starr, Dogwood, and Laurel farmscapes ranged from 956 to 5,215 per year over sites and years (Table 3). The mean number of stink bugs captured per trap per year ranged from 106.2 to 434.6. The nymph-to-adult ratio (1:9) was similar for each site and year; more adults than nymphs were captured in traps. The female-to-male ratio (1:1) also was similar for each site and year; traps captured and killed females, which have the potential to oviposit on host plants including the crops in the farmscape.

For *E. servus* and *E. tristigmus* nymphs and adults, trap capture was influenced by trap base treatment (Table 4). In both cotton and peanut, significantly greater numbers of *E. servus* and *E. tristigmus* nymphs and adults were captured in traps with a pyramid base than in traps with a bamboo pole base (Table 5). For *E. tristigmus* nymphs in cotton and *E. servus* nymphs in peanut, trap capture was affected by week (Table 4), for no *E. tristigmus* were captured in cotton in weeks 4, 7, and 8, and no *E. servus* were captured in peanut in week 1.

Each year of the study, *E. servus* adults and some nymphs were captured in traps in habitats near crop field edges before adults were present in peanut or cotton (Fig. 2A–F). The peak number of *E. servus* trap captures was very high in Jun 2008 (Fig. 2C). This stink bug species developed on peanut and cotton from Jul to Sep/Oct (Fig. 2B, D, F). In 2007, *E. servus* nymphs built up in late-season peanut (Fig. 2B), and these nymphs likely developed into adults that were captured in traps late in the season (Fig. 2A). In general, more *E. servus* adults were captured in traps than were detected in crop samples. Adults of *E. servus*, including overwintering individuals, and some nymphs were captured in traps after crops senesced (Fig. 2A–F).

Very few *E. tristigmus* adults and nymphs were detected in crops. In 2008, only *E. tristigmus* adults were found in peanut field edges at very low densities; they did not reproduce in this crop (Fig. 3B, D, F). Each year of the study, adults were detected at very low densities in cotton, mainly at or near field edges. In 2007, a single *E. tristigmus* nymph was detected ~30 m from a field edge in cotton. However, for each year of the study, *E. tristigmus* adults, and sometimes nymphs, were present in traps before, during, and after crop growth and development in these farmscapes (Fig. 3A, C, E). However, there appeared to be more adults and nymphs captured in traps late in the season (Sep though Oct) than earlier in the season. Overwintering adults were captured in these late-season traps.

Only in 2008 were *N. viridula* adults and nymphs captured in traps before crop growth and development (Fig. 4C, D). *Nezara viridula* generally developed in crops from Jul to early fall (Fig. 4B, D, F). In 2007 and 2009, trap capture of *N. viridula* adults and nymphs tended to increase once the crops senesced (Fig. 4A, E). Some *N. viridula* nymphs that built up late in the season in peanut in 2007 (Fig. 4B) may have dispersed from the crop and subsequently crawled into traps (Fig. 4A).

Over the 3 yr study, *C. hilaris* was detected only in cotton (Fig. 5B, D, F). Nymphs and/or adults of *C. hilaris* were captured in traps before adults were present in cotton (Fig. 5A–F). This stink bug species developed on cotton, and after the crop senesced, adults and nymphs were captured in traps (Fig. 5A–F).

Discussion

In this study, *E. servus* was the most frequently captured stink bug species in *Euschistus* pheromone–baited traps in habitats near cotton and peanut field edges in Georgia. Overall, the 2 predominant species captured were *E. servus* and *E. tristigmus*. Similarly, Yonce & Mizell (1997) reported that 93% of the pentatomids cap-

Table 3. Total number of stink bugs captured, mean number of stink bugs captured per trap per year, nymph-to-adult ratio (N:A), and female-to-male ratio (F:M) for combined *Euschistus servus, Euschistus tristigmus*, *Nezara viridula*, and *Chinavia hilaris* captured in the Starr, Dogwood, and Laurel farmscapes each year.

Site	No. of traps	ha	Year	Total no. of stink bugs	Mean no. of stink bugs per trap per year	N:A	F:M
Starr	12	28.3	2007	1,411	117.6	1:9	1:1
			2008	5,215	434.6	1:9	1:1
			2009	1,850	154.2	1:9	1:1
Dogwood	12	35.6	2007	1,533	127.8	1:9	1:1
			2008	3,030	252.5	1:9	1:1
			2009	2,436	203.9	1:9	1:1
Laurel	9	18.6	2007	9,56	106.2	1:9	1:1
			2009	2,059	228.8	1:9	1:1

Table 4. Mixed model of variance statistics to test for the effect of treatment (pyramid base and bamboo pole base) and sampling week on stink bug capture in pheromone-baited traps in cotton and peanut.

Crop	Species	Stage	Fixed effect	df	*F*	*P*[a]
Cotton	*E. servus*	Nymph	Treatment	1, 90	18.78	**0.0001**
			Week	6, 1	2.81	0.4273
		Adult	Treatment	1, 90	241.83	**0.0001**
			Week	6, 1	88.61	0.0811
	E. tristigmus	Nymph	Treatment	1, 84	15.89	**0.0001**
			Week	6, 84	4.52	**0.0005**
		Adult	Treatment	1, 90	87.80	**0.0001**
			Week	6, 1	9.55	0.2427
Peanut	*E. servus*	Nymph	Treatment	1, 84	13.00	**0.0005**
			Week	6, 84	2.28	**0.0437**
		Adult	Treatment	1, 90	437.19	**0.0001**
			Week	6, 1	50.52	0.1073
	E. tristigmus	Nymph	Treatment	1, 84	17.70	**0.0001**
			Week	5, 84	1.61	0.1664
		Adult	Treatment	1, 90	86.08	**0.0001**
			Week	6, 1	8.00	0.2643

[a]Significant *P* values in bold.

tured in similar pheromone-baited stink bug traps were *E. servus* and *E. tristigmus* in pecan orchards in Florida. In a study in pecan orchards in Georgia, more *E. servus* than *E. tristigmus* were captured in pheromone-baited traps, and these 2 species were the predominant ones in traps (Cottrell et al. 2000). In mid-Atlantic apple and peach orchards, *E. servus* was the predominant species captured followed by *E. tristigmus*, *C. hilaris*, and other stink bugs (*Brochymena* spp. and unidentified nymphs) (Leskey & Hogmire 2005). In field tests, capture of *N. viridula* and *C. hilaris* was higher in traps baited with their respective pheromone attractants than in traps baited with the *Euschistus* pheromone (Tillman et al. 2010). In many farmscapes, *N. viridula* and *C. hilaris*, as well as *E. servus*, are pests of crops. So, baiting pyramid traps with the pheromones attractive to *N. viridula*, *C. hilaris*, and *E. servus* could increase the effectiveness of these traps in either monitoring or managing these 3 stink bug species in farmscapes. Lures with the pheromone from *P. stali*, which is attractive to *C. hilaris*, are now commercially available, but, unfortunately, the pheromone of *N. viridula* cannot be purchased.

Generally, stink bugs exhibit negative geotaxis, moving upward on objects they encounter, and even if on a flat surface such as the ground, they walk to nearby vertical objects and climb upwards. So the explanation for why the bamboo base did not capture stink bugs as well as the pyramid base is that there is nothing to arrest and direct the stink bugs into the top of the trap to be captured unlike the pyramid shape, which exploits their innate behavior. Black pyramid traps baited with the pheromone of *P. stali* were more effective in capturing the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål), than yellow traps with this pheromone (Leskey et al. 2012). However, Mizell & Tedders (1995) found that more native stink bug species were captured by pyramid traps coated with yellow paint than by those coated with green or black paint. Thus, the yellow color of the pyramid base may have been more attractive to stink bug adults than the light brown color of the bamboo pole base.

Euschistus servus, *E. tristigmus*, *C. hilaris*, and *N. viridula* were captured in pheromone-baited traps before and during the time stink bugs colonized peanut and cotton. Jones & Sullivan (1981) reported that the majority of *C. hilaris*, *E. servus*, and *E. tristigmus* adults emerged from their overwintering habitats from late Mar to early Apr. Thus, most, if not all, of the *E. servus*, *E. tristigmus*, *C. hilaris*, and *N. viridula* adults captured in our early-season traps probably were not overwintering adults. Jones & Sullivan (1982) examined the population dynamics of stink bugs on non-crop hosts in woodlands in South Carolina. Black cherry was an early-season host of *E. servus*, *C. hilaris*, and *N. viridula*; adults were present on trees from Apr until early Jul, and large nymphs were found on trees from late May through mid-Jul. Elderberry was an early-to-mid-season host of *E. servus*, *C. hilaris*, and *E. tristigmus*; adults began colonizing this shrub in mid-May and remained on it through Jul whereas large nymphs were present from mid-Jun through Jul. Most likely, stink bug adults and nymphs in traps early in the season came from individuals on or near non-crop hosts, perhaps black cherry trees and elderberry shrubs that grew in the non-crop habitats at our study sites. Two recent studies indicated that non-crop hosts of *C. hilaris* growing near field edges in corn and cotton farmscapes were sources of this stink bug into crops, primarily cotton (Cottrell & Tillman 2015; Tillman & Cottrell 2015). Preliminary mark–recapture studies have shown that *E. servus*, *E. tristigmus*, and *C. hilaris* disperse from elderberry into cotton in late Jul to early Aug (P. G. T., unpublished data). Density of *E. tristigmus* was so low in crops that it is very plausible that the majority of individuals captured in traps originated from non-crop hosts.

Euschistus servus, *E. tristigmus*, *C. hilaris*, and *N. viridula* were captured in pheromone-baited traps in non-crop habitats adjoining crops after crop production. *Euschistus servus* and *E. tristigmus* adults feed on nuts of pecan (Demaree 1922; Turner 1923; Dutcher & Todd 1983). As in our study, Cottrell et al. (2000) reported that traps captured peak numbers of *E. tristigmus* during the late season in pecan orchards. Thus, late-season capture of some *E. tristigmus* and *E. servus* individuals may have been due to their proximity to pecan trees. After crop production, some overwintering *E. servus* and *E. tristigmus* adults were captured in traps in non-crop habitats. Herbert & Toews (2011, 2012) determined that for *E. servus*,

Table 5. Number of *Euschistus servus* and *Euschistus tristigmus* nymphs and adults in pheromone-baited traps with a pyramid base and a bamboo pole base in cotton and peanut.

		Mean (SE) per trap			
		E. servus[a]		*E. tristigmus*[a]	
Crop	Base type	Nymphs	Adults	Nymphs	Adults
Cotton	Pyramid	0.73 (0.18) a	10.41 (1.25) a	0.56 (0.11) a	3.29 (0.46) a
	Bamboo pole	0.11 (0.18) b	0.95 (1.25) b	0.06 (0.11) b	0.41 (0.46) b
Peanut	Pyramid	0.44 (0.09) a	17.19 (1.16) a	0.67 (0.15) a	4.14 (0.31) a
	Bamboo pole	0.03 (0.09) b	2.63 (1.16) b	0.03 (0.15) b	0.29 (0.31) b

[a]For each crop, least square means within a column followed by the same letter are not significantly different for treatment (Tukey's HSD, $P > 0.05$).

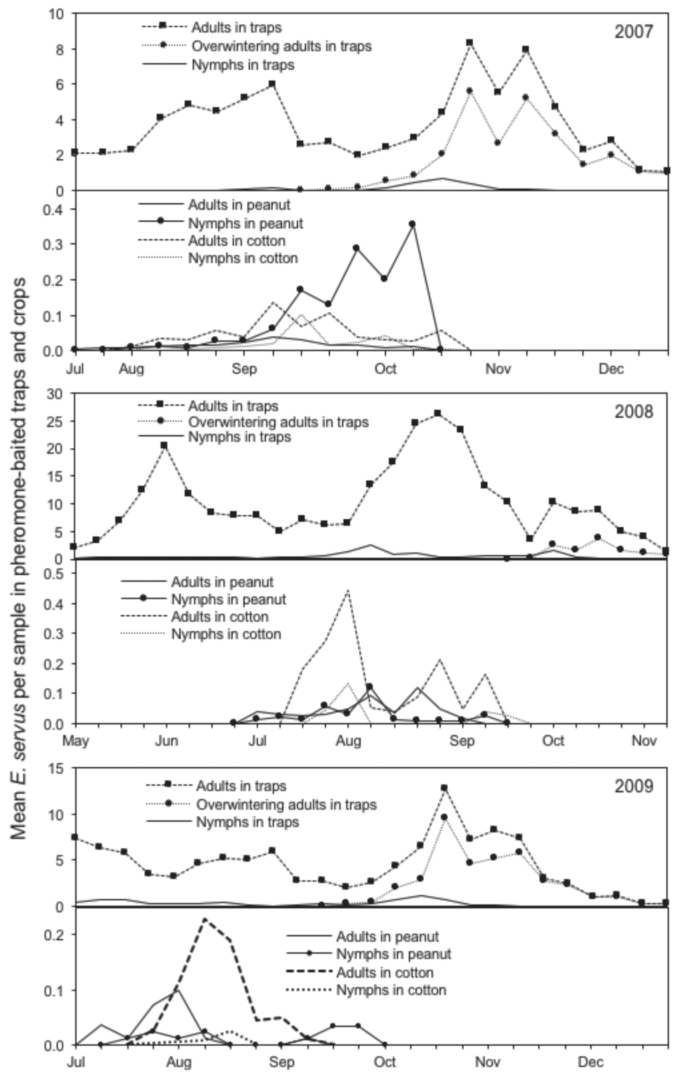

Fig. 2. Mean number of *Euschistus servus* individuals per sample in pheromone-baited traps near crop field edges and in crops in farmscapes over time in 2007, 2008, and 2009.

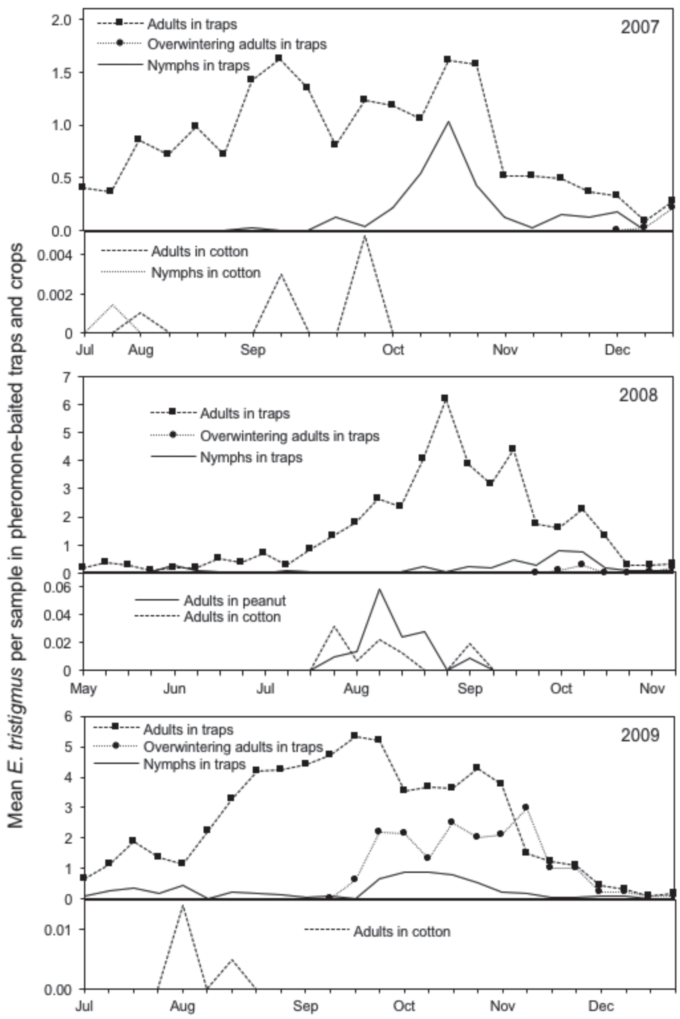

Fig. 3. Mean number of *Euschistus tristigmus* individuals per sample in pheromone-baited traps near crop field edges and in crops in farmscapes over time in 2007, 2008, and 2009.

C. hilaris, and *N. viridula*, the generation that emerges just after the autumnal equinox (22 or 23 Sep) is the overwintering population, and individuals sampled after that date show no signs of reproductive development. Using the change in color of *E. servus* and *E. tristigmus* adults from green to reddish brown as an indicator of reproductive diapause in our study matched the timing of occurrence of overwintering individuals as reported by these authors. Based on their studies, though, all the *E. servus*, *N. viridula*, and *C. hilaris* adults in our traps in non-crop habitats after the autumnal equinox were overwintering individuals.

Altogether, our results strongly indicate that *E. servus*, *E. tristigmus*, *C. hilaris*, and *N. viridula* were present on non-crop hosts before crop production, then developed on crops, and after crop senescence or harvest dispersed into non-crop habitats where they overwintered as adults. It has been well documented in other locations that the 1st generation of these stink bug species develops on non-crop hosts, the next generation often disperses to crops, and adults overwinter in grass clumps, leaf litter, hardwood understory, and under tree bark (Schoene & Underhill 1933; Woodside 1947; Borden et al. 1952; Rolston & Kendrick 1961; Jones & Sullivan 1981, 1982; Mizell & Schiffhauer 1987; Velasco & Walter 1992; Panizzi 1997; Ehler 2000).

Sustainable management strategies have the potential to disrupt this cycle of stink bug population growth and dispersal in farmscapes. Elimination of non-crop herbaceous hosts through mowing before stink bugs colonize these plants may reduce populations of stink bugs dispersing into nearby crops. Host trees also can be removed, but landowners may prefer to preserve these trees. In that case, pheromone-baited traps can be hung on limbs in the canopy of trees to capture stink bugs. In pecan, *E. servus* and *E. tristigmus* were captured in traps on the ground and in the tree canopy, although more *E. servus* individuals were captured on the ground than in traps in the canopy, and more *E. tristigmus* individuals were captured in the canopy at 9 m (Cottrell et al. 2000). Inclusion of year-round stink bug traps in non-crop habitats adjacent to crops in farmscapes potentially offers 3 major benefits: 1) capturing and killing adults before they disperse from non-crop hosts into crops and subsequently damage crop fruit; 2) eliminating females, which have the potential to oviposit on crops, and; 3) reducing the density of overwintering adults in non-crop habitats. We acknowledge that pheromone-baited stink bug traps will not trap all stink bugs in non-crop habitats, and using pheromone-baited traps to manage stink bugs can only be a tool within a set of integrated pest management

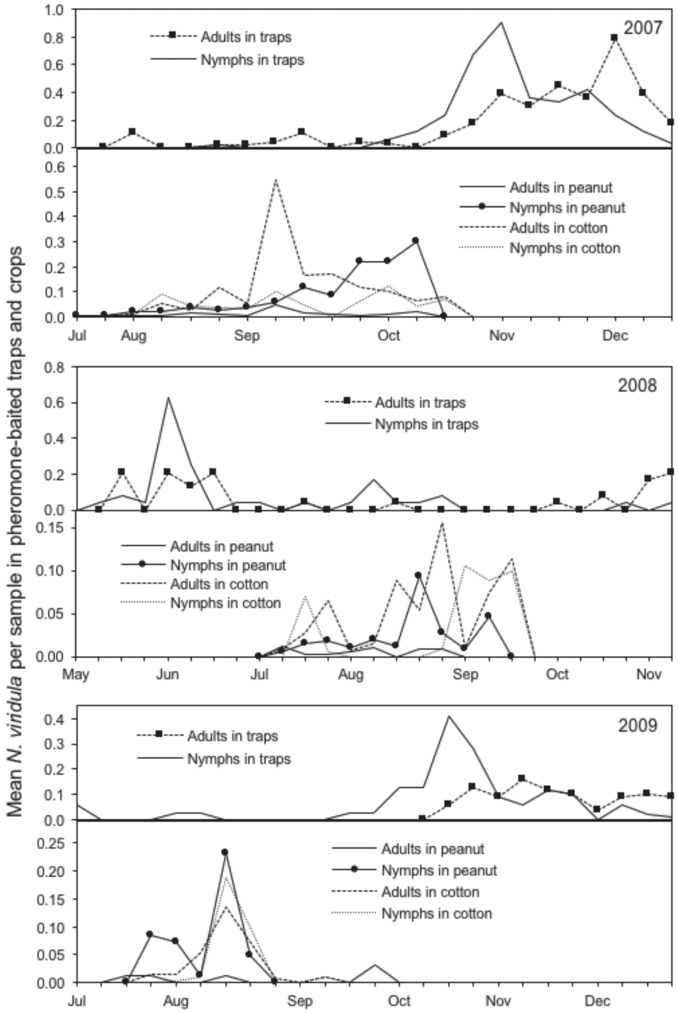

Fig. 4. Mean number of *Nezara viridula* individuals per sample in pheromone-baited traps near crop field edges and in crops in farmscapes over time in 2007, 2008, and 2009.

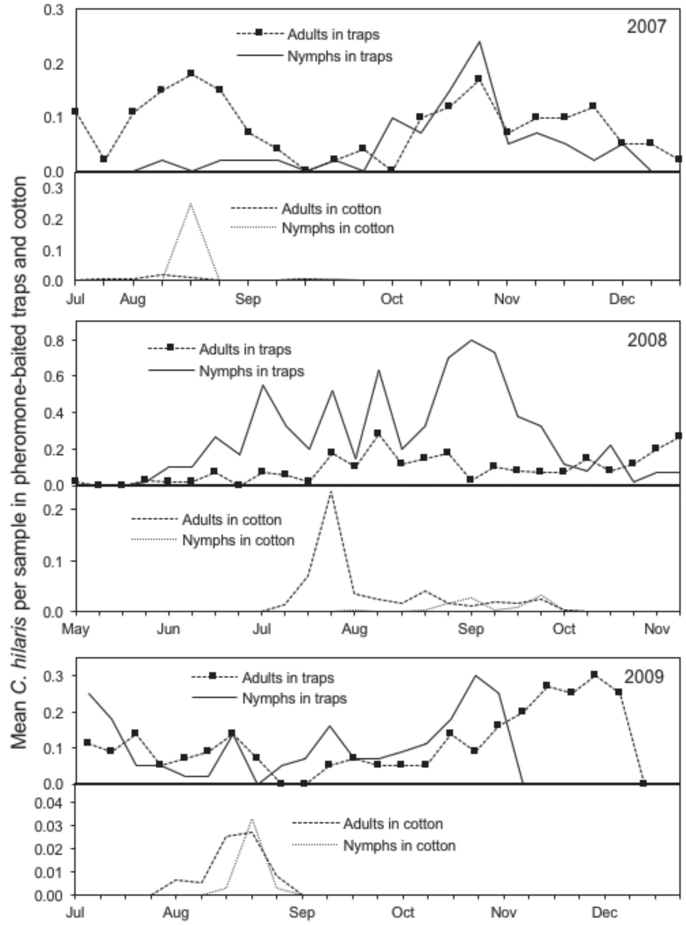

Fig. 5. Mean number of *Chinavia hilaris* individuals per sample in pheromone-baited traps near crop field edges and in crops in farmscapes over time in 2007, 2008, and 2009.

tools. Nevertheless, in this current study only a few pheromone-baited traps captured many stink bugs, including females, in non-crop habitats in farmscapes over a 2 to 3 yr period.

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