Spatiotemporal Distribution of Chinavia hilaris (Hemiptera: Pentatomidae) in Peanut-Cotton Farmscapes

P. Glynn Tillman1,2 and Ted E. Cottrell3

1United States Department of Agriculture, Agricultural Research Service, Crop Protection and Management Research Laboratory, 2747 Davis Rd., Tifton, GA 31793, USA
2Corresponding author, e-mail: Glynn.Tillman@ars.usda.gov
3United States Department of Agriculture, Agricultural Research Service, Southeastern Fruit and Tree Nut Research Laboratory, 21 Dunbar Rd., Byron, GA 31008, USA

Subject Editor: Megha Parajulee

J. Insect Sci. (2015) 15(1): 101; DOI: 10.1093/jisesa/iev081

ABSTRACT. The green stink bug, Chinavia hilaris (Say) (Hemiptera: Pentatomidae), is a pest of cotton in the southeastern United States, but little is known concerning its spatiotemporal distribution in agricultural farmscapes. Therefore, spatiotemporal distribution of C. hilaris in farmscapes where cotton fields adjoined peanut was examined weekly. Spatial patterns of C. hilaris counts were analyzed using SADIE (Spatial Analysis by Distance Indices) methodology. Interpolated maps of C. hilaris density were used to visualize abundance and distribution of C. hilaris in crops. For the six peanut-cotton farmscapes studied, the frequency of C. hilaris in cotton (94.8%) was significantly higher than in peanut (5.2%), and nymphs were rarely detected in peanut, indicating that peanut was not a source of C. hilaris into cotton. Significantly, aggregated spatial distributions were detected in cotton. Maps of local clustering indices depicted patches of C. hilaris in cotton, mainly at field edges including the peanut-to-cotton interface. Black cherry (Prunus serotina Ehrh.) and elderberry (Sambucus nigra subsp. canadensis [L.] R. Bolli) grew in habitats adjacent to crops, C. hilaris were captured in pheromone-baited stink bug traps in these habitats, and in most instances, C. hilaris were observed feeding on black cherry and elderberry in these habitats before colonization of cotton. Spatial distribution of C. hilaris in these farmscapes revealed that C. hilaris colonized cotton field edges near these two noncrop hosts. Altogether, these findings suggest that black cherry and elderberry were sources of C. hilaris into cotton. Factors affecting the spatiotemporal dynamics of C. hilaris in peanut-cotton farmscapes are discussed.

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

The green stink bug, Chinavia hilaris (Say) (Hemiptera: Pentatomidae), 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. hilaris (Bundy and McPherson 2000). Feeding on bolls by C. hilaris results in damage to bolls which can be assessed by examining bolls for internal injury (i.e., warts and damaged 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, peanut, Arachis hypogaea L., and cotton are two agricultural crops common to farmscapes. A study on colonization of C. hilaris, the southern green stink bug, Nezara viridula (L.), and the brown stink bug, Euschistus servus (Say), in farmscapes of this region revealed that cotton was a relatively good host for all three stink bug species, but surprisingly, peanut was an unlikely host for C. hilaris (Tillman 2013a). In contrast, N. viridula and E. servus (Say) develop in peanut and then disperse to feed on cotton (Tillman 2008, Tillman et al. 2009).

Compared with N. viridula and E. servus, C. hilaris feeds more often on woody shrubs and trees (Jones and Sullivan 1982). In southeastern U.S. farmscapes, numerous noncrop hosts of C. hilaris exist in habitats bordering agricultural crops. Jones and Sullivan (1982) examined the population dynamics of C. hilaris 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 nigra subsp. canadensis [L.] R. Bolli) was an early-to-mid-season host of C. hilaris. Adults began colonizing this shrub in mid-May and remained on it through July. Large nymphs appeared on elderberry from mid-June through July.

A pyramid insect trap (Tedders and Wood 1994) was modified by Mizell and Tedders (1995) to facilitate stink bug capture. The male-specific pheromones of Euschistus spp. and N. viridula attract conspecific adults and nymphs (Harris and Todd 1980, Aldrich et al. 1991). In the field, C. hilaris is cross-attracted to the pheromone produced by males of Plautia stali Scott (Tillman et al. 2010). When pyramid stink bug traps are baited with lures containing pheromones attractive to these stink bug species, they effectively capture these bugs in the field (Tillman et al. 2010, Cottrell and Horton 2011). In this study, we proposed to utilize pheromone-baited stink bug traps to monitor C. hilaris in noncrop habitats adjacent to crops.

Spatiotemporal patterns of distribution and dispersal have been reported for N. viridula and E. servus in corn (Zea mays L.), wheat (Triticum aestivum L.), soybean [Glycine max (L.)], peanut, and cotton farmscapes (Velasco and Walter 1992, Bundy and McPherson 2000, Ehler 2000, Tillman et al. 2009, Toews and Shurley 2009, Reay-Jones et al. 2010, Reeves et al. 2010, Tillman 2011, Reisig et al. 2013). In a recent study on the spatial distribution of C. hilaris in corn farmscapes, significantly aggregated spatial distributions were detected in cotton within corn-peanut-cotton farmscapes (Cottrell and Tillman 2015). Yet, there remains a dearth of information on the spatiotemporal dynamics of C. hilaris in cotton farmscapes common to this region. Thus, the key objective of this study was to examine the spatiotemporal distribution of C. hilaris in farmscapes with peanut adjoining cotton.

Material and Methods

Study Sites. Six peanut-cotton farmscapes were sampled over a 3-yr period (three in 2006, two in 2007, and one in 2008) in an ~40 km² area around Ocilla, GA. One of the sites (i.e., Dogwood) was sampled again in 2009 when only cotton was grown in the field. Sites, years, and...
locations (i.e., GPS coordinates) of farmscapes and planting dates and field sizes for crops in each farmscape are listed in Table 1. Georgia Green peanut and Delta Pine 555 cotton were used. Each crop was grown using University of Georgia Cooperative Extension Service recommended practices (Beasley 2012, Collins 2012). 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 present at the crop-to-crop interface at the Pond farmscape (planted on 14 April 2006) and at the Laurel farmscape (planted on 10 May 2007) as a trap crop for N. viridula and E. servus; this crop is not attractive to C. hilaris (Tillman 2006, Tillman and Cottrell 2012, Tillman 2013b).

**Insect Sampling Procedures.** In each farmscape, crops were examined weekly for the presence of C. hilaris during the growing season. Except for one farmscape, sampling in crops began in mid-to-late June. In the Dogwood in 2009 farmscape, sampling in crops began in mid-July. Sampling was terminated once cotton was treated for stink bugs. The only cotton not treated for stink bugs was that at the Hawthorn 2006 farmscape. 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 obtained at the laboratory for stink bugs. In order to provide a fuller understanding of timing of stink bug colonization in peanut, timing of oviposition was estimated for some of the nymphs found in peanut. Estimates of timing of oviposition for nymphs were based on reported developmental rates of immatures of C. hilaris at 27°C (Simmons and Yeargan 1988). For each sorghum sample, 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 visually examined for C. hilaris, including egg masses. All developmental stages of C. hilaris were identified and recorded in the field using a HP iPAQ pocket personal computer (Hewlett-Packard Co., Palo Alto, CA). Identification was based on rearing C. hilaris in our laboratory. Our study concentrated on populations of C. hilaris in crops. However, any noncrop host plants adjacent to crop field edges in a farmscape, except elderberry at the Pond 2006 farmscape, were randomly searched visually for feeding by C. hilaris to determine presence of this stink bug species on these plants on weeks crops were sampled. Detailed data on the density of C. hilaris per noncrop host plant was not obtained. 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 other than the interface, and (3) the interior of the field. 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 interior field transects, samples were obtained at rows 16 and 33 from the interface and then approximately every 33 rows beyond row 33 from the interface, depending on field width. In peanut, there were 9–18 interface samples and 6–9 field edge samples each year. In cotton, there were 9–18 interface samples and 6–9 field edge samples each year. Six interior transects were sampled per field. In sorghum, 36 samples were obtained per week. At the Hawthorn farmscape, some sample sites in peanut and cotton were eliminated because the plants in a part of the field died. We note that for the cotton farmscape (Dogwood 2009), only the interior of the field and field edges were sampled. The number of samples per crop are listed in Table 1. Crop sampling sites for farmscapes are shown in Figs. 1–6.

**Sticky Capture Wall.** At the Dogwood farm in 2007, six sticky capture walls were positioned at the interface to examine the direction of dispersal of C. hilaris adults between peanut and cotton. Each capture wall was placed in the 1.82 m wide area (only dirt) between the two crops and parallel with crop rows and the interface. The location of each wall along the peanut-cotton interface is shown in Fig. 4A. A sticky capture wall consisted of a 1.83 m high by 0.91 m wide sheet of clear vinyl supported by metal, T-style fence posts. Both sides of the vinyl were liberally covered with Tangle-Trap Insect Trap Coating (Contech, Victoria, BC) on 18 July. The walls were examined daily for captured C. hilaris from 19 July through 8 August.

**Stink Bug Traps.** Pheromone-baited stink bug traps were used to capture C. hilaris in field borders of three farmscapes. Traps were positioned in field borders ≈6 m from crop field edges. At the Dogwood farm in 2007, six traps were positioned near both crops, and there were 12 traps near cotton at this farm in 2009. At the Laurel farm in 2007, there were four traps near peanut and five traps near cotton. At the Starr farm in 2008, there were nine traps near peanut and three near cotton. Yellow pyramid traps (Mizell and Tedders 1995) baited with stink bug pheromone were used to capture stink bugs. The insect-collecting device was modified from that used by Mizell and Tedders (1995) in that it was made from a 2.8 liters clear plastic PET jar (United States Plastic Corp., Lima, OH) 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 spp. pheromone, methyl [E,Z]-2,4-decadienoate (Degussa AG Fine Chemicals, Marl, Germany), was placed in the collecting device. In the field, C. hilaris is cross-attracted to the pheromone produced by P. 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. hilaris (Tillman et al. 2010). Capture of C. hilaris 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, De Smet, SD) was also placed in this device to decrease stink bug escape (Cottrell 2001). Lures were produced by pipetting 40 μl of the Euschistus spp. pheromone into the opening of rubber septa (11 mm natural, rubber sleeve stoppers, Wheaton, Millville, NJ), 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 mid-July through August in 2007 and from early May through August in 2008.

**Data Analysis.** Chi-square analyses were used to compare frequencies of C. hilaris in peanut and cotton for all fields over all sampling.
To visualize abundance and distribution of *C. hilaris* in peanut-cotton farmscapes, raster maps of stink bug density were constructed for these farmscapes. ArcMap Version 10 ESRI (Environmental Systems Research Institute, Redlands, CA) was used to generate interpolated estimates of *C. hilaris* 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. hilaris* hosts in field borders adjoining crops as well as stink bug trap capture data for this stink bug species are shown on these maps.

The spatial patterns of *C. hilaris* counts were analyzed using Spatial Analysis by Distance Indices (SADIE) (SADIEShell, version 2.0, home.cogeco.ca/~sadiespatial/SADIEShell.html) (Perry et al. 1999). Mainly *C. hilaris* counts in cotton were analyzed because very few *C. hilaris* were present in peanut over the season. 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, while *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. hilaris* spatial count data also were 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*ᵣ (a negative value), respectively. The indices *v*ᵢ and *v*ᵣ measure the respective degree to which a sampling unit contributes to a 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

---

**Fig. 1.** 2006 House peanut-cotton farmscape. Spatial interpolation of *C. hilaris* density, A–C. Spatial interpolation of SADIE local aggregation indices for *C. hilaris*, D; black areas (> 1.5) indicate strong clustering as patches in distribution; gray areas (< 1.5) indicate strong clustering as gaps in distribution. Pink dots, black cherry; sample locations on A.
Fig. 2. 2006 Pond peanut-cotton farmscape. Spatial interpolation of *C. hilaris* density, A–D. Spatial interpolation of SADIE local aggregation indices for *C. hilaris*, E; black areas (> 1.5) indicate strong clustering as patches in distribution; gray areas (< 1.5) indicate strong clustering as gaps in distribution. Pink dots, black cherry; purple dashes, elderberry; red line, sorghum with no *C. hilaris*; arrow on C, nymph in sorghum; sample locations on A.
Fig. 3. 2006 Hawthorn peanut-cotton farmscape. Spatial interpolation of *C. hilaris* density, A, C, D, and F. Spatial interpolation of SADIE local aggregation indices for *C. hilaris*, B, E, and G; black areas (> 1.5) indicate strong clustering as patches in distribution; gray areas (< 1.5) indicate strong clustering as gaps in distribution. Purple dashes, elderberry; arrow on D, adult in peanut; arrows on B and E, clustering patches; sample locations on A.
Fig. 4. Dogwood farmscape. Spatial interpolation of *C. hilaris* density in peanut-cotton farmscape in 2007, A–C. Spatial interpolation of *C. hilaris* density in cotton farmscape in 2009, D and E. Spatial interpolation of SADIE local aggregation indices for *C. hilaris* in cotton farmscape in 2009, F; black areas (> 1.5) indicate strong clustering as patches in distribution; gray areas (< 1.5) indicate strong clustering as gaps in distribution. Pink dots, black cherry; purple dashes, elderberry; yellow circle on interface, sticky capture wall; black circle near field edge, stink bug trap with any trap capture data; brown number, stink bug trap number; sample locations on A and D.
clustering index over the gap units was compared with its expected value of −1. Significance levels of \( v_1 \) and \( v_2 \) are established through a two-tailed test by the 95th percentiles of the randomized distributions, where \( v_1 > 1.5 \) and \( v_2 < -1.5 \) 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* egg masses, nymphs, and adults were detected in cotton in the six peanut-cotton farmscapes and the single cotton farmscape. Adult *C. hilaris* were detected in peanut in only three peanut-cotton farmscapes while nymphs were detected in only two farmscapes. Over the six peanut-cotton farmscapes, the frequency of occurrence of *C. hilaris* in cotton (94.8%) was significantly higher than that in peanut (5.2%) (\( \chi^2 = 24.18; df = 5; P < 0.0002 \)). At the House farmscape in 2006, *C. hilaris* was found exclusively in cotton except for a single nymph detected in the interior of the peanut field. Once bolls were present on 12 July, a *C. hilaris* female dispersed into cotton at the interface relatively close to field edge D. Oviposition likely occurred in peanut by 12 July, for a fourth instar was detected in the field on 2 August (Fig. 1C). On 19 July, adults were present in cotton field edge D (Fig. 1A), spreading along this edge by 26 July (Fig. 1B). Then on 2 August, *C. hilaris* also was detected in the interior of the cotton field (Fig. 1C). An aggregation of *C. hilaris* counts in cotton was confirmed by a significant value of \( I_a \) for 19 and 26 July and 2 August (Table 2). For 2 August, the patch clustering index was significant (Table 2) with two small patches in cotton edge D (Fig. 1D). The maps for density and clustering indices were consistent for 2 August. Black cherry trees grew adjacent to field edge D (Fig. 1D), and *C. hilaris* were observed feeding on fruit of these trees on 28 June. Black cherry was the only noncrop host plant of *C. hilaris* adjacent to crops in the farmscape. Colonization and aggregation of *C. hilaris* at the cotton field edge near black cherry suggests that this noncrop host was a source of this stink bug species into this crop in the farmscape.

At the Pond farmscape in 2006, *C. hilaris* was detected in both peanut and cotton. On July 18, two *C. hilaris* egg masses were detected in cotton near field edge D, and a female was detected in peanut at the peanut-sorghum-cotton interface in the middle of the field. Oviposition likely occurred in peanut by 18 July, for third instars were present at the interface (23 and 38 m from the closest field edge) and in the interior of the field on 8 August (Fig. 2B). On 25 July, a *C. hilaris* egg mass was detected near cotton edge D, and a female was detected in peanut edge B. On 1 August, *C. hilaris* adults in cotton were detected at the interface (Fig. 2A). The index \( I_a \) showed no evidence of aggregation in cotton on 1 August (Table 2). However, the patch clustering index was significant (Table 2). Patches, though, were not visible on the clustering map. On 8 August, four *C. hilaris* adults were found in cotton near field edge B (Fig. 2B), which was adjacent to elderberry (Fig. 2A). On 15 August, *C. hilaris* density increased in cotton near field edge B and along the interface, and an aggregation of *C. hilaris* counts was confirmed by a significant value of \( I_a \) (Table 2). The patch clustering index and gap clustering index were significant (Table 2), but patches were not visible on the clustering map. In peanut on 15 August, one adult was detected at the interface and another in field edge D (Fig. 2C). On 22 August, *C. hilaris* density was high in cotton field edges B and D and near both ends of the interface (Fig. 2D). On this date, a significantly aggregated spatial distribution was detected in cotton (Table 2). The patch clustering index was significant (Table 2) with the clustering pattern characterized by two small patch clusters located in cotton at the interface, one small patch at field edge D, and one small patch at field edge B (Fig. 2E). The maps for density and clustering indices were consistent for 22 August. In peanut on 22 August, *C. hilaris* was detected at the interface and interior of the field (Fig. 2D). Throughout the season, *C. hilaris* was not significantly aggregated in peanut (Table 2). Black cherry trees, existing near cotton field edge D and peanut field edges D and C, and elderberry shrubs, growing near cotton field edge D (Fig. 2A), were the only noncrop hosts of *C. hilaris* in field borders near crops. *C. hilaris* were observed on black cherry fruit on 27 June. Colonization and aggregation of *C. hilaris* in the cotton field edge near elderberry suggests that this noncrop host was a source of this stink bug species into this field edge. For sorghum, four *C. hilaris*, one female on 18 July, one nymph on 15 August (see arrow Fig. 2C), and one nymph on 22 August (Fig. 2D), were found in the row closest to peanut. These results suggest that some individuals dispersed from black cherry near peanut field edges across peanut into sorghum at the peanut-sorghum-cotton interface.
In the Hawthorn farmscape in 2006, *C. hilaris* colonized cotton along the interface (Fig. 3A, 3C, 3D, and 3F), and except for a single adult detected in peanut at the interface on 24 August (see arrow on Fig. 3D), it was found exclusively in cotton. On 3 August, *C. hilaris* began colonizing cotton near the middle of the interface (Fig. 3A). The index $I_a$ showed no evidence of aggregation in cotton on 3 August (Table 2). However, the patch clustering index was significant (Table 2). The clustering map for 3 August depicts a very small patch at the interface (see arrow) (Fig. 3B). On 10 August, adults were spread along the interface from near edge D into the middle of the field (Fig. 3C). On 24 August, both early instars and adults were detected in cotton (Fig. 3D). The index $I_a$ showed no evidence of aggregation in cotton on this date (Table 2), but the patch clustering index was significant (Table 2). The clustering pattern on 24 August was characterized by two very small patches located at the interface (see arrows) (Fig. 3E). On 31 August, *C. hilaris* density was high in cotton at the peanut-cotton interface (Fig. 3F). On this date, a significantly aggregated spatial distribution was detected (Table 2). The patch clustering index was significant (Table 2) with two small patch clusters at the interface (Fig. 3G). The gap clustering index also was significant on this date (Table 2). Elderberry existed adjacent to the peanut-cotton interface on field edge B and D, as well as along most of peanut field edge B (Fig. 3A). This was the only noncrop host of *C. hilaris* near crop field edges. *C. hilaris* were observed feeding on elderberry every week from 22 June to 17 August. Thus, elderberry was the likely source of *C. hilaris* into cotton.

At the Dogwood farmscape in 2007, *C. hilaris* was found exclusively in cotton except for a single nymph detected in the interior of the peanut field. Black cherry trees and elderberry shrubs grew near peanut field edge A, and elderberry grew adjacent to peanut and cotton field edges B and D (Fig. 4A). No other noncrop host of *C. hilaris* existed in the habitat surrounding the farmscape. *C. hilaris* were observed feeding on black cherry on 11 July and on elderberry every week from 27 June to 8 August. On 18 July, male and female *C. hilaris* were captured in two stink bug traps in woodland habitats. On this date the first *C. hilaris*, a female, was detected in cotton at the interface near field edge B adjacent to elderberry. On 25 July, *C. hilaris* were detected in cotton at the interface in the middle of the field and near field edge B adjacent to elderberry (Fig. 4A). On 1 August, *C. hilaris* density was higher on the interface (Fig. 4B). Females were captured in stink bug traps 1 and 2.
near black cherry and elderberry on this date. On 8 August, *C. hilaris* were still present in the field interface except for one adult in field edge D. *C. hilaris* was captured in stink bug trap 10 near elderberry and in two other woodland traps, and a *C. hilaris* male was detected in peanut in the interior of the field (Fig. 4C). Even though *C. hilaris* colonized cotton primarily along the peanut-cotton interface (Fig. 4A–C), this stink bug species was not significantly aggregated in cotton on 25 July and 1 August (Table 2). For the sticky capture walls at the peanut-sorghum-cotton interface (Fig. 4A–C), this stink bug species was not significantly aggregated in cotton on 25 July and 1 August. On 9 and 16 July 2007, male and female *C. hilaris* were observed feeding on elderberry every week from 23 July to 13 August. On 9 and 16 July 2007, male and female *C. hilaris* were captured in three stink bug traps in woodland habitats. On 30 July, two *C. hilaris* adults were detected in cotton, one near each corner of field edge A near elderberry shrubs. Then on 6 August, *C. hilaris* was present primarily in one corner of the field (Fig. 4D), increasing in density in cotton in the upper third of the field by 13 August (Fig. 4E).

Significantly aggregated spatial distribution was detected for cotton on 6 and 13 August, and the patch clustering index and gap clustering index were significant on both dates (Table 2). Patches were not visible on the clustering map for 6 August. For 13 August, though, the clustering pattern was characterized by one patch cluster (Fig. 4F). The maps for density and clustering indices were consistent for this date. Colonization and aggregation of *C. hilaris* in field edges near elderberry support the likelihood of this noncrop host serving as a source of this stink bug species into cotton in this farmscape.

**Table 2. SADIE statistics for the spatial analysis of counts of *Chinavia hilaris* over time in crops in cotton farmscapes**

| Site       | Date       | Crop | Stage | $I_v$ | $P_v$ | $P_j$ | $P_i$ | $P_j$ |
|------------|------------|------|-------|-------|-------|-------|-------|-------|
| House      | 12 July 2006 | Cot A | ID    |       |       |       |       |       |
| 19 July 2006 | Cot A | 1.499 | 0.0298 | 1.345 | 0.1103 | -1.531 | 0.0463 |       |
| 26 July 2006 | Cot A | 1.46  | 0.0431 | 1.366 | 0.0918 | -1.49  | 0.0582 |       |
| 2 August 2006 | Cot N/A | 1.541 | 0.027  | 1.788 | 0.0158 | -1.468 | 0.058  |       |
| Pond       | 18 July 2006 | Cot E | ID    | 0.948 | 0.4922 | 0.939  | 0.5348 | -0.971 |
| 25 July 2006 | Cot E | ID    |       |       |       |       |       |       |
| 1 August 2006 | Cot A | 1.13  | 0.0228 | 1.696 | 0.0101 | -0.985 | 0.4148 |       |
| 8 August 2006 | Cot A | 1.129 | 0.2256 | 1.317 | 0.0865 | -1.044 | 0.3409 |       |
| 15 August 2006 | Cot N/A | 1.836 | 0.0025 | 2.301 | 0.0002 | -1.727 | 0.0156 |       |
| 22 August 2006 | Cot E | 1.392 | 0.0426 | 1.71  | 0.0178 | -1.228 | 0.1619 |       |
| 31 August 2006 | Cot N/A | 1.727 | 0.0082 | 2.409 | 0.0005 | -1.641 | 0.0189 |       |
| Hawthorn   | 3 August 2006 | Cot A | 1.184 | 0.1584 | 1.563 | 0.0147 | -1.079 | 0.3055 |       |
| 10 August 2006 | Cot A | 1.173 | 0.184  | 1.376 | 0.0732 | -1.076 | 0.303  |       |
| 17 August 2006 | Cot N/A | 0.812 | 0.8537 | 0.892 | 0.671  | 0.76  | 0.9219  |       |
| 24 August 2006 | Cot N/A | 1.341 | 0.0676 | 2.016 | 0.002  | -1.226 | 0.151  |       |
| 31 August 2006 | Cot N/A | 1.727 | 0.0082 | 2.409 | 0.0005 | -1.641 | 0.0189 |       |
| Dogwood    | 18 July 2007 | Cot A | ID    |       |       |       |       |       |
| 25 July 2007 | Cot A | 1.037 | 0.3498 | 1.205 | 0.1771 | -0.992 | 0.4294 |       |
| 1 August 2007 | Cot E/A | 0.956 | 0.5118 | 1.4  | 0.0746 | -0.788 | 0.7984 |       |
| 8 August 2007 | Cot E/A | 1.171 | 0.1842 | 1.52 | 0.0454 | -0.967 | 0.4763 |       |
| 31 August 2006 | Cot N/A | 1.727 | 0.0082 | 2.409 | 0.0005 | -1.641 | 0.0189 |       |
| Dogwood    | 30 July 2009 | Cot A | 1.284 | 0.0605 | 1.205 | 0.1176 | -1.321 | 0.059  |       |
| 6 August 2009 | Cot N/A | 1.545 | 0.0064 | 1.961 | 0.0002 | -1.497 | 0.0117 |       |
| 13 August 2009 | Cot N/A | 1.9  | 0.0005 | 1.975 | 0.0015 | -1.878 | 0.0002 |       |
| Laurel     | 25 July 2007 | Cot A | 1.023 | 0.3896 | 1.082 | 0.2988 | -0.98  | 0.4617 |       |
| 1 August 2007 | Cot A | 0.768 | 0.8785 | 0.902 | 0.5899 | -0.698 | 0.9578 |       |
| 8 August 2007 | Cot E/A | 0.93  | 0.542  | 0.983 | 0.4313 | -0.854 | 0.665  |       |
| 15 August 2007 | Cot E/N/A | 1.285 | 0.1114 | 1.401 | 0.0754 | -1.187 | 0.1981 |       |
| Starr      | 9 July 2008 | Cot A | 0.919 | 0.5507 | 0.941 | 0.4818 | -0.911 | 0.5576 |       |
| 16 July 2009 | Cot A | 1.296 | 0.1265 | 1.323 | 0.1195 | -1.325 | 0.1203 |       |
| 23 July 2009 | Cot E/A | 2.735 | 0.0002 | 4.065 | 0.0001 | -2.895 | 0.0002 |       |

| a | Cot, cotton; Pea, peanut. |
| b | E, egg mass; N, nymph; A, adult. |
| c | $I_v$ is the overall index of aggregation. |
| d | Significant aggregation is indicated when $P_v < 0.05$ (in bold). ID, insufficient data. |
| e | $v_i$ and $v_j$ correspond to the average values of the indices of clustering $v_i$ (patch) and $v_j$ (gap). |
| f | Significant clustering is indicated when $P < 0.025$. |
(Fig. 6B). *C. hilaris* were observed feeding on black cherry on 2, 9, and 16 July, and early-to-late instars were captured in stink bug traps 4 and 10 near these trees from early June to early July (Fig. 6A). In addition, males and females were captured in stink bug traps 1, 2, and 5 on 9 and/or 23 July (Fig. 6A and C). No other noncrop host of *C. hilaris* existed in the habitat surrounding the farmscape. On 9 July, *C. hilaris* dispersed into cotton at the upper peanut-cotton interface (Fig. 6A). On 16 July, *C. hilaris* adults were congregated along this interface with a single female in the field interior and one female on the lower peanut-cotton interface (Fig. 6B). The index *I* showed no evidence of aggregation on 9 and 16 July (Table 2). On 23 July, *C. hilaris* density was high in cotton, especially at the upper peanut-cotton interface (Fig. 6C). An aggregation of *C. hilaris* counts was confirmed by a significant value of *I* (Table 2). The patch clustering index was significant (Table 2) with one relatively large patch and three smaller patches at the interface (Fig. 6D). The gap clustering index also was significant (Table 2). The maps for density and clustering indices were consistent for this date. Colonization and aggregation of *C. hilaris* in cotton at the upper peanut-cotton interface suggests that individuals from black cherry dispersed across peanut and colonized cotton at this interface in this farmscape.

Discussion

In light of the fact that peanut is an unlikely host for *C. hilaris* and thus not a source as with *N. viridula* and *E. servus* (Tillman et al. 2009, Tillman 2013a), examining spatiotemporal distribution of *C. hilaris* in peanut-cotton farmscapes reveals interesting insights into some aspects of the driving forces behind dispersal and distribution of stink bugs in farmscapes. The present study confirms that *C. hilaris* primarily occurs in cotton and seldom in peanut. Even in peanut-cotton farmscapes in which *C. hilaris* was present in peanut, this stink bug species occurred in both crops simultaneously. Clearly, *C. hilaris* did not build up in peanut and then colonize cotton. Herbert and Toews (2012) and Olson et al. (2012) also reported very low populations of *C. hilaris* in peanut. A recent study has shown that *C. hilaris* is more prevalent in cotton than in corn or peanut in corn farmscapes with peanut, cotton, or both crops (Cottrell and Tillman 2015). Sorghum also apparently is not a significant host of *C. hilaris*. Of the two farmscapes with strips of sorghum, only two adults and two nymphs of *C. hilaris* were detected. Likewise, *C. hilaris* density was very low in sorghum in Georgia over a 4-yr study (Tillman 2013b).

Jones and Sullivan (1982) reported that black cherry and elderberry were noncrop host plants of *C. hilaris*. In our study, one or both of these noncrop hosts were present in habitats adjacent to crops, and *C. hilaris* were captured in pheromone-baited stink bug traps in these habitats either before or during colonization of cotton for the three peanut-cotton farmscapes in which stink bug traps were used to monitor this stink bug species. In most instances, *C. hilaris* were observed feeding on black cherry and elderberry in these habitats before colonization of cotton. Spatial distribution of *C. hilaris* in these peanut-cotton farmscapes revealed that *C. hilaris* colonized and aggregated in cotton field edges near black cherry and elderberry. Altogether, these findings suggest that black cherry and elderberry were sources of *C. hilaris* into cotton. Indeed, 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). Jones and Sullivan (1982) reported on the timing of completion of development of *C. hilaris* on black cherry and elderberry, and the initial appearance of this stink bug species in soybean suggested that these noncrop hosts were sources of this pest into this crop. Miner (1966) concluded that the first generation of *C. hilaris* developed almost entirely on noncrop hosts, in particular dogwood (*Cornus drummondii* C. A. Meyer) and elderberry, and that later infestations in soybean were greater wherever these hosts were nearby.

The presence of *C. hilaris* on black cherry and elderberry and capture of *C. hilaris* in stink bug traps near peanut field edges, colonization of *C. hilaris* in cotton at the interface even though peanut is an unlikely source of the stink bug species, and the fact that *C. hilaris* primarily occurred on the peanut side of sticky capture walls than on the cotton side of these walls suggest that peanut may facilitate stink bug dispersal into cotton from noncrop sources near peanut field edges. When peanut was grown adjacent to cotton in the 2007 Dogwood farmscape, *C. hilaris* colonized cotton at the interface of the two crops. However, when peanut was not grown in the 2009 Dogwood farmscape, *C. hilaris* began colonizing cotton field edges, not cotton in the middle of the farmscape, which further suggests that peanut facilitated dispersal of *C. hilaris* into cotton at the peanut-cotton interface in the 2007 farmscape. Reeves et al. (2010) reported that densities of *C. hilaris* were higher in cotton transects adjacent to peanut than those next to corn, cotton, soybean, and woods. In their study, *C. hilaris* may have dispersed from noncrop hosts across peanut into cotton, assuming that this stink bug species was not developing in peanut in the location in which their study was conducted. 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), indicating that low-growing peanut (~0.4 m; Tillman et al. 2014) did not impede dispersal of adult *C. hilaris*. In a previous mark-recapture study, an *E. servus* female dispersed ~400 m across a peanut field into the edge of a corn field (Tillman et al. 2009). A mark-recapture study has shown that *C. hilaris* can disperse at least 20 m between individual black cherry trees (Jones and Sullivan 1982). Kirtani and SASaba (1969) reported that within 24 h, *N. viridula* females immigrated into a rice paddy field at least 1 km from the place where they developed. So, in general, the distance *C. hilaris* would have dispersed from noncrop hosts across peanut to a crop-to-crop interface in our study is reasonable.

When *C. hilaris* was significantly aggregated in cotton, this aggregation was detected at crop field edges. For field edges unassociated with peanut, aggregation of *C. hilaris* was likely due to the fact that the noncrop host plants existed in habitats adjacent to cotton. For example, in the House peanut-cotton farmscape, *C. hilaris* aggregated in a field edge adjacent to black cherry. 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 (Mundinger 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.

Interestingly, SADIE cluster maps and maps of *C. hilaris* density in cotton farmscapes in general were consistent. SADIE is an excellent tool for examining spatiotemporal patterns in landscapes, but this methodology is not sensitive to low sample counts (Thomas et al. 2001). The relatively low density of *C. hilaris* in cotton in the Dogwood and Laurel farmscapes in 2007 may explain why an aggregated distribution was not detected for this stink bug species in cotton even though it occurred in the crop primarily along the interface in these farmscapes. Thus, 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 noncrop hosts.

Spatiotemporal distribution of *C. hilaris* in peanut-cotton 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* growing near crop field edges.

Acknowledgments

We thank Kristie Graham (USDA, ARS, Crop Protection and Management Research Laboratory, Tifton, Georgia) and Ann Amis...
(USDA, ARS, Southeastern Fruit and Tree Nut Research Laboratory, Byron, Georgia) for their technical assistance.

References Cited

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

Barbour, K. S., J. R. Bradley Jr., and J. S. Bachelor. 1990. Reduction in yield and quality of cotton damaged by green stink bug (Hemiptera: Pentatomidae). J. Econ. Entomol. 83: 842–845.

Beasley, J. P., ed. 2012. Peanut Production Update, CSS-12-0130. University of Georgia College of Agricultural and Environmental Sciences Cooperative Extension, Athens, GA.

Bundy, C. S., and R. M. McPherson. 2000. Dynamics and seasonal abundance of stink bugs (Heteroptera: Pentatomidae) in a cotton-soybean ecosystem. J. Econ. Entomol. 93: 697–706.

Bundy, C. S., R. M. McPherson, and G. A. Herzog. 2000. An examination of the external and internal signs of cotton boll damage by stink bugs (Heteroptera: Pentatomidae). J. Entomol. Sci. 35: 402–410.

Collins, G., ed. 2012. The 2012 Georgia Cotton Production Guide, CSS-12-01. University of Georgia College of Agricultural and Environmental Sciences Cooperative Extension, Athens, GA.

Cottrell, T. E. 2001. Improved trap capture of Euschistus servus and Euschistus tristigmus (Hemiptera: Pentatomidae) in pecan orchards. Fla. Entomol. 84: 731–732.

Cottrell, T. E., and D. Horton. 2011. Trap capture of brown and dusky stink bugs (Hemiptera: Pentatomidae) as affected by pheromone dosage in dispensers and dispenser source. J. Entomol. Sci. 46: 135–147.

Cottrell, T. E., and P. G. Tillman. 2015. Spatiotemporal distribution of Chinavia hilaris (Hemiptera: Pentatomidae) in corn farmscapes. J. Insect. Sci. 15: 28.

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

Cressie, N.A.C. 1993. Statistics for spatial data, revised edition. Wiley, New York.

Ehler, L. E. 2000. Farmscape ecology of stink bugs in northern California. Memorial Thomas Say Publications of Entomology, Entomological Society of America Press, Lanham, MD.

Harris, V. E., and J. W. Todd. 1980. Male-mediated aggregation of male, female and 5th-instar southern green stink bug and concomitant attraction of a tachinid parasite, Trichopoda pennisima. Environ. Exp. Appl. 27: 117–126.

Herbert, J. J., and M. D. Toews. 2012. Seasonal abundance and population structure of Chinavia hilaris and Nezara viridula (Hemiptera: Pentatomidae) in Georgia farmscapes containing corn, cotton, peanut, and soybean. Ann. Entomol. Soc. Am. 105: 582–591.

Jones, W. A., and M. J. Sullivan. 1982. Role of host plants in population dynamics of stink bug pests of soybean in South Carolina. Environ. Entomol. 11: 867–875.

Kiritani, K., and T. Sasaba. 1969. The difference in bio- and ecological characters between neighbouring populations in the southern green stink bug, Nezara viridula L. Jap. J. Ecol. 19: 177–184.

Miner, F. D. 1966. Biology and control of stink bugs on soybean. Arkansas Agric. Exp. Sta. Bulletin 708: 1–40.

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

Mundinger, F. G., and P. J. Chapman. 1932. Plant bugs as pests of pear and other fruits in the Hudson Valley. J. Econ. Entomol. 25: 655–658.

Olson, D. M., J. R. Ruberson, and D. A. Andow. 2012. Effects on stink bugs of field edges adjacent to woodland. Agric. Ecosys. Environ. 158: 17–25.

Perry, J. N., L. Winder, J. H. Holland, and R. D. Alston. 1999. Red-blue plots for detecting clusters in count data. Ecol. Letter 2: 106–113.

Reay-Jones, F.P.F., M. D. Toews, J. K. Greene, and R. B. Reeves. 2010. Spatial dynamics of stink bugs (Hemiptera: Pentatomidae) and associated boll injury in southeastern cotton fields. Environ. Entomol. 39: 956–969.

Reeves, R. B., J. K. Greene, F.P.F. Reay-Jones, M. D. Toews, and P. D. Gerardi. 2010. Effects of adjacent habitat on populations of stink bugs (Heteroptera: Pentatomidae) in cotton as part of a variable agricultural landscape in South Carolina. Environ. Entomol. 39: 1420–1427.

Reigis, D. D., M. Roe, and A. Dhammi. 2013. Dispersal pattern and dispersion of adult and nymph stink bugs (Hemiptera: Pentatomidae) in wheat and corn. Environ. Entomol. 42: 1184–1192.

SAS Institute. 2010. PROC user’s manual, version 9.3. SAS Institute, Cary, NC.

Simmons, A. M., and K. V. Yeargan. 1988. Development and survivorship of the green stink bug (Hemiptera: Pentatomidae) on soybean. Environ. Entomol. 17: 527–532.

Tedders, W. L., and B. W. Wood. 1994. A new technique for monitoring pecan weevil emergence (Coleoptera: Curculionidae). J. Entomol. Sci. 29: 18–30.

Thomas, C.F.G., L. Parkinson, G.J.K. Griffiths, A. Fernandez Garcia, and E.J.P. Marshall. 2001. Aggregation and temporal stability of carabid beetle distributions in field and hedgerow habitats. J. Appl. Ecol. 38: 100–116.

Tillman, P. G. 2006. Sorghum as a trap crop for Nezara viridula (L.) (Heteroptera: Pentatomidae) in cotton. Environ. Entomol. 35: 771–783.

Tillman, P. G. 2008. Peanuts harbor populations of stink bugs (Heteroptera: Pentatomidae) and their natural enemies. J. Entomol. Sci. 43: 191–207.

Tillman, P. G. 2011. Influence of corn on stink bugs (Heteroptera: Pentatomidae) in subsequent crops. Environ. Entomol. 40: 1159–1176.

Tillman, P. G. 2013a. Likelihood of stink bugs colonizing crops: a case study in southeastern farmscapes. Environ. Entomol. 42: 438–444.

Tillman, P. G. 2013b. Stink bugs (Heteroptera: Pentatomidae), a leaf-footed bug (Hemiptera: Coreidae), and their predators in sorghum in Georgia. J. Entomol. Sci. 48: 9–16.

Tillman, P. G. 2014. Physical barriers for suppression of movement of adult stink bugs into cotton. J. Pest Sci. 87: 419–427.

Tillman, P. G., and T. E. Cottrell. 2012. Case study: trap crop with pheromone capture traps for managing Euschistus servus (Heteroptera: Pentatomidae) in cotton. (http://www.hindawi.com/journals/psyche/2012/401703/) (accessed 1 April 2015).

Tillman, P. G., J. R. Aldrich, A. Khrimian, and T. E. Cottrell. 2010. Pheromone attraction and cross-attraction of Nezara, Acrosternum, and Euschistus spp. stink bugs (Heteroptera: Pentatomidae) in the field. Environ. Entomol. 39: 610–617.

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

Tillman, P. G., T. E. Cottrell, R. F. Mizell, III, and E. Kramer. 2014. Effect of field edges on dispersal and distribution of colonizing stink bugs across farmscapes of the Southeast US. Bull. Entomol. Res. 104: 56–64.

Toews, M. D., and W. D. Shurley. 2009. Crop juxtaposition affects cotton fiber quality in Georgia farmscapes. J. Econ. Entomol. 102: 1515–1522.

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

Received 8 April 2015; accepted 23 June 2015.