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Research article

Pest Management

Identifying a Potential Trap Crop for a Novel Insect Pest, *Halyomorpha halys* (Hemiptera: Pentatomidae), in Organic Farms

Anne L. Nielsen,[1,2] Galen Dively,[3] John M. Pote,[1] Gladis Zinati,[4] and Clarissa Mathews[5]

[1]Department of Entomology, Rutgers University, 121 Northville Rd., Bridgeton, NJ 08302 (nielsen@aesop.rutgers.edu; jmp497@scarletmail.rutgers.edu), [2]Corresponding author, e-mail: nielsen@aesop.rutgers.edu, [3]Department of Entomology, University of Maryland, College Park, MD (galen@umd.edu), [4]The Rodale Institute, Kutztown, PA (Gladis.zinati@rodaleinstitute.org), and [5]Redbud Farm, LLC, Inwood, WV and Shepherd University, Shepherdstown, WV (CMathews@shepherd.edu)

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Abstract

The invasive brown marmorated stink bug, *Halyomorpha halys*, poses significant risk to organic farming systems because they rely on biological control, nonsynthetic inputs, and cultural tactics for pest management. This study evaluated the potential of five crop plants (sorghum, admiral pea, millet, okra, and sunflower) to be used as trap crops under organic production in four mid-Atlantic states. Stink bug (*H. halys* and endemic species) densities and host plant phenologies were recorded weekly (mid-June through September). Sorghum attracted significantly more *H. halys* than the other crops evaluated, followed by sunflower and okra. Seasonal average *H. halys* density was 1.5–4× higher on sorghum than the other crops ($P < 0.05$), depending on site. Endemic stink bugs were equally attracted to all crops except admiral pea. A significant effect of time was detected ($P < 0.0001$), with *H. halys* densities initially higher on sunflower; as the sunflower senesced, sorghum supported significantly higher average *H. halys* densities. While sunflower and sorghum phenologies differed, these crops together provided a 5-wk attraction period coinciding with peak *H. halys* activity. The efficacies of pheromone-baited traps, flaming, applying OMRI-approved insecticides (Azera and Venerate), and vacuuming to removing stink bugs were evaluated as a management tactic. Flaming was the most effective treatment against *H. halys* and endemic stink bugs. Our results suggest that a trap crop composed of sorghum and sunflower may be an effective management tool for the mid-Atlantic stink bug complex, including *H. halys.* Future research should address the appropriate size and placement of trap crop within the farm.

Key words: stink bug, organic, management, habitat manipulation, host choice

Pest management in organic farming systems relies on primarily nonsynthetic inputs, biological control, and habitat manipulation. While organic systems commonly are resilient to many pest species (Zehnder et al. 2007), invasive species provide novel challenges. One invasive species, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), the brown marmorated stink bug, has become a significant pest in the mid-Atlantic region (Leskey et al. 2012) and dominates the stink bug pest complex, which is increasing in economic importance (Nielsen and Hamilton 2009). *Halyomorpha halys*' pest status is increasing in other parts of the country such as the southeastern and western regions, although populations are variable from year to year.

Halyomorpha halys, like other stink bugs, feeds primarily on the reproductive structures of plants, causing corking or deformed fruit or seed formation (McPherson and McPherson 2000). Throughout the growing season, populations increase dramatically with high densities occurring in late July to mid-August (Nielsen and Hamilton 2009), a time that coincides with the development and ripening of many agriculturally important food crops in the United States. Management for *H. halys* in organic systems is difficult due to the lack of effective organic insecticides and because of its long life cycle, high capacity to disperse, and polyphagous nature. Such characteristics have created a landscape-level agroecosystem threat posed by *H. halys*. One tactic for management that is amenable to organic production would be habitat manipulation, such as trap cropping, which would capitalize on the strong perimeter-driven behavior exhibited by *H. halys* and endemic stink bugs such as *Euschistus spp*. in multiple cropping systems (Tillman et al. 2009, Blaauw et al. 2014, Venugopal et al. 2014).

Habitat manipulation through the identification and planting of a preferred plant species over another for pest management is the basis of trap cropping (Hokkanen 1991). This form of integrated pest management has numerous attributes and modalities. The "ideal" trap crop would protect a crop at a vulnerable stage from insect damage, be easy to manage, provide secondary benefits, and be affordable. Shelton and Benedez-Perez (2006) defined trap cropping broadly as "plant stands that are . . . deployed to attract, divert, intercept, and/or retain targeted insects or the pathogens they vector in order to reduce damage to the main crop." Thus, a trap crop exploits insect host finding and selection behaviors as a management tool. Host plant finding itself is a multistage process that involves visual and olfactory cues. A successful trap crop should satisfy both processes and have had some success as a management tactic for stink bug species. When used as a trap crop, sorghum reduced insecticide applications in cotton and black mustard reduced kernel injury by 22% in sweet corn for *Nezara viridula* L. (Rea et al. 2002, Tillman et al. 2009). Recently, Soergel et al. (2015) evaluated sunflower as a trap crop for *H. halys.* While high populations of *H. halys* colonized the sunflower, their results suggest that sunflower alone may not be an effective trap crop. Management of multiple insect pests through trap crops is not frequently the primary goal; however, controlling a complex of species, such as stink bugs, has been evaluated in soybean by planting early maturing varieties (Hokkanen 1991), and triticale was identified as a potential trap crop for the stink bug complex in Florida by Mizell (2008).

Our goal was to identify preferred host plants that could serve as a trap crop for *H. halys* and endemic species of stink bugs (i.e., *Euschistus servus* (Say), *E. tristigmus* (Say), *E. variolarius* (Palisot), and *Chinavia hilare* (Say)). Stink bugs are polyphagous (Panizzi 1997), and colonization of suitable host plants is largely dependent on plant phenology, generally feeding during development of the fruit or panicle. Differences in life history exist between endemic species and *H. halys* in that *Euschistus spp.* generally prefer grasses, while *H. halys* is generally considered to be an arboreal species, although it will also feed on grass species and vegetable crops. Identification of candidate plant species that are highly attractive to a highly mobile, polyphagous species such as *H. halys* is a critical first step to implementing trap crop experiments. However, management within a trap crop was needed in 9 out of 10 identified "successful" trap cropping systems reviewed by Shelton and Benedez-Perez (2006). If successful, a trap crop, with or without management, would be deployed around an attractive cash crop with the potential to provide a whole-farm management strategy for *H. halys*.

Materials and Methods

Comparison

In 2013, research plots were established on USDA-certified or in-transition land at Rutgers Agricultural Research and Extension Center ("RAREC," Bridgeton, NJ), University of Maryland ("UMD," Clarksville, MD), Redbud Farm ("Redbud," Inwood, WV), and the Rodale Institute ("Rodale," Kutztown, PA). Trap crop species evaluated were grain sorghum var. 65B3cnv (*Sorghum bicolor* L. Moench), pearl millet var. Tifleaf 3 (*Pennisetum glaucum* (L.) R.Br.), okra var. Clemson spineless (*Abelmoschus esculentus* Moench), field pea var. Admiral (*Pisum sativum* subsp. *arvense* (L.)), and an open-pollinated sunflower seed mix for shoots (Johnny's Seed #2160SG.36) (*Helianthus annuus* L.). Plant species were identified through conversations with organic growers and observations by researchers as part of an organic working group for *H. halys*. Plots were arranged in a Latin square design with five replicates. All seeds met USDA organic certification criteria and were purchased from Johnny's Select Seed (Winslow, ME) or Blue River Hybrids (Ames, IA). Plots were 3 m by 6 m, with 2 m between plots, planted by hand at the suggested seeding rate and spacing for each species (sorghum and millet 2.5–5.0 cm, sunflower and admiral pea 15.2 cm, okra 30.5 cm). Planting dates were 23 May, 20 May, 19 May, 5 June for UMD, Redbud, RAREC, and Rodale, respectively. Plots were hand weeded and sampled weekly from 1 July through mid-September. At Redbud and RAREC, after the admiral pea senesced, buckwheat (*Fagopyrum esculentum* Moench) was broadcast over the plot and was sampled in the same manner as other crops.

Stink bugs were assessed by whole-plant counts on a 1.5-m row length with two people simultaneously assessing alternate sides of the row for a minimum of 3 min per sample. Each sample row was randomly selected each week from the interior rows. Generalized plant phenological stage (vegetative, flowering, seed head/pod, senescence) and height was recorded for three plants per row from ground to highest leaf.

Management

During the summers of 2013 and 2014, organic management techniques for controlling *H. halys* and other stink bugs in trap crops were evaluated on small experimental plots of sunflowers (see above) at RAREC. Sunflowers were planted on late May by hand in 3- by 6-m plots. Each plot consisted of three 6-m-long rows with 15 cm between each plant. In 2013, the plots were arranged in a 5×5 Latin square design with 2 m of tilled ground between each plot. In 2014, the distance between each plot was increased to 10–15 m of mown rye to increase independence of plots because an aggregation pheromone trap was included as a management tactic. Due to subsequent size limitations, individual plots were organized in a completely randomized design.

We utilized a mark–recapture technique to standardize starting population densities. Ten *H. halys* third–fifth-instar nymphs were marked with a small dot of paint and released 2 h prior to treatment application. Treatment efficacy was assessed by visually surveying all sunflower plants in the center row of each plot (6 m row sample) immediately after treatment, 1 d and 3 d after treatment. Marked and unmarked *H. halys* nymphs and adults and endemic stink bugs were recorded. Unmarked *H. halys* had either molted or naturally colonized plots. This process was repeated, with plots receiving identical applications and surveys, 7 d (2013 only) and 14 d following initial treatment.

In 2013, treatments included a single application of 56 ml Azera (Azadirachtin, MGK, Minneapolis, MN), a single application of 3 qt. Venerate (*Burkholderia* spp. strain A396, Marrone BioInnovations, Davis, CA), brief flame treatment using a propane weed torch (Red Dragon Torches and Equipment, Lacrosse, KS, product no.: VT1-32C), and removal of foliar insects with a custom vacuum sampler and an untreated control. Insecticide applications were applied using a backpack mist blower (#451, Solo USA, Newport News, VA). In 2014, the vacuum treatment was replaced with a black pyramid trap (1.22 m tall, AgBio Inc., Westminster, CO) baited with *H. halys* pheromone plus synergist (10 mg (3*S*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol and (3*R*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol plus 60 mg 2*E*,4*E*,6*Z* methyl decatrienoate).

Statistical Analysis

The total number of *H. halys* and endemic stink bugs, respectively, were summed by replicate and trap crop species at each site. Data did not meet assumptions of normality and were $\log(x + 1)$ transformed. A two-way ANOVA analyzing trap crop species and site were performed. Post hoc means separation was performed with Tukey's HSD and analyzed in JMP Pro v.11.2 (SAS, Cary, NC). A repeated measures analysis on log(x + 1) transformed data evaluated the effects of time and host plant on total *H. halys* (nymphs plus adults) densities over seven consecutive sample weeks (starting 12 August 2013) during the active period (compound symmetry covariance structure, Satterthwaite Degrees of Freedom method, mean separation via LSD; SAS Version 9.2, Cary, NC). Rodale was omitted from the repeated measures analysis due to low season-long *H. halys* densities, and the three other field sites (Redbud, UMD, and RAREC) were included as replicates. A nested ANOVA on log(x + 1) transformed data for *H. halys* or endemic species density/1.5 m was conducted with plant species nested within phenological stage. Admiral pea was excluded from analysis due to zero colonization. A linear regression of BMSB and endemic stink bug population densities (per 1.5 m) was conducted, although MD was excluded from this data set, as plant height was not recorded. Analysis was conducted in JMP Pro v.11.2.

In the management trial, count data did not meet assumptions of normality and were transformed using the two-parameter Box-Cox algorithm. Due to significant variation between years and between successive treatment applications of the same year, data were separated by these factors and analyzed using a repeated measures ANOVA (with sampling date as the repeated measure). Post hoc means comparison was performed with Tukey's HSD using the Holm method of *P*-value adjustment and a critical value of $P \leq 0.05$. For ease of analysis, counts of endemic stink bugs and unmarked *H. halys* include both adults and nymphs of the respective species. Analysis was performed in R.

Results

Comparison

Although buckwheat was planted after admiral pea senesced, germination was successful at only one site, and it was excluded from analysis. The two-way ANOVA found a significant site by trap crop interaction ($F = 14.29$, df = 3,12, $P < 0.0001$). At UMD, a seasonal mean of 437.08 *H. halys* were observed on the sorghum, compared to 105.77 and 102.72 on sunflower and okra, respectively. Comparatively, at RAREC the average density of *H. halys* totaled across the season was 13.60 on sorghum, followed by 5.6 and 2.6 on millet and okra, respectively (Table 1). The main effects of research site ($F = 101.62$, df = 3,12, $P < 0.0001$) and trap crop species ($F = 188.61$, df = 4,12, $P < 0.0001$) also were statistically significant. Post hoc tests showed that UMD hosted significantly higher populations of *H. halys* than all the other sites ($P < 0.05$), followed by Redbud, RAREC, and then Rodale. Within the trap crop species, sorghum had significantly higher seasonal populations of *H. halys* than any other trap crop species evaluated ($P < 0.05$). Sunflower and okra hosted the second highest populations, followed by millet and then admiral pea. Except for admiral pea, all trap crop species studied supported *H. halys* of every life stage (egg, nymph and adult), indicating that they are host plants. Egg masses were not found on admiral pea at any location, and this species only hosted nymphs at RAREC, suggesting that it is not an idea host plant. There was a significant effect of plant phenology on *H. halys* ($F = 13.53$, df = 4, 13, $P < 0.001$) with seed head/pod hosting higher densities per 1.5 m sample than the other stages (Fig. 1a). Similarly, plant phenology also had a significant effect on endemic stink bug density per 1.5 m ($F = 4.02$, df = 4, 13, $P < 0.0001$; Fig. 1b). There was not a significant relationship between plant height and stink bug densities (*H. halys:* $y = 0.574 + 1.911x$, $R^2 = 0.008$; Endemic: $y = 0.044 + 0.085x$, $R^2 = 0.009$), which could be due to an effect of individual attractiveness of plant species.

Endemic stink bugs, primarily *Euschistus servus*, also colonized the trap crop species; however, *H. halys* dominated the species complex comprising 99.38, 71.34, 51.06, and 97.65% of the stink bug community at UMD, RAREC, Rodale, and Redbud, respectively. There were significant main effects of site ($F = 4.29$, df = 3,12, $P = 0.007$) and trap crop species ($F = 9.30$, df = 4,12, $P < 0.0001$) for endemic stink bugs. RAREC and Redbud hosted the highest population of endemic stink bug species ($P < 0.05$). All crops except for admiral pea equally attracted endemic stink bug species ($P < 0.05$), with sunflower having the highest seasonal density (Table 2). There also was a significant interaction between trap crop and site for endemic stink bugs ($F = 2.59$, df = 3,12, $P = 0.006$). The seasonality of *H. halys* and endemic stink bugs, primarily *Euschistus spp*., were similar, although the endemic species sometimes arrived at the trap crops about a week earlier; as populations of endemic stink bugs declined on the plants, *H. halys* densities increased (Fig. 2).

There was a highly significant host plant by week interaction for *H. halys* densities ($F = 5.69$, df = 18, 384, $P < 0.0001$). During each of the seven sample periods, millet generally supported the lowest density of *H. halys*, with statistically lower average *H. halys* densities than observed on sorghum during weeks 4, 6, and 7 (LSD, $\alpha = 0.05$). In the first two sample weeks, *H. halys* densities were highest on sunflower, but by July both sunflower and sorghum supported high *H. halys* densities (Fig. 3). Average densities remained consistent on sunflower through the sixth week, after which time the plants senesced and sorghum was more attractive. In the third sample week, *H. halys* density on sorghum surpassed that of the other host plants and remained higher throughout the study; average *H. halys* densities on sorghum were statistically higher than those on millet during weeks 4, 6, and 7 (LSD, $\alpha = 0.05$).

Management

There were significant differences in abundance of marked nymphs between treatments in 2013, following each application (*application 1*: $F = 16.78$, df = 4, 8, $P = 0.0005$; *application 2*: $F = 5.63$, df = 4, 8, $P = 0.0196$; *application 3*: $F = 10.84$, df = 4, 8, $P = 0.003$). For all applications, the number of marked nymphs found in the flame treated plots was significantly lower than in the majority of other treatments (Fig. 4). The abundance of marked *H. halys* nymphs in all other treatments was not significantly different from that in the control. There were no significant differences due to treatment in the abundance of endemic stink bugs following any application (*application 1*: $F = 1.813$, df = 4, 8, $P = 0.22$; *application 2*: N/A; *application 3*: $F = 0.105$, df = 4, 8, $P = 0.977$). After the second

Table 1. Seasonal mean (± SEM) per 1.5-m row sample of *H. halys* present on potential trap crops at four locations

Site	Admiral Pea	Millet	Okra	Sunflower	Sorghum
UMD	0.61 ± 0.37	33.53 ± 6.23	102.72 ± 6.33	105.77 ± 19.96	437.08 ± 20.24
RAREC	0.20 ± 0.20	5.60 ± 2.62	2.60 ± 0.81	1.40 ± 0.60	13.60 ± 3.31
Rodale	0.00 ± 0.00	0.40 ± 0.24	0.20 ± 0.20	1.40 ± 0.75	2.80 ± 1.16
Redbud	0.00 ± 0.00	18.20 ± 10.53	52.60 ± 7.32	134.80 ± 41.48	229.40 ± 52.64

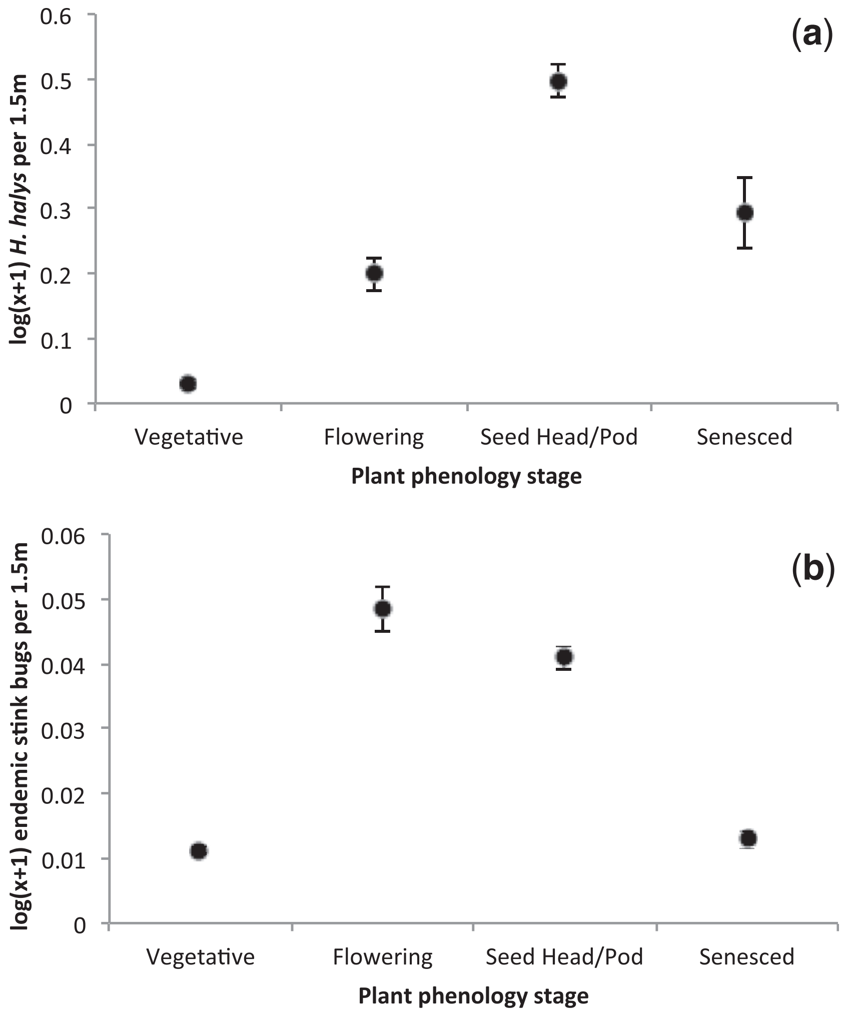


Fig. 1. Log(x + 1) mean ± SEM of (**a**) *H. halys* and (**b**) endemic stink bugs per 1.5-m row in potential trap crop species by plant phenology stage. Nested ANOVA of trap crops within phenology was significant at $P < 0.05$ for *H. halys* and endemic stink bug species.

Table 2. Seasonal mean (±SEM) per 1.5-m row sample of endemic stink bugs (i.e., *E. servus*) present on potential trap crops at four locations

Site	Admiral Pea	Millet	Okra	Sunflower	Sorghum
UMD	0.00 ± 0.00	0.30 ± 0.30	1.22 ± 0.57	0.91 ± 0.61	1.83 ± 1.12
RAREC	0.00 ± 0.00	2.40 ± 0.93	0.80 ± 0.49	3.80 ± 0.73	2.40 ± 0.24
Rodale	0.00 ± 0.00	1.40 ± 0.51	1.00 ± 0.63	0.60 ± 0.24	1.60 ± 0.68
Redbud	0.40 ± 0.40	0.20 ± 0.20	4.00 ± 1.38	3.80 ± 1.16	2.20 ± 1.20

application, no endemic stink bugs were found in any treatment plot, so statistical analysis could not be completed. Additionally, there were no significant differences in abundance of unmarked *H. halys* between treatments during any application (*application 1*: $F = 0.538$, df = 4, 8, $P = 0.712$; *application 2*: $F = 0.754$, df = 4, 8, $P = 0.583$; *application 3*: $F = 3.171$, df = 4, 8, $P = 0.077$).

No significant differences in the abundance of marked nymphs were found between treatments in 2014 after the first treatment application ($F = 1.892$, df = 4, 8, $P = 0.205$; Fig. 4a). Significant differences were identified for the second application ($F = 5.628$, df = 4, 8, $P = 0.0187$; Fig. 4b). Marked nymph abundance was lowest in flame- and Azera-treated plots and highest in plots with pheromone traps although the latter was not significantly different from the untreated control.

After a single round of treatment applications, there were significant differences between treatments in the abundance of endemic stink bugs; however, this effect was not observed after the second application (*application 1*: $F = 14.8$, df = 4, 8, $P < 0.001$; *application 2*: $F = 1.73$, df = 4, 8, $P = 0.236$). The abundance of endemic stink bugs after one application of treatments was significantly higher in plots with pheromone-baited traps than the control plots. Conversely, endemic stink bugs were significantly less abundant in flame-treated plots than in the controls. There were no significant differences in abundance of unmarked *H. halys* between treatments during either application (*application 1*: $F = 1.643$, df = 4, 8, $P = 0.255$; *application 2*: $F = 2.239$, df = 4, 8, $P = 0.154$).

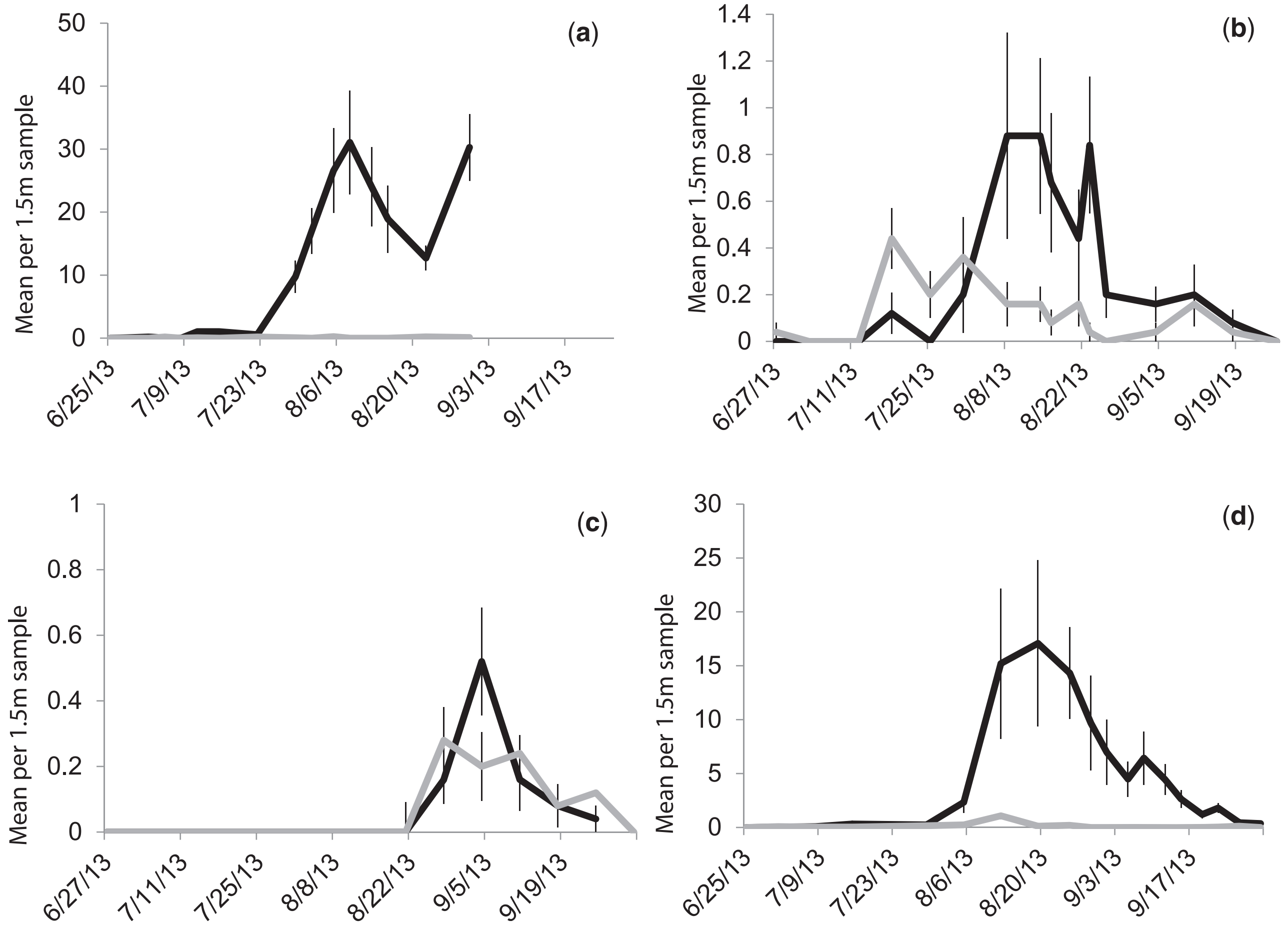


Fig. 2. Mean ± SEM total *H. halys* and endemic stink bugs (primarily *Euschistus servus*) per 1.5-m row in potential trap crop species in (**a**) Clarksville, MD, (**b**) Bridgeton, NJ, (**c**) Rodale Institute (PA), and (**d**) Inwood, WV. *H. halys* is represented by the solid black line, while endemic species are in grey.

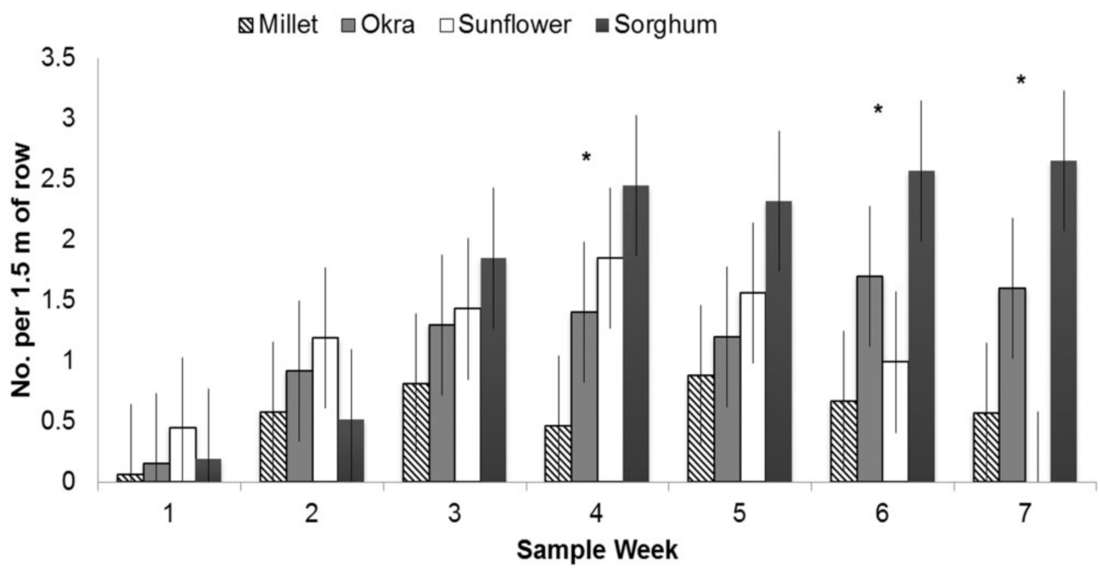
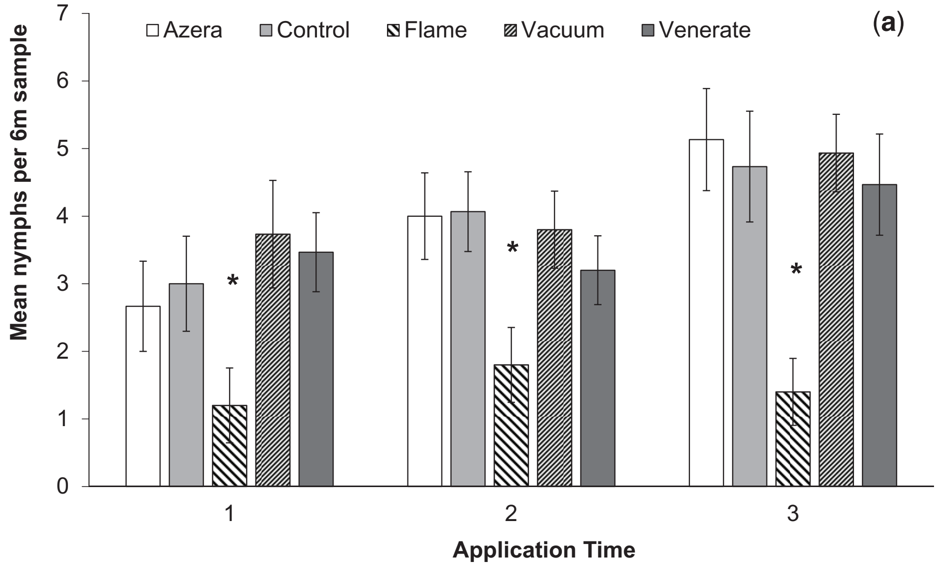


Fig. 3. Mean (± SEM) per 1.5-m sample row population densities of *H. halys* on potential trap crops sampled weekly (late June through mid-September 2013) at three replicate field sites (UMD, RAREC, and Redbud); millet is shown with black diagonal hash marks, okra with grey, sunflower with white, sorghum with black; asterisk indicates significant differences in average densities within sample week ($P < 0.05$ by LSD).



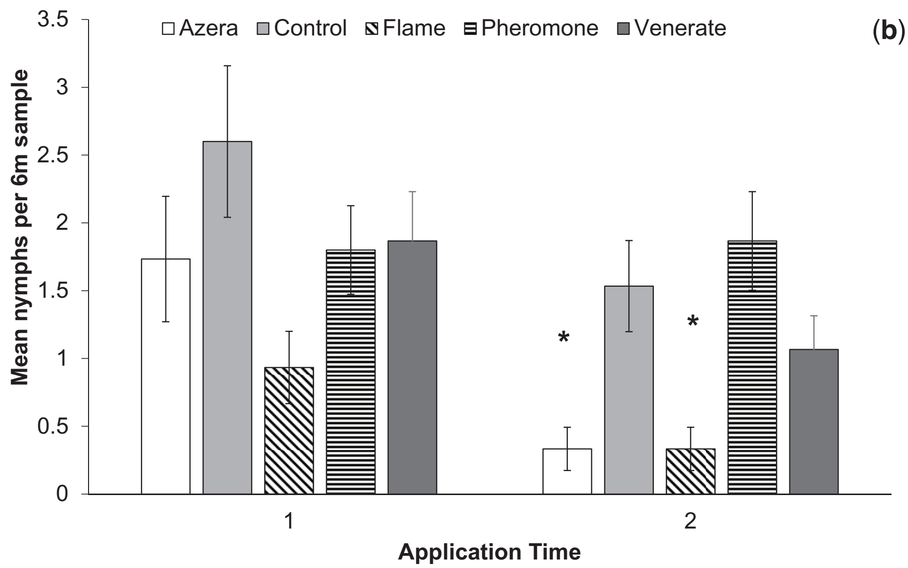


Fig. 4. Mean (± SEM) number per 6-m row of recovered *H. halys* nymphs from sunflower plots treated with Azera (white), flame (black diagonal stripe), vacuum (grey diagonal stripe), Venerate (dark grey), and untreated control (light grey) in (**a**) 2013 and (**b**) 2014 in Bridgeton, NJ. Asterisks indicate significant treatment effects within an application timing ($P < 0.05$ by Tukey's HSD).

Discussion

In organic farming systems, trap crops present an opportunity to manipulate the agroecosystem habitat for pest management. We identified attractive host plants for the invasive *H. halys* that could serve as a trap crop. Sorghum was the most attractive host plant evaluated, followed by sunflower and okra. These host plants were also attractive to endemic stink bug species such as *Eushistus spp.*, suggesting that the phytophagous stink bug complex could be targeted. Although attractive to stink bugs, okra may not be a suitable trap crop because the pods need to be removed for continuous production, a tactic that would require additional labor. Mizell et al. (2008) also identified sorghum and sunflower as potential trap crops against *E. servus*, *C. hilaris*, and *Nezara viridula* (L.) in Florida, suggesting that these and triticale could serve as trap crops throughout most of the eastern United States. The slight differences in colonization timing we observed between sunflower and sorghum suggest that they could be used synergistically to provide at least a 5-wk period of attraction to *H. halys*. Together, the attractive period of sunflower and sorghum coincides with the peak activity of *H. halys* in eastern agroecosystems, from mid-July through mid September. In mid-July through early fall, *H. halys* is found on fruit and vegetable crops including tomatoes, peppers, eggplant, and corn. At the end of September, *H. halys* is commonly found in soybean, apples, grapes, and is beginning its dispersal to overwintering sites. Ehler (2000) reported that endemic stink bugs track plant phenology and Mizell et al. (2008) further validated this for potential trap crop species in Florida. The data presented here further validate this since differences in host plant selection and utilization varied over time and host plant phenology had a significant effect on colonization, specifically during the formation or presence of seed heads or pods.

Organic agroecosystems are known to host higher levels of insect biodiversity, and habitat manipulation tactics, such as trap cropping, may further enhance natural enemy services by providing nectar and pollen resources for beneficial insects. Although this was not a primary objective of this evaluation, natural enemies were found in high numbers on millet, sunflower, and sorghum and may provide additional ecosystem benefits. Whether this would result in enhanced predation upon stink bugs is unknown.

Despite the design of trap crops as a management tool, they frequently require additional management applications or ratooning (harvesting a crop while leaving the roots and the lower parts of the plant uncut) to maintain attractive plant phenology (Shelton and Badenes-Perez 2006, Mizell et al. 2008). We decided not to ratoon plants for this trial to reduce the amount of labor required. However, we did investigate management using common management tools in organic systems. Brief flaming was found to be effective against nymphs in both years and could be a feasible management option for small plots. In 2014, we integrated the *H. halys* aggregation pheromone trap as a management tool. However, the pheromone trap is designed as a monitoring tool, not a mass-trapping tool, and the aggregation pheromone acts as an attractant with only a percentage of individuals entering the trap. The small plot size we evaluated corresponded to the purported zone of aggregation of 2.5 m (in apple) (Morrison et al. 2015), and thus, it did not remove significantly high numbers of *H. halys*, although it could increase retention time within the trap crop (Tillman 2006).

Research is still needed to determine if trap cropping is an effective management tool for *H. halys* as well as the appropriate size and placement within the farm. Soergel et al. (2015) investigated sunflowers as a trap crop in peppers against *H. halys*. In this case, utilizing a single plant species was ineffective as a stand-along management tool, although sunflower was identified as a highly attractive host plant. Retention time of a trap crop or how long it attracts or diverts the target pests from the cash crop is critical to its success (Holden et al. 2012). Retention time could be increased by multiple plantings of trap crops, increasing the size of the trap crop, identification of repellent plants (Khan et al. 2000) or augmentation with aggregation pheromone as discussed above. The data presented here identify previously undocumented host plants for the invasive *H. halys* and suggest that trap cropping may be an effective management tool for multiple stink bug species, including *H. halys,* in organic agroecosystems.

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