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RESEARCH

Spatiotemporal Distribution of *Chinavia hiliaris* (Hemiptera: Pentatomidae) in Corn Farmscapes

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ABSTRACT. The green stink bug, *Chinavia hiliaris* (Say) (Hemiptera: Pentatomidae), is a pest of cotton in the southeastern United States but little is known concerning its spatiotemporal distribution in corn cropping systems. Therefore, the spatiotemporal distribution of *C. hiliaris* in farmscapes, when corn was adjacent to cotton, peanut, or both, was examined weekly. The spatial patterns of *C. hiliaris* counts were analyzed using Spatial Analysis by Distance Indices methodology. Interpolated maps of *C. hiliaris* density were used to visualize abundance and distribution of *C. hiliaris* in crops in corn–peanut–cotton farmscapes. This stink bug was detected in six of seven corn–cotton farmscapes, four of six corn–peanut farmscapes, and in both corn–peanut–cotton farmscapes. The frequency of *C. hiliaris* in cotton (89.47%) was significantly higher than in peanut (7.02%) or corn (3.51%). This stink bug fed on noncrop hosts that grew in field borders adjacent to crops. The spatial distribution of *C. hiliaris* in crops and the capture of *C. hiliaris* adults and nymphs in pheromone-baited traps near noncrop hosts indicated that these hosts were sources of this stink bug dispersing into crops, primarily cotton. Significant aggregated spatial distributions were detected in cotton on some dates within corn–peanut–cotton farmscapes. Maps of local clustering indices depicted small patches of *C. hiliaris* in cotton or cotton–sorghum at the peanut–cotton interface. Factors affecting the spatiotemporal dynamics of *C. hiliaris* in corn farmscapes are discussed.

Key Words: inverse distance weighting, SADIE methodology, spatial distribution, field border, noncrop host plant

The green stink bug, *Chinavia hiliaris* (Say) (Hemiptera: Pentatomidae), also known as *Acrosternum hilare* (Say) but formally resolved to *C. hiliaris* (Schwertner and Grazia 2007, Rider 2009), is an economic pest of cotton, *Gossypium hirsutum* L. (Barbour et al. 1990). In the coastal plain of the southeastern United States, cotton is a mid-to-late-season host of *C. hiliaris* (Bundy and McPherson 2000). Feeding on bolls by *C. hiliaris* results in injury to bolls, which can be assessed by examining bolls for internal injury (i.e., warts and stained lint) (Bundy et al. 2000).

Generally, a farmscape is composed of multiple fields of different crops whose edges interface with each other and with noncrop habitats. In the coastal plain of the southeastern United States, corn, *Zea mays* L., peanut, *Arachis hypogaea* L., and cotton are three agricultural crops common to farmscapes. In corn, the southern green stink bug, *Nezara viridula* (L.), and the brown stink bug, *Euschistus servus* (Say), (Hemiptera: Pentatomidae) feed on fruit (i.e., ears), which can result in economic damage (Clower 1958, Ni et al. 2010). In peanut, *N. viridula* and *E. servus* females oviposit on leaves, and subsequent nymphs and adults feed on leaves and stems (Tillman 2008). A recent study on colonization of *C. hiliaris*, *N. viridula*, and *E. servus* in farmscapes of this region revealed that cotton was a relatively good host for all three stink bug species, but surprisingly, corn and peanut were uncommon hosts for *C. hiliaris* (Tillman 2013a).

Compared with *N. viridula* and *E. servus*, *C. hiliaris* feeds more often on woody shrubs and trees (Jones and Sullivan 1982). In southeastern U.S. farmscapes, numerous noncrop hosts of *C. hiliaris* exist in woodlands bordering agricultural crops. Jones and Sullivan (1982) examined the population dynamics of *C. hiliaris* on noncrop hosts in woodlands in South Carolina. Black cherry (*Prunus serotina* Ehrh.) was an early-season host; adults were present on black cherry trees from April until early July, and large nymphs were found on trees from late May through mid-July. Elderberry (*Sambucus canadensis* L.) was an early-to-mid-season host of *C. hiliaris*. Adults began colonizing this

shrub in mid-May and remained on it through July. Large nymphs appeared on elderberry from mid-June through July. Mimosa (*Albizia julibrissin* Durazz.) was a mid-to-late-season host of *C. hiliaris*. Adults and large nymphs were present on trees from mid-July to early September. Adult stink bugs, including *C. hiliaris*, are known to feed on nuts of pecan [*Carya illinoensis* (Wangenh.) K. Koch.] (Miner 1966, Yates et al. 1991). Pecan trees in commercial and abandoned orchards, as well as volunteer seedlings in woods and fencerows, are common around crop fields. In the southeast, stink bugs can feed on nuts before shell hardening (through mid-August) and later can penetrate through the shuck and hardened shell of the pecan nut to feed on kernels (Yates et al. 1991, Hudson 2012, Sparks 2013).

Spatiotemporal patterns of distribution and dispersal have been reported for *N. viridula* and *E. servus* in corn, soybean [*Glycine max* (L.)], peanut, and cotton farmscapes (Panizzi et al. 1980, Velasco and Walter 1992, Bundy and McPherson 2000, Ehler 2000, Tillman et al. 2009, Toews and Shurley 2009, Tillman 2011). Yet there is a dearth of information on the spatiotemporal dynamics of *C. hiliaris* in corn farmscapes common to this region. Thus, the objective of this on-farm study was to examine the spatiotemporal distribution of *C. hiliaris* in farmscapes with corn adjacent to cotton, peanut, or to both crops.

Materials and Methods

Study Sites. Over the 5-yr study, seven corn–cotton farmscapes (four in 2004, two in 2006, and one in 2007), six corn–peanut farmscapes (five in 2005 and one in 2008), and two corn–peanut–cotton farmscapes (2008) were sampled in an approximately 40 km² area around Ocilla, GA. Locations (i.e., GPS coordinates) of farmscapes are listed in Table 1, and sites, years, and farmscape types along with varieties, planting dates, and field sizes for crops in each farmscape are listed in Table 2. Only field corn (i.e., not sweet corn) was grown (Table 2). Each crop was grown using University of Georgia Cooperative Extension Service recommended practices (Collins 2010, Beasley 2012, Lee 2012).

Table 1. Sites and locations of corn farmscapes

Site	Location
Bigfield	31° 36' 29.13" N 83° 19' 03.71" W
Pivot	31° 37' 29.62" N 83° 19' 14.78" W
Substation	31° 37' 20.15" N 83° 20' 29.81" W
Palm	31° 32' 54.86" N 83° 19' 52.05" W
Laurel	31° 33' 19.52" N 83° 20' 10.32" W
Mimosa	31° 36' 08.96" N 83° 20' 03.39" W
Shop	31° 35' 55.97" N 83° 19' 37.00" W
Hardwood	31° 36' 53.31" N 83° 19' 44.71" W
Powerline	31° 38' 23.40" N 83° 19' 49.66" W

Crop rows were planted 0.91 m apart; rows in adjacent crops ran parallel to each other. An eight-row-wide strip of grain sorghum, *Sorghum bicolor* (L.) Moench (DeKalb 54), was planted at the crop-to-crop interface in three corn-cotton farmscapes (i.e., Bigfield, Pivot, and Substation farmscapes) on 5 May 2004 and between peanut and cotton in one corn-peanut-cotton farmscape (i.e., Mimosa farmscape) on 30 May 2008 in an effort to attract *N. viridula* and *E. servus*. Boll damage was assessed to determine when stink bug thresholds were reached. One boll (≈ 2.5 cm in diameter) per sample was examined for internal injury (i.e., warts and stained lint) caused by stink bugs as described by Bundy et al. (2000). The treatment threshold was set at 20% internal boll injury during the second week of bloom, 10–15% internal boll injury during the third to fifth weeks of bloom, 20% during the sixth week of bloom, and 30% during the seventh week of bloom (Bacheler et al. 2009). When a grower decided that an insecticide application was necessary for control of stink bugs in cotton, dicotophos (Bidrin 8, Amvac, www.amvac-chemical.com) was applied to the crop at a rate of 420 g a.i./ha.

Insect Sampling Procedures. In each farmscape, crops were examined weekly for the presence of *C. hiliaris* during the growing season. Corn sampling began at tasseling (i.e., entire tassel was present). For each corn sample, all plants within a 1.83-m length of row were visually examined for *C. hiliaris*. Peanut sampling started at the initiation of pegging (i.e., when budding ovaries or “pegs” grow down into the soil). The peanut canopy within a 7.31-m length of row was swept (38-cm-diameter sweep net) to capture stink bugs. Sweep samples were examined in the laboratory for stink bugs. In cotton, sampling began with the onset of flowering. For each cotton sample, all plants within a 1.83-m length of row were shaken over a drop cloth and visually examined for *C. hiliaris*. Except for peanut, insect species and developmental stage were identified and data recorded in the field using a HP iPAQ pocket personal computer (Hewlett-Packard Co., www.hp.com). Even though our study concentrated on populations of *C. hiliaris* in crops, in some farmscapes observations were made of *C. hiliaris* feeding on non-crop hosts along field borders and recorded. Voucher specimens are stored in the USDA, ARS, Crop Protection and Management Research Laboratory, Tifton, GA.

Within a farmscape, a crop field was partitioned into three sampling locations: 1) the crop-to-crop interface, 2) the three field edges excluding the interface, and 3) the interior of the field. At the interface in corn and cotton, samples were obtained at rows 1 and 5 from the field edge during 2004 and at rows 1, 2, 5, and 9 from the field edge the remaining years. At the interface in peanut, samples were taken at rows 1, 6, and 10 from the field edge for all years. For field edges, samples were obtained at rows 1 and 5 in corn, rows 1, 5, and 9 in cotton, and rows 1, 6, and 10 in peanut. In interior field transects, samples were obtained at rows 16 and/or 33 from the interface and then approximately every 33 rows beyond row 33 from the interface, depending on field width. In corn, two samples were obtained at the interface and each side in 2004, but for other years, there were 9–18 interface samples and 3–9 side samples. In peanut, there were 9–18 interface samples and 3–9 side samples each year. In cotton, there were 9–18 interface samples and 6–9 side samples each year. Six interior transects were sampled per field except

for corn in 2004 and 2005 when three transects were sampled per field. In sorghum, 36 samples were obtained per week. The number of samples per crop is listed in Table 2. Crop sampling sites for the two corn-peanut-cotton farmscapes are shown in Figs. 1 and 3.

Stink Bug Pheromone Traps. Stink bug pheromone traps were used to capture *C. hiliaris* in field borders in the Shop and Mimosa corn-peanut-cotton farmscapes in 2008. Traps were positioned in field borders ≈ 6 m from crop field edges. At the Shop farm, four traps were placed near each crop, but at the Mimosa farmscape, six traps were located near corn and peanut and two traps were near cotton. Stink bug pheromone traps were made by painting pyramid traps (Teddies and Wood 1994) yellow. The insect-collecting device was made from a 2.8-l clear plastic PET jar (United States Plastic Corp., www.usplastic.com) with a screw-cap lid and seated atop the 1.22-m-tall yellow pyramid base (Cottrell et al. 2000). A lure with the *Euschistus* spp. pheromone, methyl [E,Z]-2,4-decadienoate (Degussa AG Fine Chemicals, Marl, Germany), was placed in the collecting device. In the field, *C. hiliaris* is cross-attracted to the pheromone produced by *Plautia stali* Scott (Tillman et al. 2010), but this compound was not commercially available at the time of this study. However, traps baited with *Euschistus* spp. pheromone can capture *C. hiliaris* (Tillman et al. 2010). Capture of *C. hiliaris* nymphs in these traps was likely a result of being able to access the trap from the ground. An insecticidal ear tag (10% λ -cyhalothrin and 13% piperonyl butoxide) (Saber extra insecticides ear tags, Sagebrush Tags, www.sagebrushtags.com) was also placed in this device to decrease stink bug escape (Cottrell 2001). Lures were produced by pipetting 40 μ l of the *Euschistus* spp. pheromone into the opening of rubber septa (11 mm natural, rubber sleeve stoppers, Wheaton, wheaton.com), holding the septa upright in a laboratory rack and allowing septa to absorb the pheromone at room temperature (Cottrell and Horton 2011). In the field, lures were changed and insects collected on a weekly basis from early May through August.

Data Analysis. Chi-square analyses were used to compare frequencies of *C. hiliaris* in corn, peanut, and cotton (PROC FREQ, SAS Institute 2010). To visualize abundance and distribution of *C. hiliaris* in corn-peanut-cotton farmscapes, raster maps of stink bug density were constructed for these farmscapes. ArcMap Version 10 ESRI (Environmental Systems Research Institute, www.esri.com) was used to generate interpolated estimates of *C. hiliaris* density for each crop in a farmscape by the inverse distance weighting (IDW) spatial statistical method (Tillman et al. 2009). Interpolation of insect density requires a minimum of 20 sample points per map (Cressie 1993); this requirement was met for each map generated. For these analyses, insect counts in peanut were converted to number per 1.83-m length of row (Tillman et al. 2009). The IDW interpolated estimates of insect density were mapped using ArcMap. Locations of known *C. hiliaris* hosts in field borders adjoining crops and pheromone trap capture data for this stink bug are shown on these maps.

The spatial patterns of *C. hiliaris* counts were analyzed using Spatial Analysis by Distance Indices (SADIE) (SADIEShell, version 2.0, home.cogeco.ca/~sadiespatial/SADIEShell.html) (Perry et al. 1999). Generally, only *C. hiliaris* counts in cotton were analyzed because no more than two *C. hiliaris* were present in other crops over the season. For the 2008 Mimosa farmscape, *C. hiliaris* counts in both cotton and sorghum were analyzed. SADIE computes an overall aggregation index, I_a . Values of $I_a = 1$ indicate randomly arranged counts, $I_a < 1$ indicate a regular pattern of counts, whereas $I_a > 1$ indicate aggregation of observed counts into clusters. The probability, P_a , that the observed data is more aggregated than expected from a random permutation of the observed counts is significant at $P < 0.05$.

The *C. hiliaris* spatial count data were also analyzed with SADIE to determine the degree of clustering. A clustering index was determined for every location. Clustering indices for sampling locations with observed counts above and below the mean are indicated by v_i (a positive value) and v_j (a negative value), respectively. The indices v_i and v_j measure the respective degree to which a sampling unit contributes to a

Table 2. Site, year, farmscape (FS), variety, planting date (PD), field size (ha), and number of samples (NS) for corn, peanut, and cotton in corn farmscapes

	Year	FS ^a	Corn				Peanut				Cotton			
			Variety ^b	PD	ha	NS	Variety	PD	ha	NS	Variety	PD	ha	NS
Bigfield	2004	C-C	DK 697	3/12	19	25	.	.	.	.	DP 458	5/6	20	47
Pivot	2004	C-C	DK 697	3/17	7	25	.	.	.	.	FM 960	4/23	4	45
Substation	2004	C-C	DK 697	3/10	9	25	.	.	.	.	DP 449	5/8	9	43
Palm	2004	C-C	PI 33M54	3/15	16	25	.	.	.	.	DP 555	5/6	17	43
Laurel	2006	C-C	PI 31N27	4/15	9	131	.	.	.	.	DP 555	4/27	11	177
Mimosa	2006	C-C	PI 31N26	4/4	13	135	.	.	.	.	DP 488	5/9	12	150
Shop	2007	C-C	PI 33M53	3/27	17	192	.	.	.	.	DP 555	6/11	24	192
Bigfield	2005	C-P	DKC69-72	3/12	19	50	AP-3	5/17	20	105	.	.	.	.
Hardwood	2005	C-P	DKC69-72	4/16	6	50	Ga Green	5/19	10	105	.	.	.	.
Pivot	2005	C-P	DKC69-72	4/19	7	50	AP-3	5/16	4	81	.	.	.	.
Powerline	2005	C-P	DKC69-72	4/15	5	112	Ga Green	5/19	4	99	.	.	.	.
Mimosa	2005	C-P	PI 3167	4/23	12	56	Ga-02C	5/14	13	105	.	.	.	.
Laurel	2008	C-P	DKC69-72	4/10	11	138	Ga Green	5/15	9	135	.	.	.	.
Shop	2008	C-P-C	PI 31N26	4/15	19	156	Ga Green	5/28	17	200	DP 555	6/13	24	194
Mimosa	2008	C-P-C	PI 31N26	4/15	12	114	Ga Green	5/28	13	156	DP 555	6/12	18	207

^aC-C, corn-cotton; C-P, corn-peanut; C-P-C, corn-peanut-cotton.

^bDK, DeKalb; PI, Pioneer; DKC, Dekalb; GA, Georgia; DP, Deltapine; FM, Fibermax.

member of a patch and a member of a gap. To test for nonrandomness, the mean value of the clustering index over the patch units was compared with its expected value of 1. Similarly, the mean value of the clustering index over the gap units was compared with its expected value of -1 . Significance levels of v_i and v_j are established through a two-tailed test by the 95th percentiles of the randomized distributions, where $v_i > 1.5$ and $v_j < -1.5$ are considered significant at the 0.025 and 0.975 levels, respectively. Interpolation maps of local aggregation indices were generated using the IDW spatial statistical method with ArcMap.

Results

C. hilaris was detected in six of the seven corn-cotton farmscapes, primarily from cotton, never in sorghum, and only from two corn fields. This stink bug was detected in four of the six corn-peanut farmscapes: in both crops in one farmscape, in only peanut in two farmscapes, and in only corn in one farmscape. For the two corn-peanut-cotton farmscapes, *C. hilaris* occurred primarily in cotton, rarely in peanut, and never in corn. Of the four farmscapes with a strip of sorghum, *C. hilaris* was detected in this strip only at the Mimosa corn-peanut-cotton farmscape. Over the 15 corn farmscapes, *C. hilaris* was found in four corn fields, five of eight peanut fields, and eight of nine cotton fields. *C. hilaris* first through fifth instars and adults of both sexes were present in cotton. Only an egg mass, two nymphs, and two adults were detected in corn. Only one nymph and five adults were found in peanut. The frequency of occurrence of *C. hilaris* in cotton (89.47%) was significantly higher than that in peanut (7.02%) and corn (3.51%) ($\chi^2 = 80.95$; $df = 2$; $P < 0.0001$). Daily density for *C. hilaris* and crop phenology for crops in corn farmscapes for each site and year of the study are listed in Table 3. Generally, *C. hilaris* density was low in fruiting cotton in these farmscapes.

At the Bigfield farmscape, mimosa trees grew adjacent to a field edge, and adult and immature *C. hilaris* were observed feeding on their leaves and fruits from mid-July to early September in 2004 and 2005. This stink bug was not detected on corn either year, but on 26 July 2004, two males were detected in a cotton field edge adjacent to the mimosa trees, a third male was sampled in another field edge, and nymphs were detected at the interface and within the field. *C. hilaris* was not significantly aggregated in cotton on this date (Table 4). Dicrotophos was applied to cotton for control of stink bugs after this sampling date. On 9 August 2005, a male was found in a peanut field edge near the mimosa trees.

At the Pivot and Powerline farmscapes, a fencerow lined with black cherry trees existed next to a crop field edge. Adult and immature *C. hilaris* were observed feeding on fruit and leaf veins of these trees

from early-June to mid-July in 2004 and 2005. At the Pivot farmscape on 28 June 2004, nymphs were detected in the corn field edge near the black cherries. Then in cotton, two *C. hilaris* adults were sampled within the field on 12 July. This stink bug was not significantly aggregated in corn or cotton on these dates (Table 4). Two additional adults were detected in the cotton field edge near black cherry on the latter sampling dates. On 20 June 2005, a *C. hilaris* female was detected in the corn field edge bordering black cherry, and a male was found in peanut at the interface near this edge. At the Powerline farmscape, a third-instar *C. hilaris* was detected in the peanut field edge near black cherry on 19 July. At the Hardwood farmscape, *C. hilaris* was not detected in peanut, but an egg mass parasitized by *Trissolcus basalis* (Wollaston) (Hymenoptera: Platygasteridae) was found in a corn field edge near the end of July.

For the Substation, Palm, Laurel, and Shop corn-cotton farmscapes, only a single, adult *C. hilaris* was detected in corn (Table 3). A few *C. hilaris*, though, were detected in cotton. At the Substation farmscape on 27 July 2004, adults were detected along the interface and a field edge near this interface. On the same date at the Palm farmscape, an adult was detected in cotton in two field edges. After sampling on this date, dicrotophos was applied to cotton in both of these farmscapes for control of stink bugs. At the Laurel farmscape in late August, a *C. hilaris* fifth instar and adult were detected in a cotton field edge adjacent to a large pecan tree and also in another cotton field edge. This stink bug was not significantly aggregated in cotton in these farmscapes on these dates (Table 4). At the Shop farmscape, a *C. hilaris* female was detected at the cotton interface on two dates in August.

In the 2008 Shop and Mimosa corn-peanut-cotton farmscapes, elderberry shrubs and unmanaged pecan trees grew in field borders (Figs. 1A and 3A). At the Shop farmscape, black cherry trees also grew in field borders, and at the Mimosa farmscape, a mimosa tree grew adjacent to a peanut field edge. Seasonal feeding of *C. hilaris* on mimosa and black cherry in these farmscapes was similar to that mentioned above. In both of the corn-peanut-cotton farmscapes, *C. hilaris* was observed feeding on elderberry fruit from mid-June to mid-August. Also, fifth-instar *C. hilaris* were observed feeding on pecan nuts in late August and early September.

As mentioned above, *C. hilaris* was never detected on corn at the Shop farmscape even though black cherry and elderberry existed near corn and females were captured in two pheromone traps near these non-crop hosts in late May through July (Fig. 1A). The only *C. hilaris*, a female, in peanut was found on 16 July at the corn-peanut interface. Early-season presence of this stink bug on black cherry and elderberry and capture of females in two traps bordering peanut suggest that this female dispersed from one of these noncrop hosts into peanut.

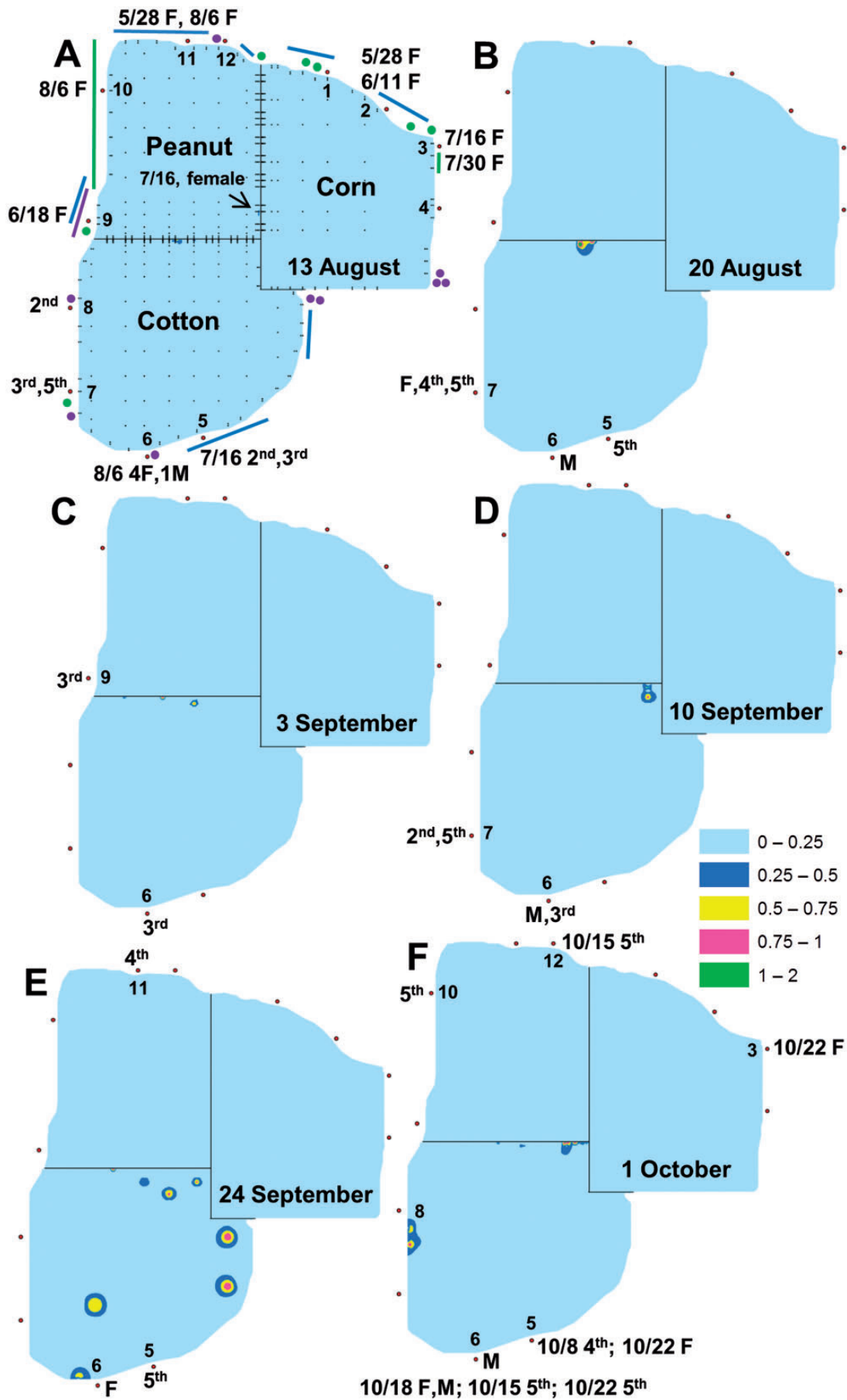


Fig. 1. Spatial interpolation of *C. hilaris* density for the 2008 Shop corn-peanut-cotton farmscape. Green, black cherry; blue, elderberry; purple, pecan; red dot, pheromone trap; trap number and capture data next to trap; sample locations on (A).

Table 3. Daily density for *C. hilaris* and crop phenology for crops in corn farmscapes (FS) for each site and year of the study

Site	Year	Date	FS ^a	Crop ^b	Phenology	<i>C. hilaris</i>		
						Stage ^c	Mean (SE)	n
Bigfield	2004	7/26	C-C	Cot	Fourth week bloom	N + A	0.45 (0.36)	21
Pivot	2005	8/9	C-P	Pea	Fruiting	A	0.01 (0.01)	1
	2004	6/28	C-C	Cor	Dough	N	0.08 (0.06)	2
		7/12		Cot	First week bloom	A	0.04 (0.03)	2
		7/19		Cot	Second week bloom	A	0.02 (0.02)	1
		7/26		Cot	Third week bloom	A	0.02 (0.02)	1
Pivot	2005	6/20	C-P	Cor	Tassel	A	0.02 (0.02)	1
		6/20		Pea	bloom	A	0.01 (0.01)	1
Powerline	2005	7/19	C-P	Pea	fruiting	N	0.01 (0.01)	1
Substation	2004	7/27	C-C	Cot	Fourth week bloom	A	0.09 (0.06)	4
Hardwood	2005	7/25	C-P	Cor	Tassel	E	0.02 (0.02)	1
Palm	2004	7/27	C-C	Cot	Fifth week bloom	A	0.05 (0.03)	2
Laurel	2006	8/28	C-C	Cot	Eighth week bloom	N + A	0.02 (0.02)	4
Shop	2007	6/19	C-C	Cor	Milk	A	0.01 (0.01)	1
		8/2		Cot	Fourth week bloom	A	0.01 (0.01)	1
		8/16		Cot	Sixth week bloom	A	0.01 (0.01)	1
Shop	2008	7/16	C-P-C	Pea	Fruiting	A	0.01 (0.01)	1
		8/13		Cot	Second week bloom	A	0.03 (0.01)	5
		8/20		Cot	Third week bloom	A	0.04 (0.01)	8
		8/27		Cot	Fourth week bloom	A	0.02 (0.01)	4
		9/3		Cot	Fifth week bloom	A	0.03 (0.01)	5
		9/10		Cot	Sixth week bloom	N + A	0.03 (0.01)	5
		9/17		Cot	Seventh week bloom	N + A	0.04 (0.01)	8
		9/24		Cot	Eighth week bloom	N + A	0.05 (0.01)	9
		10/1		Cot	Maturing	N + A	0.06 (0.01)	12
	2008	7/29	C-P-C	Pea	Fruiting	A	0.01 (0.01)	1
Mimosa		9/9		Pea	Maturing	A	0.01 (0.01)	1
		8/19		Cot	Third week bloom	A	0.01 (0.01)	1
		8/26		Cot	Fourth week bloom	A	0.02 (0.01)	4
		9/2		Cot	Fifth week bloom	A	0.02 (0.01)	4
		9/9		Cot	Sixth week bloom	N + A	0.03 (0.01)	7
		9/16		Cot	Seventh week bloom	A	0.02 (0.01)	4
		9/23		Cot	Eighth week bloom	N + A	0.03 (0.01)	7
		9/30		Cot	Maturing	N + A	0.02 (0.01)	4

^aC-C, corn-cotton; C-P, corn-peanut; C-P-C, corn-peanut-cotton.^bCor, Corn; Pea, Peanut; Cot, Cotton.^cE, egg mass; N, nymph; A, adult.

Furthermore, capture of nymphs in trap 5 near elderberry suggests that this stink bug was developing on this noncrop host.

On 6 August, female *C. hilaris* were captured in two pheromone traps near black cherry and elderberry bordering Shop peanut, and adults were captured in one trap bordering cotton (Fig. 1A). The following week, adult *C. hilaris* began colonizing cotton at the peanut-cotton interface near the middle of the field. The index I_a showed no evidence of aggregation (Table 4) even though all five individuals were located at the interface. On 20 August, density of *C. hilaris* adults increased at the cotton interface, again near the middle of the field (Fig. 1B).

An aggregation of *C. hilaris* counts was confirmed by a significant value of I_a (Table 4). The patch clustering index was significant (Table 4) with a small patch at the interface (Fig. 2A). The maps for density and clustering indices were consistent for this date. On 3 September, *C. hilaris* females were still present at this interface (Fig. 1C). The index I_a showed no evidence of aggregation (Table 4). However, the patch clustering index was significant (Table 4). The clustering map depicts a very small patch at the interface (Fig. 2B). The following week, a significant aggregated spatial distribution was detected (Table 4). The patch clustering index was significant (Table 4), and the clustering pattern was characterized by a single patch located near the corner of the three crops (Fig. 2C). This clustering pattern was similar to the spatial pattern observed for density (Fig. 1D). On 24 September, *C. hilaris* were present at various locations in cotton (Fig. 1E), and the index I_a showed no evidence of aggregation (Table 4). On this date, a female was detected in a cotton field edge near a pecan (Fig. 1E). The capture of *C. hilaris* adults and nymphs in trap 6, close to this pecan tree, from early September to mid-October (Fig. 1C–F) strongly suggests *C. hilaris* was developing on pecan and may account for the female in cotton in late September. On 1 October, *C. hilaris* was significantly aggregated in two small patches at the cotton interface near the corner of the three crops (Table 4, Fig. 2D).

In the Mimosa farmscape, corn was not colonized by *C. hilaris* although adults and nymphs were captured in pheromone traps near this crop (Fig. 3A). *C. hilaris* was rare in peanut in this farmscape; only two females were detected in the crop throughout the season. One female occurred in a peanut field edge adjacent to elderberry on 29 July (Fig. 3A). The second female was found at the peanut-sorghum interface near the middle of the field on 9 September (Fig. 3C).

On 19 August, the first *C. hilaris*, a female, was sampled from Mimosa cotton at the peanut-sorghum-cotton interface (not close to any field edge) (Fig. 3A). Two *C. hilaris* females and some first instars were also present in sorghum. The index I_a showed no evidence of aggregation on this date (Table 4). By the following week, *C. hilaris* females were spread across the strip of sorghum, and females were detected in cotton at the interface near the middle of the field (Fig. 3B). An aggregation of *C. hilaris* counts was confirmed by a significant value of I_a (Table 4). The clustering pattern was characterized by two small patches located at the interface (Fig. 4A) and was similar to the spatial pattern observed for density.

Pheromone traps 3 and 4, near elderberry, captured *C. hilaris* nymphs and adults from June through mid-August indicating that this stink bug was developing on this noncrop host during this time (Fig. 3A). Nymphs also were captured in trap 10 near elderberry and peanut from late July to mid-August suggesting that *C. hilaris* was developing on this noncrop host and that the female in peanut on 29 July could have dispersed into the crop from nearby elderberry. From early July through mid-August, adults and nymphs were captured in trap 13 near a relatively large mimosa tree that may have been a noncrop host as previously documented. On 12 August, two traps near elderberry and cotton field edge D each contained a *C. hilaris* female. By 26 August, very few *C. hilaris* were captured in pheromone traps (Fig. 3B). Altogether, these pheromone trap capture data suggest that elderberry and mimosa were sources of *C. hilaris* dispersing into cotton and sorghum in August.

By the first week of September, *C. hilaris* adults were detected in cotton at the peanut-sorghum-cotton interface and the corn-cotton interface. *C. hilaris*, a female, was detected for the first time in a cotton field edge, i.e., edge C, on this date. The index I_a showed no evidence of aggregation (Table 4). Then on 9 September, *C. hilaris* density increased at this field edge (Fig. 3C), but the stink bug was not significantly aggregated (Table 4). A female and first instars were found in the interior of the cotton field on this same date. The capture of *C. hilaris* adults and nymphs in trap 6, close to a pecan tree, during September (Fig. 3D–F) strongly suggests *C. hilaris* was developing on this host and that the adults in edge C of the cotton field may have dispersed from this pecan tree. On 16

Table 4. SADIE statistics for the spatial analysis of counts of *C. hilaris* over time in crops in corn farmscapes for each site and year of the study

Site	Year	Date	Crop ^a	I_a^b	P_a^c	v_i^d	$P(v_i)$	v_j^d	$P(v_j)$
Bigfield	2004	7/26	Cot	1.001	0.429	0.874	0.6779	−0.962	0.4932
	2005	8/9	Pea	ID					
Pivot	2004	6/28	Cor	1.443	0.0503	1.435	0.0344	−1.432	0.0483
		7/12	Cot	0.91	0.6658	1.011	0.1748	−0.9	0.6481
		7/19, 26	Cot	ID					
Pivot	2005	6/20	Cor/Pea	ID					
Powerline	2005	7/19	Pea	ID					
Hardwood	2005	7/25	Cor	ID					
Substation	2004	7/27	Cot	1.32	0.0533	1.469	0.0282	−1.302	0.0595
Palm	2004	7/27	Cot	0.87	0.6166	0.786	0.8971	−0.89	0.5891
Laurel	2006	8/28	Cot	1.105	0.2812	0.978	0.4414	−1.126	0.2502
Shop	2007	6/19	Cor	ID					
		8/2, 16	Cot	ID					
Shop	2008	7/16	Pea	ID					
		8/13	Cot	1.207	0.1463	2.055	0.0015	−1.036	0.3317
		8/20	Cot	1.505	0.0241	2.259	0.0002	−1.308	0.1188
		8/27	Cot	1.031	0.3724	1.211	0.1624	−0.919	0.5098
		9/3	Cot	1.291	0.086	2.004	0.0042	−1.082	0.2769
		9/10	Cot	1.528	0.0211	2.316	0.0003	−1.451	0.068
		9/17	Cot	1.261	0.1057	1.623	0.0265	−1.241	0.1435
		9/24	Cot	0.919	0.6083	0.893	0.5968	−0.937	0.5085
		10/1	Cot	1.544	0.0169	2.441	0.0007	−1.453	0.0704
Mimosa	2008	7/29	Pea	ID					
		9/9	Pea	ID					
		8/19	Cot/Sor	1.156	0.1899	1.607	0.0317	−1.002	0.3774
		8/26	Cot/Sor	1.482	0.0315	2.597	0.0002	−1.232	0.1616
		9/2	Cot	0.765	0.9139	0.874	0.6737	−0.723	0.9011
		9/9	Cot/Sor	0.955	0.5266	0.655	0.9529	−0.918	0.5385
		9/16	Cot/Sor	1.071	0.3144	1.653	0.033	−0.88	0.5998
		9/23	Cot	1.455	0.0327	2.31	0.0012	−1.23	0.1651
		9/30	Cot	0.989	0.4454	1.379	0.0913	−0.847	0.6687

^aCot, cotton; Pea, peanut; Cor, corn; Sor, sorghum.^b I_a is the overall index of aggregation.^cSignificant aggregation is indicated when $P_a < 0.05$. ID, insufficient data.^d v_i and v_j correspond to the average values of the indices of clustering v_i (patch) and v_j (gap). Significant clustering is indicated when $P < 0.025$.

September, *C. hilaris* adults were present in cotton–sorghum at the peanut–sorghum–cotton interface (Fig. 3D). The index I_a showed no evidence of aggregation (Table 4). On 23 September, adults, as well as some nymphs, were located in cotton only at the peanut–cotton interface (Fig. 3E). A significant aggregated spatial distribution was detected (Table 4). The clustering pattern was characterized by four small patch clusters located at the interface (Fig. 4B). The maps for density and clustering indices were consistent for this date. This stink bug was not significantly aggregated on 30 September (Table 4).

Discussion

In light of the fact that both corn and peanut are unlikely hosts for *C. hilaris* and thus not sources as with *N. viridula* and *E. servus* (Tillman 2013a), examining spatiotemporal distribution of *C. hilaris* in corn farmscapes with peanut and/or cotton reveals interesting insights into some aspects of the driving forces behind dispersal and distribution of stink bugs in farmscapes. Indeed, noncrop hosts have a more significant role in the early-season buildup of *C. hilaris* than they have for either of the other two stink bug species (Jones and Sullivan 1982). This study confirms that *C. hilaris* primarily occurs in cotton and seldom in corn or peanut. Herbert and Toews (2012) and Olson et al. (2012) also reported very low populations of *C. hilaris* in corn and peanut. We note, though, that *C. hilaris* may feed/develop more often on corn under different environmental conditions in other regions. Munding and Chapman (1932) observed them feeding on ears of sweet corn in New York. However, that field of sweet corn was located near a pear orchard already heavily populated by *C. hilaris* that may have moved from pear to corn. Tonhasca and Stinner (1991) collected *C. hilaris* from corn in Ohio, but they considered it to be a general feeder on this crop.

Three species of plants: black cherry, elderberry, and mimosa are known noncrop hosts of *C. hilaris* (Jones and Sullivan 1982). In our study, *C. hilaris* fed on each of these noncrop hosts that grew in field borders in corn farmscapes, and our results indicate that this stink developed on these hosts, which were sources of this stink bugs into crops, primarily cotton. Preliminary mark-recapture studies have shown that *C. hilaris* disperses from elderberry into cotton in late July to early August (P.G.T., unpublished data). In a previous study, an edge effect in dispersal of *C. hilaris* adults was detected in cotton adjacent to woodlands (Tillman et al. 2014). This edge effect in distribution of *C. hilaris* has been reported for other cropping systems. Damage to apple by *C. hilaris* was greatest near woodlands (Munding and Chapman 1932). Miner (1966) consistently found the heaviest infestations of *C. hilaris* in soybean on border rows next to woodlands, and Olson et al. (2012) determined that this pest was often more common near woodland edges than in field interiors in cotton.

Stink bugs are known to feed on pecan (Miner 1966, Jones and Sullivan 1982, Yates et al. 1991, Hudson 2012, Sparks 2013). Observations of *C. hilaris* feeding on pecan, capture of *C. hilaris* nymphs in pheromone traps near pecan, and detection of this stink bug in cotton field edges near pecan suggest that pecan is a host for this stink bug in these farmscapes. We are currently conducting studies to closely assess the growth and development of *C. hilaris* on pecan in these farmscapes, as well as determining the impact of noncrop hosts in field borders on crops, primarily cotton, in these farmscapes.

Density of *C. hilaris* in cotton remained relatively low over the nine corn farmscapes with cotton. Previous research showed that the risk of crop colonization by *C. hilaris* was highest for cotton in peanut–cotton,

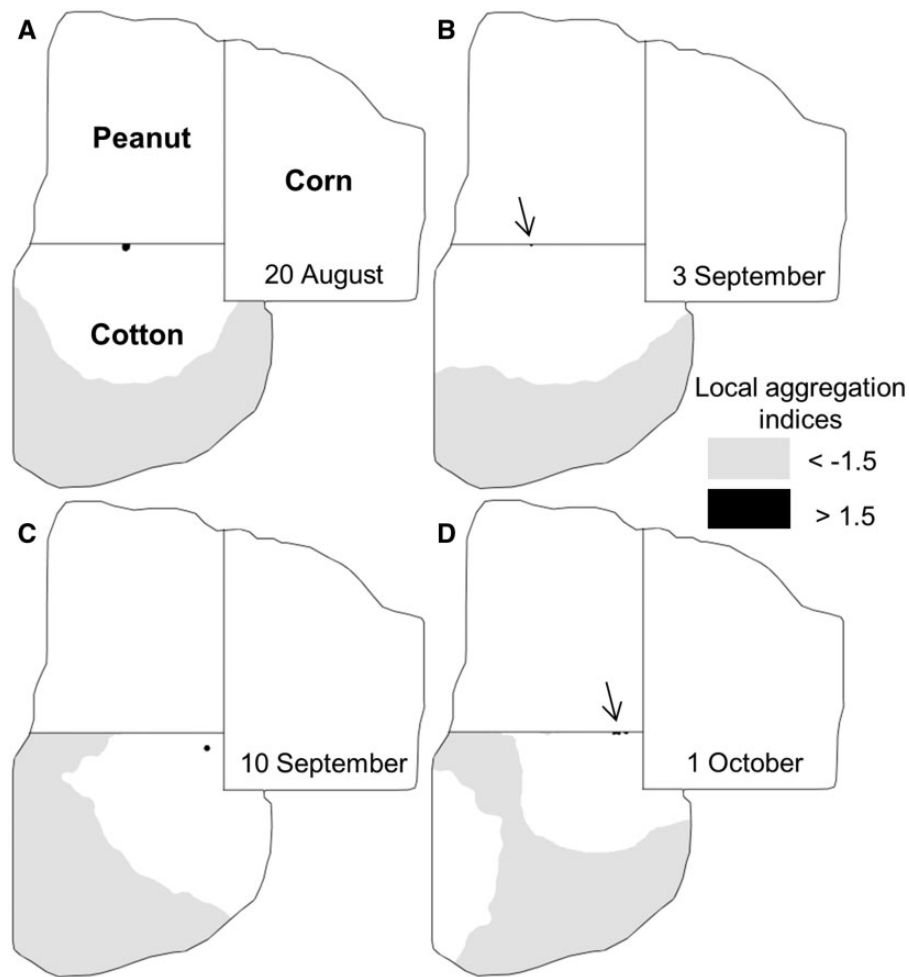


Fig. 2. Spatial interpolation of SADIE local aggregation indices for *C. hilaris* in Shop farmscape for four dates in 2008. Black areas indicate strong clustering as patches in distribution; gray areas indicate strong clustering as gaps in distribution.

followed by corn–peanut–cotton, and lastly corn–cotton farmscapes (Tillman 2013a). However, when *C. hilaris* was significantly aggregated in cotton, this aggregation was detected at crop-to-crop interfaces. In previous studies, we determined that colonization of *C. hilaris*, as well as *N. viridula* and *E. servus*, was highest at crop-to-crop field edges (Tillman 2011, Tillman et al. 2014). However, density of *N. viridula* and *E. servus* was in general higher than that of *C. hilaris* in corn farmscapes probably because corn and peanut are both sources for the former stink bug species (Tillman 2011). It is well documented that stink bugs move within and between closely associated crop and non-crop habitats throughout the growing season in response to deteriorating suitability of their current host plants (Toscano and Stern 1976, Velasco and Walter 1992, Ehler 2000, Tillman et al. 2009). The structure of the farmscape and crops within the farmscape may also impact the dispersal and distribution of *C. hilaris* and other stink bug species within and between crops in a farmscape.

Corn is not only an unlikely host crop in the farmscapes studied, but the relatively tall field edges of corn may prevent dispersal of *C. hilaris* from noncrop hosts along field borders near corn into other crops. It should be noted that, in this study, *C. hilaris* was never detected in the interior of a corn field. At one of the corn–peanut–cotton farmscapes, a single *C. hilaris* was detected in peanut, and this adult was located at the peanut–corn interface. At the other corn–peanut–cotton farmscape, a single adult was located in cotton at the cotton–corn interface, and later a fifth instar was detected in cotton at this interface. We have evidence that a physical barrier, either plant-based or synthetic, can affect

dispersal of *C. hilaris* into crops. Mature corn (≈ 2.7 m tall), sorghum sudangrass (≈ 2.4 m tall), or a vinyl wall (1.8 m in height), erected at a peanut–cotton boundary, deterred dispersal of *C. hilaris* into cotton (Tillman 2014, Tillman et al. 2014). Crop height affecting dispersal may explain in part the lower density of *C. hilaris* in corn farmscapes compared with farmscapes without corn.

Sorghum also apparently is not a significant host of *C. hilaris*. Of the four farmscapes with strips of sorghum, *C. hilaris* was detected in only one farmscape. In addition, over a 4-yr study, density of this stink bug was very low in sorghum in Georgia (Tillman 2013b). Nevertheless, *C. hilaris* adults were sampled for 4 wk in sorghum at the peanut–sorghum–cotton interface in one of the corn–peanut–cotton farmscapes. Also, one adult was located in peanut next to sorghum. Thus, sorghum likely not only suppressed dispersal of *C. hilaris* into cotton but may have been partly responsible for retaining stink bugs at this interface. The ability of sorghum to deter stink bugs from entering cotton was demonstrated for *N. viridula* in an earlier study (Tillman 2006).

Peanut is another uncommon host for this stink bug. A recent study demonstrated that a low vinyl wall (0.5 m tall) at the peanut–cotton interface did not prevent dispersal of *C. hilaris* into cotton (Tillman 2014). These findings indicate that low-growing peanut (≈ 0.4 m; Tillman et al. 2014) does not impede dispersal of adult *C. hilaris* and thus is likely an easy crop for it to fly over and reach other crops. Stink bug adults are known to move along corridors such as along rows rather than across rows (Panizzi et al.

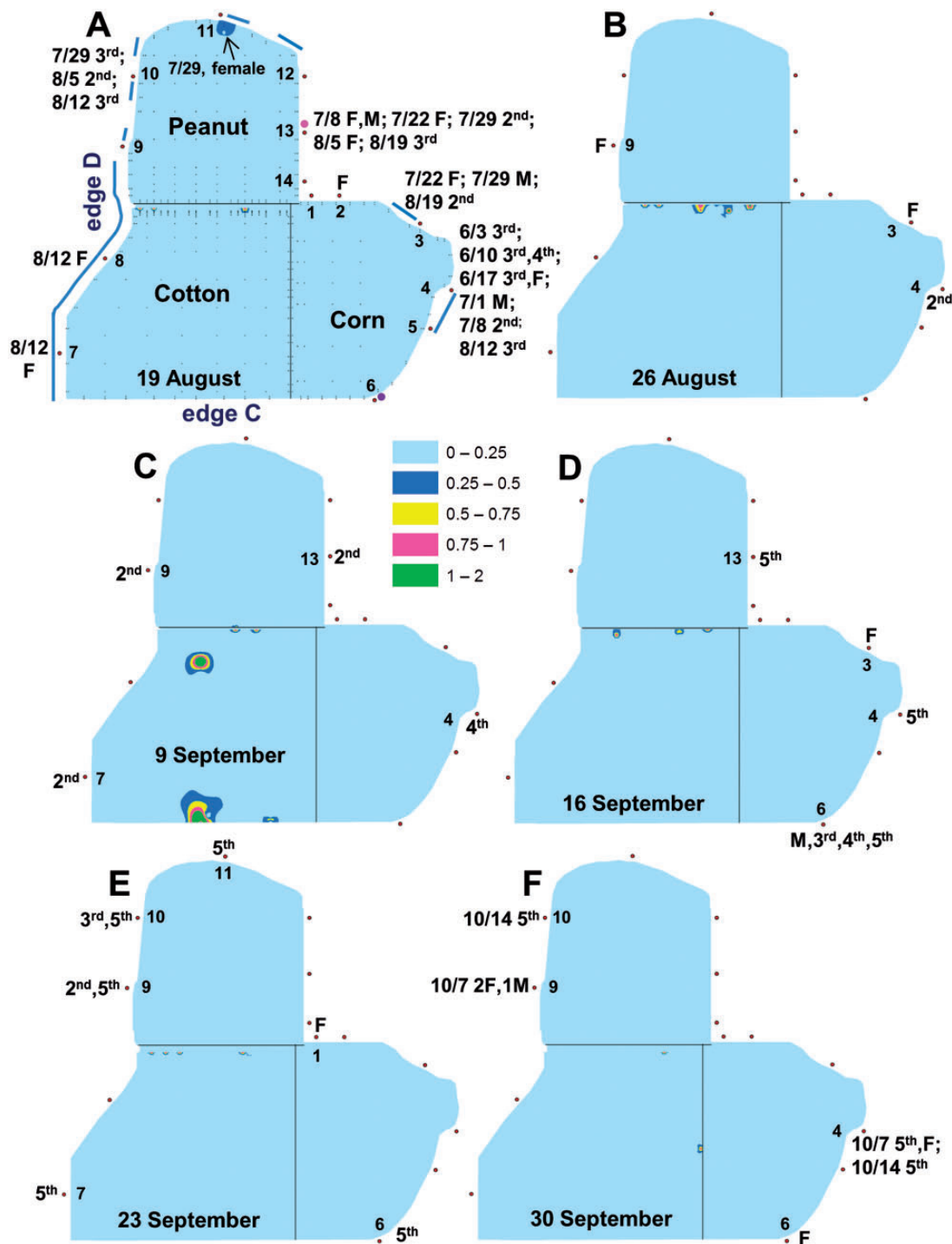


Fig. 3. Spatial interpolation of *C. hilaris* density for the 2008 Mimosa corn–peanut–cotton farmscape. Blue, elderberry; pink, mimosa; purple, pecan; red dot, pheromone trap; trap number and capture data next to trap; sample locations on (A).

1980, Tillman et al. 2009). In a mark-recapture study at the Shop corn–peanut–cotton farmscape in 2008, an *E. servus* female dispersed ~400 m across the peanut field into the edge of a corn field (Tillman et al. 2009). In this study, noncrop hosts of *C. hilaris* existed in field borders near peanut, and *C. hilaris* were captured in nearby traps likely indicating that *C. hilaris* utilizes these noncrop hosts. Furthermore, *C. hilaris* colonized cotton at the peanut–cotton interface near the middle of the field (versus field edge) in corn–peanut–cotton farmscapes. Altogether, these findings indicate that *C. hilaris* dispersed across peanut into sorghum and cotton. Indeed, dispersal of *C. hilaris*

across peanut may provide an explanation for why *C. hilaris* is more likely to be found in cotton in corn–peanut–cotton and peanut–cotton farmscapes than in corn–cotton farmscapes (Tillman et al. 2014). A mark-recapture study has shown that *C. hilaris* can move at least 20 m between individual black cherry trees (Jones and Sullivan 1982). Kiritani and Sasaba (1969) reported that within 24 h, *N. viridula* females migrated at least 1 km from the place where they developed into a rice paddy field. So the distance *C. hilaris* would have flown from noncrop hosts across peanut to a crop-to-crop interface in our study is not unreasonable.

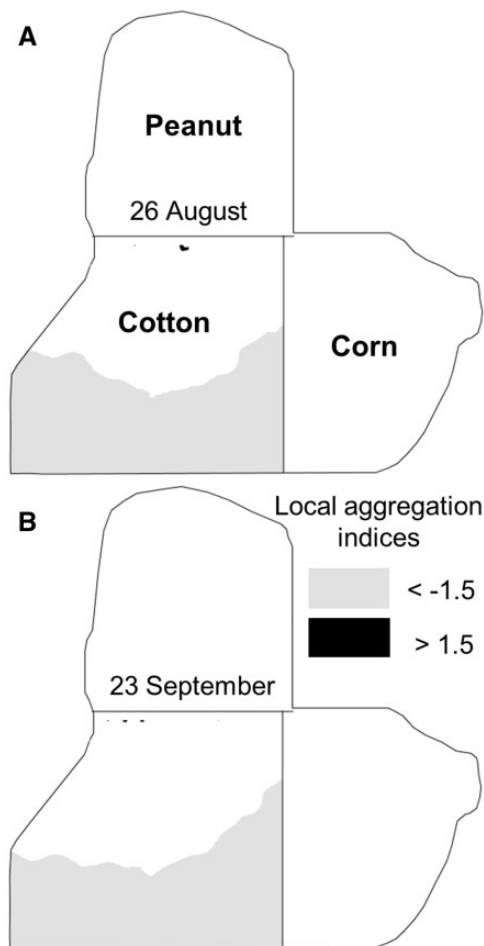


Fig. 4. Spatial interpolation of SADIE local aggregation indices for *C. hilaris* in Mimosa farmscape for two dates in 2008. Black areas (>1.5) indicate strong clustering as patches in distribution; gray areas (<1.5) indicate strong clustering as gaps in distribution.

Interestingly, SADIE cluster maps and maps of density for *C. hilaris* in corn farmscapes in general were consistent. SADIE is an excellent tool for examining spatiotemporal patterns in landscapes. However, SADIE is not sensitive to low sample counts (Thomas et al. 2001), and so visualizations of *C. hilaris* were also important to understanding spatial patterns in these farmscapes. Density maps were also important for determining timing of entry into crops and overall distribution within crops, including dispersal into field edges near non-crop hosts.

Spatiotemporal distribution of *C. hilaris* in corn farmscapes has important implications for all stink bug species. Awareness and detection of edge-mediated dispersal in farmscapes is essential for designing management strategies to protect economically valuable crops. Edge-specific control measures could include eliminating or reducing the impact of noncrop sources of *C. hilaris* in woodlands bordering crops. Considering the relatively low density of *C. hilaris* in corn farmscapes, this management option may provide long-term protection. This proactive control strategy focuses on the eco-biology of stink bugs in these farmscapes rather than simply concentrating on stop-gap control measures.

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