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Research Article

Case Study: Trap Crop with Pheromone Traps for Suppressing *Euschistus servus* (Heteroptera: Pentatomidae) in Cotton

P. G. Tillman[1] and T. E. Cottrell[2]

[1] *USDA, ARS, Crop Protection and Management Research Laboratory, P.O. Box 748, Tifton, GA 31793, USA*
[2] *USDA, ARS, Southeastern Fruit & Tree Nut Research Laboratory, 21 Dunbar Road, Byron, GA 31008, USA*

Correspondence should be addressed to P. G. Tillman, glynn.tillman@ars.usda.gov

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The brown stink bug, *Euschistus servus* (Say), can disperse from source habitats, including corn, *Zea mays* L., and peanut, *Arachis hypogaea* L., into cotton, *Gossypium hirsutum* L. Therefore, a 2-year on-farm experiment was conducted to determine the effectiveness of a sorghum (*Sorghum bicolor* (L.) Moench spp. *bicolor*) trap crop, with or without *Euschistus* spp. pheromone traps, to suppress dispersal of this pest to cotton. In 2004, density of *E. servus* was lower in cotton fields with sorghum trap crops (with or without pheromone traps) compared to control cotton fields. Similarly, in 2006, density of *E. servus* was lower in cotton fields with sorghum trap crops and pheromone traps compared to control cotton fields. Thus, the combination of the sorghum trap crop and pheromone traps effectively suppressed dispersal of *E. servus* into cotton. Inclusion of pheromone traps with trap crops potentially offers additional benefits, including: (1) reducing the density of *E. servus* adults in a trap crop, especially females, to possibly decrease the local population over time and reduce the overwintering population, (2) reducing dispersal of *E. servus* adults from the trap crop into cotton, and (3) potentially attracting more dispersing *E. servus* adults into a trap crop during a period of time when preferred food is not prevalent in the landscape.

1. Introduction

Agronomic crops across the southeastern US face significant economic losses from stink bugs (Hemiptera: Pentatomidae), mainly the southern green, *Nezara viridula* (L.), the brown, *Euschistus servus* (Say), and the green, *Chinavia hilaris* (Say) [1]. For example, in cotton (*Gossypium hirsutum* L.), eradication of the boll weevil, *Anthonomus grandis grandis* Boheman (Coleoptera: Curculionidae), along with adoption of *Bt*-crops has decreased use of broad-spectrum insecticides leading to the emergence of stink bugs as major pests [2].

Stink bugs are generalist feeders that exhibit edge-mediated dispersal from early-season crops into subsequent adjacent crops as adults forage for food and sites for oviposition [3–10]. Each year in Georgia, corn (*Zea mays* L.) is one of the earliest agronomic host plants available to stink bugs [11, 12], with peanut (*Arachis hypogaea* L.) and cotton being mid-to-late-season hosts for these pests [13, 14]. Where these three crops are closely associated in farmscapes, *E. servus* disperses from corn into peanut and cotton and from peanut into cotton at the common boundary, or interface, of the source crop and cotton [15, 16].

One strategy for managing dispersing pests is trap cropping where an attractive plant species is used to arrest the pests and reduce their likelihood of entering a crop field [17]. Trap crops have been shown to effectively manage stink bugs in conventional and organic crop production systems [18–22]. Grain sorghum (*Sorghum bicolor* (L.) Moench spp. *Bicolor*) is an important host plant for panicle-feeding stink bugs in Georgia [23], and it can suppress populations of *N. viridula* in farmscapes in Georgia [24].

The pheromone of *Euschistus* spp. is attractive to males, females, and nymphs of *E. servus* and other *Euschistus* spp. [25]. A pyramidal trap [26] was modified [27] to facilitate stink bug capture. When these capture traps contain lures of

Table 1: Planting date (PD) and variety for cotton in sorghum trap crop with pheromone traps (STC/PTs), sorghum trap crop (STC), and control (CO) fields in 2004 and 2006.

Year	Treatment	Rep	Variety	PD
2004	STC/PT	1 & 2	Deltapine 449	5/6
		3	Fibermax 960	5/10
		4	Deltapine 555	5/8
	STC	1	Deltapine 458	5/6
		2	Fibermax 960	4/23
		3 & 4	Deltapine 555	5/6
		5	Deltapine 555	5/15
	CO	1	Deltapine 444	5/31
		2 & 3	Deltapine 555	5/6
		4 & 5	Deltapine 555	5/8
		6	Fibermax 960	5/12
		7	Fibermax 960	4/29
		8	Deltapine 555	5/15
2006	STC	1	Deltapine 555	5/4
		2	Deltapine 555	4/28
		3	Deltapine 555	5/10
	CO	1	Deltapine 555	5/4
		2	Deltapine 555	5/26
		3	Deltapine 555	5/1

a specific stink bug pheromone, they effectively capture *E. servus*, *N. viridula*, and *C. hilaris* [27, 28]. The addition of an insecticidal ear tag improved trap captures of *Euschistus* spp. in pecan orchards by preventing escape of the bugs [29].

Our hypothesis was that sorghum planted in a narrow strip along the length of the interface of a source crop and cotton would attract *E. servus* adults. Additionally, capture traps baited with *Euschistus* spp. pheromone within the sorghum would help reduce dispersal out of sorghum by capturing and killing the pests in the sorghum. Thus, a full-scale field experiment was conducted to determine the effectiveness of sorghum with *Euschistus* spp. pheromone traps to suppress *E. servus* in cotton.

2. Materials and Methods

2.1. Study Sites. Twenty-three commercial cotton fields were sampled during this 2-year study (Table 1). These cotton fields were located in Irwin County GA and ranged from 5 to 15 ha in size. Overall, five cotton varieties were planted (Table 1). Sorghum, variety DK E57, was planted in a 4-row-wide strip along the length of the edge of a cotton field next to a source crop (corn or peanut) on May 5 2004 and on April 14 2007. Growers followed recommended agricultural practices for production of sorghum [30] and cotton [31]. Row width was 0.91 m for each crop, and rows of adjacent crops ran parallel.

2.2. Stink Bug Pheromone Traps. A pheromone trap consisted of a 2.84-liter clear plastic poly-ethylene terephthalate jar (United States Plastic Corp., Lima, OH, USA) on top of a 1.22 m-tall yellow pyramidal base [27]. An insecticidal ear tag (Saber Extra, Coppers Animal Health, Inc., Kansas City, KS, USA) was placed in the plastic jar at the beginning of a test. Active ingredients in the ear tag were lambda-cyhalothrin (10%) and piperonyl butoxide (13%). Rubber septa, each loaded with 40 μL of the *Euschistus* spp. pheromone, methyl (*E*,*Z*)-2,4-decadienoate (CAS registry no. 4493-42-9) (Degussa AG Fine Chemicals, Marl, Germany), were used as lures [32]. Lures were changed weekly for the duration of a test. Insects from weekly collections were taken to the laboratory for identification.

2.3. 2004 Experiment. Two treatments at the edge of cotton fields were examined for their ability to suppress stink bugs dispersing from an adjacent source crop into cotton: a sorghum trap crop with *Euschistus* spp. pheromone traps (STC/PTs) and a sorghum trap crop only (STC). Control fields had no sorghum or pheromone traps. For STC/PT fields, 21 pheromone traps were placed 12 m apart in sorghum on the row next to the source crop. At the beginning of the study, 17 cotton fields were selected, and each treatment was assigned randomly to various fields (four fields for STC/PT, five fields for STC, and eight fields for control) similar to a completely randomized design. Individual fields were used as replicates because the sorghum trap crops were planted along the full width between the cotton field and source crop.

2.4. 2006 Experiment. Only the STC/PT treatment and a control, both as explained above for the 2004 experiment, were used. At the beginning of the study, six cotton fields were selected, and each treatment was assigned randomly to three fields similar to a completely randomized design. For the STC/PT treatment, 25–28 pheromone traps (depending on field width) were placed 12 m apart in the first row of sorghum closest to the source crop.

2.5. Insect Sampling. Each year of the study, cotton, sorghum, and pheromone traps were examined for the presence of stink bugs on a weekly basis: from the week of 16 June to the week of 28 July in 2004 and from the week of 28 June to the week of 23 August in 2006. Due to time constraints of sampling these large fields, not all fields were sampled on the same day of the week, but crops and/or pheromone traps within a field were sampled on the same day. For each sorghum sample, the aerial parts of all plants within a 1.83 m length of row were visually checked thoroughly for all stink bugs. For each cotton sample, all plants within a 1.83 m length of row were shaken over a drop cloth and the aerial parts of all plants were visually checked thoroughly for all stink bugs. Voucher specimens are stored in the USDA, ARS, Crop Protection & Management Research Laboratory in Tifton, GA, USA.

For sampling purposes, the edge of a cotton field adjacent to a source crop was referred to as side A, and in a clockwise direction the other 3 sides of a field were referred to as side B, C, and D. In 2004, samples were obtained in each cotton field at two different distances from the field edge along each of the 4 sides of the field. The first edge location was 0–3.66 m from the outside edge of the field, and the second edge location was 3.67–7.31 m from the outside edge of the field. The interior of the field was subdivided into 9 equally sized blocks. During weeks 3–6, samples were collected in each field as follows: 2 samples from each side at the 0–3.66 m location, 2 samples from each side at the 3.67–7.31 m location, and 1 sample from the center of each interior block. During week 7, samples were collected as follows: 2 samples from the center of each interior block and 2 samples from each side at the 3.67–7.31 m location, but at the 0–3.66 m location, 6–12 samples (depending on length of field edge) were collected from each field edge.

In 2006, samples were obtained at 3 distances from the edge on side A (i.e., at rows 1, 2, and 5 from the edge of the cotton field), and from 6 interior locations down the length of the field near to side C (i.e., rows 16, 33, 100, 167, 233, and 300 from the edge of the field on side A). For sides B–D, samples were taken from 2 edge locations, rows 1 and 5 from the edge of the field. The numbers of samples from each field on each date were as follows: 9 from each row on side A, 3 from each row on sides B–D, and 6 from each interior location.

During 2004, the 4-row strip of sorghum was sampled by taking five random samples from rows 1 and 2 and four random samples from rows 3 and 4. In 2006, 9 random samples were obtained from each of the 4 rows.

2.6. Statistical Analysis. For cotton, trap crop treatments in 2004 and 2006 were analyzed using PROC MIXED [33]. For both years of data, preliminary analyses revealed that there was only a significant treatment × week × field location interaction; there were no significant differences among fields. So, when trap crop data were analyzed, the fixed effect was treatment by week by field location, and random effects were replicate within treatment and residual error. Least squares means were separated by least significant difference (LSD) [33] where appropriate. In 2004, two cotton fields (one STC/PT field and one control field) were not included in the data set for sampling week 7 because the grower treated for stink bugs after sampling on week 6. In 2006, one STC cotton field was not included in the data set for sampling during week 9 because it was treated for stink bugs after sampling on week 8. Chi-square analyses were used to compare frequencies of *E. servus*, *N. viridula*, and *C. hilaris* for each trap crop treatment by week in 2004 and 2006 (PROC FREQ, [33]).

For 2004 data, numbers of *E. servus* per sample in the pheromone traps, sorghum with and without pheromone traps, cotton with sorghum trap crops with and without pheromone traps, and control cotton were plotted over time. Least squares means from the above analyses were used for number of *E. servus* per sample for cotton, and only data for side A were used because statistical differences in *E. servus* density were detected among trap crop treatments mainly on this field edge. Means were obtained for number of *E. servus* adults per pheromone trap using PROC MEANS [33]. The numbers of *E. servus* adults per sample per week in the sorghum trap crop, with and without pheromone traps, were compared using t-tests; the means were used to plot number of *E. servus* adults per sample in sorghum over time.

For 2006 data, numbers of *E. servus* per sample in pheromone traps, sorghum with pheromone traps, cotton with sorghum trap crops with pheromone traps, and control cotton were plotted over time. Means were obtained for number of *E. servus* adults per sample for sorghum and pheromone traps using PROC MEANS [33]. Least squares means from above analyses were used for number of *E. servus* per sample for cotton, and only data for side A, rows 1 and 2, were used because statistical differences in *E. servus* density were detected between trap crop treatments at these field locations.

3. Results and Discussion

3.1. Stink Bug Species Composition. Eight species of stink bugs species, that is, *E. servus*, *N. viridula*, *Oebalus pugnax pugnax* (F.), *Euschistus quadrator* (Rolston), *Euschistus ictericus* (L.), *C. hilaris*, *Euschistus tristigmus* (Say), and *Piezodorus guildinii* (Westwood), were found in sorghum over both years of this on-farm study in Georgia. These stink bugs species were also captured in *Euschistus* spp. pheromone traps (Table 2). As expected, more *Euschistus* spp., especially *E. servus*, were captured in traps baited with the *Euschistus* spp. pheromone than any other stink bug species. *N. viridula* was the predominant species in sorghum, whereas *C. hilaris* was rarely found in sorghum or captured in the pheromone traps. *Thyanta custator custator* (F.) was captured in the pheromone traps but was not found in sorghum even though this species has been collected from other sorghum plots (first author, unpublished data). *E. servus* nymphs were rarely captured in the pheromone traps; only 0.4% of all *E. servus* in these traps were nymphs. Also, for both years of the study,

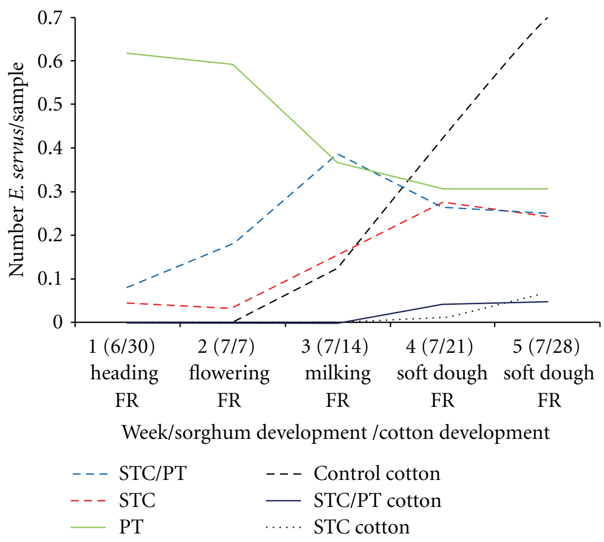

Figure 1: Mean number of *E. servus* per sample in sorghum trap crop with pheromone traps (STC/PTs), sorghum trap crop without pheromone traps (STC), and pheromone traps (PTs), and least squares means for number of *E. servus* in STC/PT cotton, STC cotton, and control cotton in 2004. FR: cotton with fruit. Number of stink bugs in pheromone traps was divided by 10. Only data on side A were used for cotton. Date refers to middle of sampling week.

a range of 60–70% of the *E. servus* killed in these pheromone traps were females. Incorporating pheromone traps in a sorghum trap crop may decrease nymphal development of *E. servus* in the trap crop by reducing oviposition.

3.2. 2004 Experiment. For the first two weeks of the study, the number of *E. servus* per pheromone trap was relatively high, but density of the pest remained relatively low in sorghum with or without pheromone traps (Figure 1). These results indicate that *E. servus* was attracted to pheromone traps and uninterested in feeding on sorghum in the heading and flowering stages. Once sorghum finished flowering and reached the milking stage, *E. servus* began feeding on developing seeds in sorghum heads. Similarly, in an earlier study *E. servus* was observed on sorghum heads soon after completion of flowering [23], and in an additional study, the milking stage of sorghum heads was the most preferred stage for feeding by *E. servus* [22].

The number of *E. servus* adults was statistically higher in sorghum with pheromone traps compared to sorghum without these traps on weeks 2 and 3 (Table 3) indicating that the pheromone traps attracted more dispersing *E. servus* adults into the trap cropping system during a period of time when preferred food was not prevalent in sorghum. As *E. servus* density increased in sorghum, the number of *E. servus* dropped in pheromone traps (Figure 1). A similar response was observed for *E. servus* in peanut-cotton farmscapes as fruit became available on cotton [28]. There are at least two possible explanations for this observed response: (1) once *E. servus* has dispersed into sorghum and fruit are available in the crop, these insects may begin to become more

Table 2: Phytophagous stink bugs in *Euschistus* spp. pheromone traps and in sorghum trap crops.

Species	% in pheromone traps	% in sorghum trap crops
E. servus	69.1	10.9
N. viridula	10.6	71.5
O. p. pugnax	8.2	13.2
E. quadrator	7.4	2.8
E. ictericus	2.8	0.1
C. hilaris	1.1	1.3
E. tristigmus	0.6	0.1
P. guildinii	0.1	0.1
T. c. custator	0.1	0

interested in feeding than in responding to the aggregation pheromone, or (2) the attractiveness of the pheromone in the capture traps may decrease as pheromone from *E. servus* males aggregating on sorghum heads disperses throughout sorghum. These results also suggest that the number of *E. servus* in pheromone traps can be more a reflection of dispersal activity of *E. servus* into a crop rather than the density of the pest in a specific crop. Similarly, for the consperse stink bug, *Euschistus conspersus* Uhler, migration of sexually mature females from overwintering sites results in an elevated pheromone (*Euschistus* spp.) trap response relative to the surrounding field population early in the growing season before fruit are available in processing tomatoes, *Lycopersicon esculentum* Miller [34–36]. Also, the synthetic pheromone of the Neotropical brown stink bug, *Euschistus heros* (F.), is attractive to this pest in the field [37], and pheromone-baited traps are more efficient than field sampling mainly during the colonization of soybean [38].

For this trap crop experiment, factorial analyses revealed a significant treatment × week × field location effect ($F = 1.76$; $df = 83, 406$; $P = 0.0002$) for number of *E. servus* per 1.83 m of row in cotton (Table 4). Density of *E. servus* adults per sample on side A was lower in cotton fields with sorghum trap crops (with or without pheromone traps) compared to control cotton fields on weeks 4 and 5. Indeed, for control cotton, density of *E. servus* was significantly higher on side A on weeks 4 and 5 compared to all other locations for those two weeks indicating that there was an edge effect in distribution of stink bugs in these farmscapes. There was no significant difference in density of *E. servus* adults between cotton fields with a sorghum trap crop, with or without pheromone traps, at this location on these two weeks. So, even though sorghum trap crops with pheromone traps may attract more *E. servus* than trap crops without pheromone traps, this increase in attraction does not translate into higher densities of the pest moving into cotton. A total of 4042 and 1406 *E. servus* adults were captured and killed in pheromone traps in these farmscapes in 2004 and 2006, respectively. Evidently, the pheromone traps effectively capture *E. servus*, but not all of them at any point in time, probably because they continue to disperse into the trap crop.

E. servus was first observed in control cotton with fruit on week 3 (Figure 1). In control cotton, *E. servus* density

Table 3: Number (mean ± SE) of *E. servus* adults per 1.83 m of row in sorghum trap crops with pheromone traps (STC/PTs) and sorghum trap crops alone (STC) in 2004.

Week	STC/PT	STC	$\|t\|$	df	P
1	0.0833 ± 0.0467	0.0444 ± 0.0311	0.69	63	0.4908
2	0.1806 ± 0.0636	0.0333 ± 0.019	2.43	160	0.0163
3	0.3889 ± 0.0852	0.1556 ± 0.0497	2.47	160	0.0144
4	0.2639 ± 0.0559	0.2778 ± 0.057	0.17	160	0.8642
5	0.25 ± 0.0585	0.2444 ± 0.0507	0.07	160	0.9427

Table 4: Least squares means for number of all *E. servus* per 1.83 m of row in different locations in cotton for sorghum trap crop with pheromone traps (STC/PTs), sorghum trap crop (STC), and control (CO) fields in 2004.

Location	Week	STC/PT	STC	CO
side A[a]	2	0 1,a,A	0 1,a,A	0 3,a,A
	3	0 1,a,A	0 1,a,A	0.125 3,a,A
	4	0.041 1,b,A	0.0103 1,b,A	0.4292 2,a,A
	5	0.0476 1,b,A	0.0677 1,b,B	0.7015 1,a,A
side B	2	0.125 1,a,A	0 1,a,A	0 1,a,A
	3	0 1,a,A	0.15 1,a,A	0 1,a,A
	4	0.0478 1,a,A	0.2 1,a,A	0.1651 1,a,B
	5	0.0329 1,a,A	0.0254 1,a,B	0.0095 1,a,B
side C	2	0 1,a,A	0 1,a,A	0 1,a,A
	3	0.0625 1,a,A	0.05 1,a,A	0.0003 1,a,A
	4	0 1,a,A	0.05 1,a,A	0.0818 1,a,B
	5	0 1,a,A	0.2494 1,a,AB	0.1224 1,a,B
side D	2	0 1,a,A	0 2,a,A	0 1,a,A
	3	0.125 1,a,A	0.05 2,a,A	0 1,a,A
	4	0 1,a,A	0 2,a,A	0 1,a,B
	5	0 1,b,A	0.3315 1,a,A	0.0836 1,ab,B
block 1	2	0 1,a,A	0 1,a,A	0.0833 1,a,A
	3	0.0833 1,a,A	0.0667 1,a,A	0 1,a,A
	4	0.1346 1,a,A	0.0667 1,a,A	0 1,a,B
	5	0.2444 1,a,A	0.1504 1,a,AB	0.0095 1,a,B
block 2	2	0.0833 1,a,A	0 1,a,A	0 1,a,A
	3	0 1,a,A	0.0667 1,a,A	0.0833 1,a,A
	4	0.0774 1,a,A	0.0667 1,a,A	0 1,a,B
	5	0.0774 1,a,A	0.1028 1,a,B	0.1206 1,a,B
block 3	2	0 1,a,A	0 1,a,A	0 1,a,A
	3	0.0833 1,a,A	0 1,a,A	0.0833 1,a,A
	4	0 1,a,A	0.0667 1,a,A	0 1,a,B
	5	0.2444 1,a,A	0.0551 1,a,B	0.0095 1,a,B

Least squares means within a column followed by the same number are not significantly different between weeks within a location for a single treatment. Least squares means within a row followed by the same lowercase letter are not significantly different between trap crop treatments within a location for a single week. Least squares means within a column followed by the same uppercase letter are not significantly different between locations within a treatment for a single week. (PROC MIXED, LSD, $P > 0.05$, for all *E. servus*, $n = 1550$, SE = 0.0938, df = 1040).
[a]Cotton edge along the common boundary of a cotton field and a field of another crop that was a source of stink bugs.

was significantly higher on week 4 compared to week 3 and higher on week 5 compared to week 4 on Side A (Table 4). Thus, *E. servus* density increased in control cotton from week 3 to 5 as depicted in Figure 1. During this time, the pest probably dispersed from the source crops into control cotton as previously reported in other cotton farmscapes in Georgia [15, 16]. *E. servus* first occurred in cotton with sorghum trap crops (with or without pheromone traps) on week 4. For both trap crop treatments, density of *E. servus* in cotton was similar on weeks 4 and 5 (Table 4). As *E. servus* density increased in control cotton, it remained relatively low in the two treatments with sorghum trap crops (Table 4, Figure 1). Thus, both trap cropping systems effectively arrested *E. servus* reducing dispersal of this pest into cotton. Edge effects occur on other field edges, as expected, and not just at the interface of the source crop and cotton. For the sorghum

TABLE 5: Frequency (%) of *E. servus*, *N. viridula*, and *C. hilaris* in cotton by week for sorghum trap crop with pheromone traps (STC/PTs), sorghum trap crop (STC), and control (CO) fields in 2004 and sorghum trap crop (STC) and control (CO) fields in 2006.

Year	Wk	Trt	*E. servus* *n*	*E. servus* %	*N. viridula* *n*	*N. viridula* %	*C. hilaris* *n*	*C. hilaris* %	χ^2	df	*P*
2004	3	Control	7	15.91	37	84.09	0	0			
		STC/PT	5	20.83	8	33.33	11	45.83			
		STC	8	53.33	5	33.33	2	13.33			
		Total	**20**	**20.83**	**8**	**33.33**	**11**	**45.83**	**36.4**	**4**	**0.0001**
	4	Control	11	8.09	121	88.97	2	2.94			
		STC/PT	5	11.36	38	86.36	1	2.27			
		STC	8	11.43	57	81.43	5	7.14			
		Total	**24**	**9.6**	**216**	**86.4**	**10**	**4.0**	**3.5**	**4**	**0.4852**
	5	Control	22	5.45	373	92.33	9	2.23			
		STC/PT	13	6.4	182	87.89	8	3.94			
		STC	41	11.68	287	81.77	23	6.55			
		Total	**76**	**7.93**	**842**	**87.89**	**40**	**4.18**	**20.9**	**4**	**0.0003**
2006	6	Control	8	18.18	29	65.91	7	15.91			
		STC/PT	1	14.29	0	0	6	85.71			
		Total	**9**	**17.65**	**29**	**56.86**	**13**	**25.49**	**16.2**	**2**	**0.0003**
	7	Control	19	32.2	37	62.71	3	5.08			
		STC/PT	2	3.08	26	40.0	37	56.92			
		Total	**21**	**16.94**	**63**	**50.81**	**40**	**32.26**	**44.4**	**2**	**0.0001**
	8	Control	43	32.82	76	58.02	12	9.16			
		STC/PT	3	2.42	34	27.42	87	70.16			
		Total	**46**	**18.04**	**110**	**43.14**	**99**	**38.82**	**107.5**	**2**	**0.0001**

trap crop alone treatment, *E. servus* density was significantly higher on side D on week 5 than on side A and B and block 2 and 3 (Table 4).

Three species of stink bugs, *E. servus, N. viridula*, and *C. hilaris*, were observed feeding on cotton fruit in both years (Table 5). In 2004, *E. servus* in cotton comprised 5–53% of the stink bug species over the three treatments. *N. viridula* was the predominant stink species in cotton except during week 3 when *C. hilaris* was predominant (with trap crops and stink bug capture traps). Also, during this same week in STC cotton, *E. servus* was the predominant species on cotton, and frequency of this pest was higher in these cotton fields than in STC/PT and control fields. On week 5, frequency of *E. servus* in cotton with sorghum trap crops alone was twice that for cotton with the STC/PT and control treatments. Apparently, incorporating the pheromone traps with the sorghum trap crop reduced dispersal of *E. servus* from the trap crop at least two out of three weeks.

3.3. 2006 Experiment. While sorghum was flowering, *E. servus* was captured in pheromone traps, but pest density was relatively low in sorghum (Figure 2). There was a slight drop in the number of *E. servus* per pheromone trap as the pest peaked during the milking stage of sorghum. Apparently, *E. servus* was drawn into the pheromone traps and then was arrested on sorghum when it was available as food. *E. servus* first appeared when small fruits were available in control cotton fields during week 3. Trap capture of *E. servus* increased from week 6 to week 7, and *E. servus* density increased in control cotton on week 7 and 8. This major influx of *E. servus* into pheromone-baited traps and control cotton indicates a significant dispersal of adults from the source crop as has been previously reported for peanut-cotton farmscapes in Georgia [15]. The pest occurred in cotton with sorghum trap crops and pheromone traps for the first time on week 7 indicating that the trap cropping system had effectively stopped *E. servus* from dispersing into cotton for 4 weeks, from weeks 3 through 6.

For this trap crop experiment, factorial analyses revealed a significant treatment × week × field location effect ($F = 4.68$; df $= 71, 779$; $P = 0.0001$) for numbers of *E. servus* per 1.83 m of row in cotton (Table 6). There was an edge effect in distribution of stink bugs in control cotton; density of *E. servus* was significantly higher on row 1 on side A compared to all other locations except row 2 on week 7 and on rows 1 and 2 on side A compared to all other locations on week 8. In control cotton, *E. servus* density was significantly higher on week 7 compared to week 6 and higher on week 8 compared to week 7 so density of the pest increased in cotton over time probably due to continual dispersal of *E. servus* from the source crop into the adjacent cotton rows as has been observed in other peanut-cotton farmscapes in Georgia [15]. The trap cropping system, though, effectively suppressed this pest in these farmscapes, for density of *E. servus* per sample was higher in control cotton fields compared to cotton fields with sorghum trap crops with pheromone traps on rows 1 and 2 of side A on weeks 7 and 8.

Table 6: Least squares means for number of all *E. servus* per 1.83 m of row in different locations in cotton for sorghum trap crop with pheromone traps (STC/PT) and control (CO) fields in 2006.

Side	Row	Week	STC/PT	CO
A[a]	1	6	0 1,a,A	0.037 3,a,A
	2		0 1,a,A	0.0926 1,a,A
	5		0.0185 1,a,A	0.0185 1,a,A
	16		0 1,a,A	0 1,a,A
	33		0 1,a,A	0 1,a,A
	100		0 1,a,A	0 1,a,A
	167		0 1,a,A	0 1,a,A
	233		0.0006 1,a,A	0 1,a,A
	300		0.0006 1,a,A	0 1,a,A
B			0 1,a,A	0 1,a,A
C			0 1,a,A	0 1,a,A
D			0 1,a,A	0 1,a,A
A	1	7	0.0142 1,b,A	0.1667 2,a,A
	2		0.0003 1,b,A	0.1111 1,a,AB
	5		0.0003 1,a,A	0.0370 1,a,B
	16		0.0003 1,a,A	0 1,a,B
	33		0.0003 1,a,A	0 1,a,B
	100		0.0003 1,a,A	0 1,a,B
	167		0.0419 1,a,A	0.0556 1,a,B
	233		0.0008 1,a,A	0 1,a,B
	300		0.0008 1,a,A	0 1,a,B
B			0.0003 1,a,A	0 1,a,B
C			0.0003 1,a,A	0 1,a,B
D			0.0003 1,a,A	0.0185 1,a,B
A	1	8	0 1,b,A	0.4259 1,a,A
	2		0.0550 1,b,A	0.1852 1,a,B
	5		0 1,a,A	0.037 1,a,C
	16		0 1,a,A	0.0556 1,a,C
	33		0 1,a,A	0 1,a,C
	100		0 1,a,A	0 1,a,C
	167		0 1,a,A	0 1,a,C
	233		0.0002 1,a,A	0 1,a,C
	300		0.0002 1,a,A	0 1,a,C
B			0 1,a,A	0.0741 1,a,C
C			0.0273 1,a,A	0.0185 1,a,C
D			0 1,a,A	0.037 1,a,C

Least squares means within a column followed by the same number are not significantly different between weeks within a location for a single treatment. Least squares means within a row followed by the same lowercase letter are not significantly different between trap crop treatments within a location for a single week. Least squares means within a column followed by the same uppercase letter are not significantly different between locations within a treatment for a single week. (PROC MIXED, LSD, $P > 0.05$, for all *E. servus*, $n = 2539$, SE = 0.0342, df = 1811).
[a]Cotton edge along the common boundary of a cotton field and a field which was a source of stink bugs.

In 2006, *N. viridula* was the predominant stink bug species in control cotton, and *C. hilaris* was the predominant species in cotton with sorghum trap crops (Table 5). On weeks 7 and 8, the frequency of *E. servus* was higher in control cotton than that in cotton with sorghum trap crops with pheromone traps. Apparently, incorporating the pheromone traps with the sorghum trap crop reduced the dispersal of *E. servus* into cotton.

3.4. Effectiveness of Trap Cropping System for Suppression of E. servus . An ideal trap cropping system should include a host plant which is strongly preferred by the pest over the cash crop and should be able to reduce the likelihood of the pest dispersing into the cash crop [17]. In 2004, when sorghum alone was utilized as a trap cropping system, *E. servus* adults strongly preferred sorghum (from the milking stage through the soft dough stage) to cotton (with fruit). Furthermore,

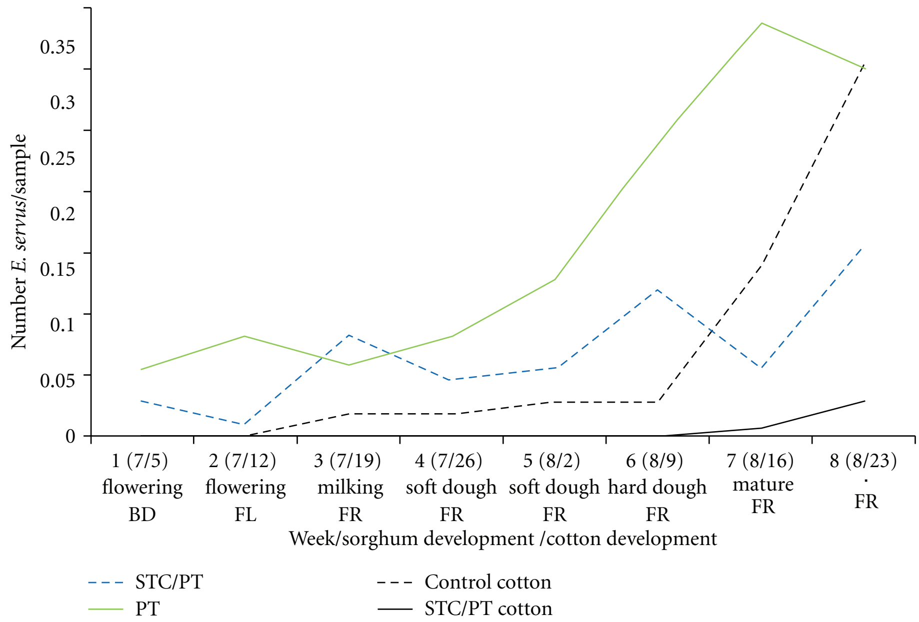

Figure 2: Mean number of *E. servus* per sample in sorghum trap crop with pheromone traps (STC/PTs), pheromone traps (PTs), STC/PT cotton, and cotton control in 2006. BD: cotton with buds; FL: cotton with flowers; FR: cotton with fruit. Number of stink bugs in pheromone traps was divided by 10. Only data for side A, rows 1 and 2, are used for cotton. Date refers to middle of sampling week.

over both years of the study a sorghum trap crop with or without pheromone traps effectively attracted *E. servus* in sorghum reducing dispersal of this pest into cotton.

Strategic placement of the trap cropping system in time and space also apparently was essential to the success of this suppression tactic in these farmscapes. Corn is an early summer source of stink bugs dispersing to peanut and cotton, and peanut is a mid-to-late summer source of stink bugs moving to cotton, especially at the interface of these farmscapes [15, 16]. Thus, in this study, a trap cropping system was established at the interface of a source crop (i.e., corn or peanut) and cotton, and the trap crop was planted in time to provide preferred food to stink bugs dispersing from the source crop into cotton. In farmscapes where stink bugs are active throughout the season, a season-long trap cropping system may be needed to protect cotton. Season-long trapping of stink bugs should reduce stink populations throughout the seasonal succession of host plants, possibly eliminating the need for additional control measures in cotton. A season-long stink bug trap cropping system that includes triticale, hairy vetch, and crimson clover during the spring followed by sunflower, buckwheat, sorghum, and pearl millet during the summer and fall has been developed to effectively manage stink bugs in organically grown soybean [22]. The system is economical to culture and manage provides a range of physical practices, including ratooning (mowing), and a range of maturity dates. All of these could be used alone or together by growers to customize the system for general use.

Stink bugs are well-adapted opportunists that will take advantage of available food resources at crop interfaces with both sorghum and soybean [13] being preferred over cotton. However, some stink bugs will still move into cotton near the preferred trap crop. In the current study, even though sorghum trap crops arrested *E. servus* and subsequently reduced dispersal of this pest into cotton, some *E. servus* apparently dispersed from sorghum into cotton. Indeed, in the 2004 experiment, some *E. servus* moved into cotton even though the sorghum heads were still in the attractive developmental stage. In a preliminary on-farm test, *E. servus* adults were significantly higher in a soybean trap crop than in adjacent fruiting cotton, but adult stink bugs still fed on some cotton fruit in the first two rows adjacent to soybean, over the period of attractiveness of soybean (first author, unpublished data).

Stink bug pheromone traps containing lures with *Euschistus* spp. pheromone (and insecticidal ear tags) have been shown to effectively capture and kill *E. servus* [27, 28], and thus they have great potential to suppress this pest in agricultural landscapes. One of the questions to be considered on how to utilize these traps as a management tool is whether they have the ability as a single tool to suppress *E. servus* in crops. In two separate experiments, establishing *Euschistus* spp. pheromone traps at the interface of peanut-cotton plots did not inhibit dispersal of *E. servus* when cotton fruit became available as a food source [28]. In another small-plot trap cropping experiment in peanut-cotton plots, *Euschistus* spp. pheromone traps captured *E. servus* adults, but *E. servus* density was equally high in cotton in plots with only the pheromone traps and control plots when cotton fruits were present (first author, unpublished data). These results indicate that as the sole management tool, *Euschistus* spp. pheromone traps cannot effectively stop dispersal of *E. servus* from peanut into fruiting cotton. However, in the second experiment, it was also determined that density of *E. servus* in cotton was statistically lower in cotton in plots with a soybean trap crop with pheromone traps compared to control plots suggesting that pheromone traps are more effective in suppressing *E. servus* when used in combination with a trap crop. Apparently, stink bugs require a source of preferred food to remain in a location. Interestingly, though, *Euschistus* spp. pheromone can attract *E. servus* adults, dispersing from an adjacent crop within the agricultural landscape, into a sorghum trap crop even when sorghum heads have not yet developed to the preferred feeding stage. Perhaps, pheromone traps should be established in sorghum before heads develop seeds and remain in the trap crop throughout the period cotton that is susceptible to economic damage. Initially pheromone traps would attract and kill *E. servus* dispersing from a source crop and then pheromone traps would capture and kill *E. servus* attracted to sorghum.

Even with incorporation of pheromone traps, some *E. servus* still dispersed from sorghum into cotton. During 2004, preferred food was still available in sorghum when stink bugs moved into cotton. In this experiment pheromone traps were placed only on the sorghum row adjacent to a source crop. Perhaps, placing pheromone traps on every row of sorghum would decrease dispersal from sorghum into cotton. During 2006, *E. servus* probably began dispersing from sorghum into cotton because the seeds were no longer in the preferred feeding stage for the pest. Ratooning the sorghum heads or providing multiple plantings of the trap crop could extend the length of time preferred food available to the pest. In a small-plot trap cropping experiment, *E. servus* density was significantly lower in cotton plots with a stink bug barrier (1.83 m tall plastic wall) than in cotton plots with a soybean trap crop (first author, unpublished data). Thus, planting a tall crop such as Sudan grass (*Sorghum bicolor* (L.) Moench spp. *drummondii* (Nees ex Steud.) de We & Harlan) between a trap crop and cotton could possibly further decrease opportunistic movement from the trap crop into the cash crop.

The question remains whether a trap crop with pheromone traps is more effective in suppressing *E. servus* in cotton than a trap crop alone. Even though there was no significant difference in density of *E. servus* in cotton between the two trap crop treatments in 2004, incorporation of pheromone traps in trap crops can provide additional benefits including the following:

(1) reducing the density of *E. servus* adults in a trap crop, especially females, to possibly decrease the local population over time and reduce the overwintering population,

(2) reducing the dispersal of *E. servus* adults from the trap crop into cotton,

(3) potentially attracting more dispersing *E. servus* adults into a trap crop during a period of time when preferred food is not prevalent in the landscape.

A multifunctional habitat with a combination of trap crops to detract stink bugs from feeding and ovipositing on cash crops and pheromone traps with insecticidal ear tags to capture and kill stink bugs has the greatest potential for suppressing stink bugs in cotton. In Georgia, *N. viridula* and *C. hilaris*, along with *E. servus*, can cause economic damage to cotton fruit. Thus, a trap cropping system established to protect cotton from stink bugs must provide host plants preferred for feeding by all three stink bugs. Unfortunately, *C. hilaris* rarely occurs in sorghum, but because they readily feed on soybean (*Glycine max* (L.) Merr.) pods (first author, unpublished data), this plant may be a more suitable trap crop for this pest. However, *N. viridula* is highly attracted to grain sorghum heads in the milk stage through the hard dough stage [39], and *N. viridula* adults prefer sorghum to cotton [24]. Thus, a combination of grain sorghum and soybean could serve as an effective trap cropping system for these three stink bug species. In addition, other host plant species could be added to the trap cropping system to extend its longevity. Even though *N. viridula* prefers sorghum to cotton, some individuals of this pest can disperse into cotton rows adjacent to the trap crop [24]. Under field conditions, *N. viridula* can be trapped with its reported pheromone, and *C. hilaris* is significantly cross-attracted to the *Plautia stali* Scott pheromone [28]. Perhaps lures with these attractants could be included in the pheromone traps to reduce dispersal of these two pests from a trap cropping system designed to arrest all three stink bug species.

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