

# Sunflower as a Potential Trap Crop of *Halyomorpha halys* (Hemiptera: Pentatomidae) in Pepper Fields

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**ABSTRACT** The brown marmorated stink bug, *Halyomorpha halys* (Stål), feeds on a variety of fruits and vegetables, and is an economically important invasive hemipteran pest. Trap cropping of *H. halys* was examined at the Pennsylvania State University Southeast Agriculture Research and Extension Center (SEAREC) in Lancaster Co., PA, from 2012 to 2013, with sunflowers used as a trap crop to protect bell pepper. *H. halys* were observed frequently on sunflowers planted surrounding the pepper field, and in both years of this experiment significantly more *H. halys* were observed in sunflowers than peppers. Both adults and nymphs were observed with equal frequency, with higher numbers of both observed in September. A 2:1 ratio of females to males was observed throughout both years. While sunflowers were attractive to *H. halys*, no difference in fruit damage was observed in peppers surrounded by the sunflower trap crop versus those peppers surrounded by peppers. While sunflowers present an interesting potential trap crop for *H. halys*, future research is needed to clarify the feasibility of this crop protection technique.

**KEY WORDS** *Halyomorpha halys*, trap cropping, vegetable, pepper, sunflower

The brown marmorated stink bug, *Halyomorpha halys* (Stål), is an invasive hemipteran pest prominent in the mid-Atlantic United States (Nielsen and Hamilton 2009). Native to Asia, including China, Japan, Korea, and Taiwan, *H. halys* has been recently reported in Switzerland, Germany, France, Liechtenstein, Italy, Canada, and the United States, and was most likely introduced through international commerce in bulk freight containers (Hoebeke and Carter 2003, Khri-mian et al. 2008, USDA 2010, Lee et al. 2013, Mais-trello et al. 2014). While positive North American identification of *H. halys* did not occur until 2001, Allentown Pennsylvania homeowners informed extension service personnel of the presence of this pest in 1996 and the United States Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS) intercepted *H. halys* at various ports of entry prior to 1996 (Hoebeke and Carter 2003, USDA 2010). Between 2004 and 2011, *H. halys* populations increased in New Jersey by 75% annually, illustrating how quickly an invasive insect can become established (Nielsen et al. 2013).

*H. halys* is economically important, as it feeds on a variety of fruit, vegetable, legume, and ornamental plant species (Maryland Cooperative Extension 2010). In 2010 alone, *H. halys* caused over US\$37 million in damage to mid-Atlantic apple production (United States Apple Association [USAA] 2011). *H. halys* moves

easily between fields, attacking various vegetable crops between late July and October (Rice et al. 2014). Vegetable crops damaged by *H. halys* including pepper, tomato, eggplant, okra, sweet corn, cucumbers, soybean, asparagus, and eggplant (Fukuoka et al. 2002, Bidding-er et al. 2011, Leskey et al. 2012). *H. halys* feeds by inserting its stylet into plant tissue, secreting digestive enzymes into the plants, allowing it to feed on plant fluids (Haye et al. 2014). Primary damage in vegetable crops, such as pepper and tomato, manifests as white and discolored spongy tissue beneath the skin (Rice et al. 2014). Damage to corn results in discolored and collapsed kernels (Leskey et al. 2012). Secondary plant damage, e.g., infections from the transmission of pathogens through *H. halys* feeding, is also a concern (Hiruki 1999).

With a variety of vegetables at risk from both primary and secondary feeding damage, the development of effective integrated pest management tactics is important to vegetable producers. Trap cropping, the planting of a secondary, less-economically important plant to protect the main crop, works when the trap crop is more attractive than the main crop and has the potential to provide protection against stink bugs in vegetable production (Hokkanen 1991). This tactic has been used with some success to reduce stink bug damage in some field crops, e.g., soybeans and cotton, and to reduce damage from other insects in vegetable production (McPherson and Newsom 1984, Boucher and Durgy 2004, Tillman 2006, Mizell et al. 2008). *Nezara viridula* (L.) has been successfully trapped with

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sorghum to protect cotton (Tillman 2006). Boucher and Durgy (2004) saw a direct economic benefit of US\$153/acre with the use of a preferred pepper cultivar as a trap crop when dealing with pepper maggot, *Zonosemata electa* (Say). Swezey et al. (2014) reported using alfalfa as a trap crop to reduce *Lygus* spp. in strawberries and to improve biological control opportunities. To provide season-long control of *Euschistus servus* (Say), *Acrosternum hilare* (Say), and *N. viridula*, as well as other stink bug species in the southern United States, a mixture of triticale, sorghum, millet, buckwheat, and sunflowers have been recommended as trap crops due to their highly attractive nature, regardless of cash crop (Mizell et al. 2008).

Sunflowers (*Helianthus annuus* L.) are a particularly intriguing trap crop option, as they have been used with success as attractive plants for Coleopteran, Lepidopteran, and Hemipteran pests (Hokkanen 1991, Shelton and Badenes-Perez 2006). *H. halys* is often reared on sunflower seeds in the laboratory, and has shown preference for sunflower seeds when given a choice between sunflower seeds and Japanese cedar seeds, the food of choice in their native habitat (Aldrich et al. 2009).

The objectives of this study were to determine if 1) *H. halys* are attracted to sunflower plants, 2) whether *H. halys* are attracted to other vegetation near study site, 3) the timing of *H. halys* immigration to different crops varied, 4) there is a different expression of attraction between adults and nymphs and males and females, and 5) damage in peppers differs by the type of surrounding crop. Results of this work may be used to design crop protection methods.

## Materials and Methods

**Field Site.** During the 2012 and 2013 growing seasons, research plots to observe the effect of sunflower and sweet bell pepper plants on the movement of *H. halys* were established at the Pennsylvania State University Southeast Agricultural Research and Extension Center (SEAREC) in Landisville, PA (40° 7'6.3012" N, 76° 25'30.219" W). During both seasons, a 158.5-m-long field was divided into four blocks to create a replicated complete block design (Fig. 1). Each block contained both treatment groups and was surrounded by a 3-m "alley" with no plants. Within treatment one, a 13.7-m distance was planted with 12 rows of bell peppers cv. Revolution (Miller Plant Farm, York, PA) at ~46-cm spacing. Treatment two, adjacent to treatment one, consisted of a 13.7-m distance of 8 rows of bell peppers (cv. Revolution) surrounded by sunflowers. The outer two rows of treatment two were planted with sunflowers, with the most exterior row consisting of cv. Giant Grey Stripe and Mammoth Grey Stripe and the inner row consisting of organic sunflowers cv. Zohar F1 (Johnny's Select Seeds Winslow, Maine). The mix of sunflower cultivars was designed to provide a temporal sequence of plant growth stages and heights. The same sunflower cultivars were also planted on the edges of the treatment, perpendicular to the pepper rows, thus surrounding the eight rows of bell pepper.

Blocks 1 and 3 were the mirror image of blocks 2 and 4 to ensure sunflowers were always next to each other (Fig. 1). In 2013, a 1.8-m center aisle was added down the middle of the field to allow for weed maintenance and harvesting.

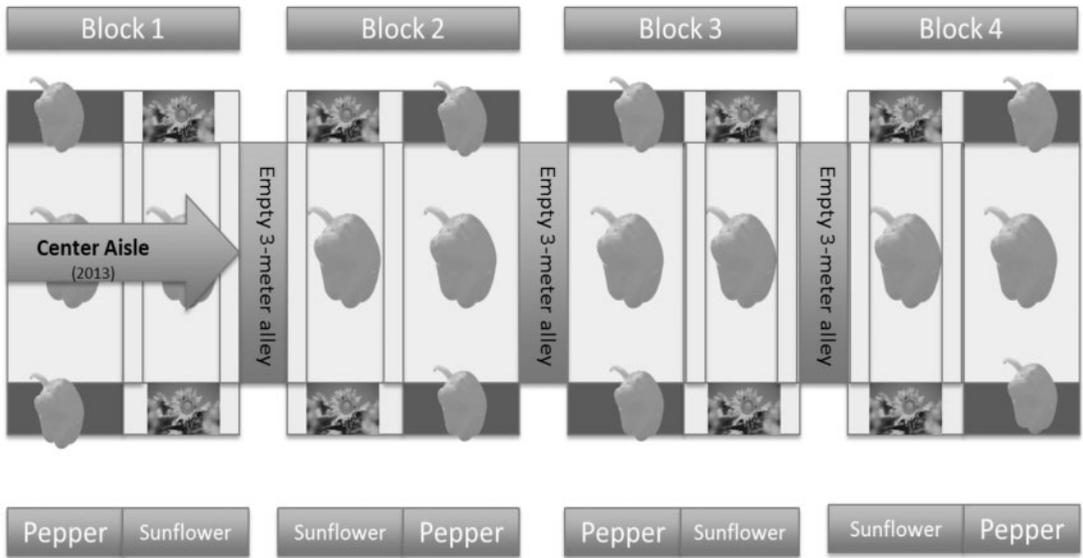
Sunflowers and peppers were planted into rows of raised beds, covered with black plastic and drip irrigation. Both sunflowers and peppers were planted May 29, 2012 and May 7, 2013 with a replant date of May 20, 2013 to replace plants killed by frost on May 13, 2013.

The experimental fields were located within different surroundings during the two years of observations. In 2012, crabapple trees (east), a cornfield and a wood line (north), a cornfield (west), and a fallow field (south) surrounded the experimental plot (Fig. 2). In 2013, the field site was several hundred meters southeast of the 2012 location and was surrounded by soybean, corn, maple and pine trees (east), a small dirt road (south), a hay field (west), and a barn and flower variety trial plots (north; Fig. 2).

**Data Collection.** Each year's observations on *H. halys* presence were conducted once per week starting on June 29, 2012, and June 14, 2013. Total numbers of *H. halys* adult males, females, and 1st instar, 2nd-3rd instars, and 4th-5th instars were recorded. At the beginning of the year when *H. halys* populations were low or nonexistent on the planted crops (peppers and sunflowers), 3-min visual counts were conducted for every treatment plot (peppers and sunflowers); this method covers more plants and field area and provides information as to when *H. halys* first arrives in a crop. Three-minute visual counts were also used to monitor the *H. halys* presence on noncrop plants [crabapples, corn, and the woodland trees (2012) and crabapples, corn, soy, maple, and pine trees (2013)]. As *H. halys* became more prevalent, every fifth plant in every other row of peppers was visually searched for every *H. halys* on the plant, while 3-min counts continued along the edges of noncrop plants (July 9, 2012, and July 19, 2013). Observations continued weekly before being completed on September 27, 2012 and October 4, 2013.

Peppers were harvested following commercial standards approximately every 2 wk. Damage to pepper fruit was evaluated prior to harvest from a sample of fruit obtained at least 24 h prior to harvest. In 2012, evaluations were conducted August 22, September 2, and September 16. During the 2013 season, fruit evaluations were July 12, July 24, August 6, August 28, September 13, and October 4. Two peppers were randomly collected from each of the eight inner rows of each treatment (128 peppers per harvest) and analyzed for injury, defined as white spongy tissue on the pepper (Fig. 3). The number of injury spots per pepper was recorded. Injury to sunflowers was not quantified.

**Analyses.** Cumulative *H. halys* observations from 2012 and 2013 were analyzed with SAS 9.3 (PROC MIXED followed by the SLICE command and a Fisher Exact test of independence) to determine if the independent factors (block, year, crop) affected total *H. halys* abundance. Weekly *H. halys* observations from



**Fig. 1.** Plot layout of sunflower and pepper blocks. The 2012 plot layout of pepper and sunflower blocks. Either peppers or sunflowers surrounded inner peppers. 2013 included a center aisle, to aid in harvest.

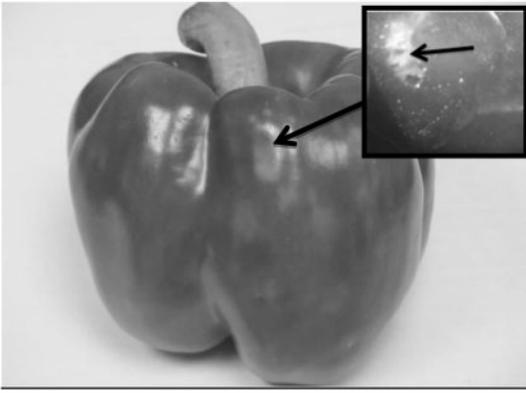


**Fig. 2.** Field plots and surrounding environment. In 2012 (A, left), the field plot was next to corn and crabapples, while adjacent to a wood line. In 2013 (B, right), the field plot was next to soy, corn, hay, and flower fields, and near to pine and maple trees.

2012 and 2013 were analyzed to determine season long differences in 1) *H. halys* abundance on pepper and sunflower, 2) adult and nymph abundance, and 3) male and female abundance. Weekly *H. halys* observations from 2012 and 2013 were analyzed using serial repeated measures (PROC MIXED SAS 9.3) followed

by a Tukey–Kramer multiple comparison test with adult/nymph, sex, crop, month, and year as the independent variables and the total number of *H. halys* as the dependent variable.

To analyze if difference in fruit damage can be predicted by treatment (bell peppers surrounded by



**Fig. 3.** Feeding damage on pepper fruit. External pepper damage from stink bug feeding. The external, pale discoloration is indicative of damaged tissue. Internal injury where feeding occurred is spongy and pale, as shown in insert.

sunflowers or bell peppers surrounded by bell peppers), a Fisher Exact test of independence was used. Differences in damage throughout the season in the center eight rows were analyzed using serial repeated measures PROC MIXED analysis (SAS 9.3), followed by a multiple comparison test (Tukey–Kramer) with crop, year, and month as the independent variables. All analyses used an  $\alpha$  of 0.05.

## Results

**Cumulative Observation of *H. halys*.** Significantly more *H. halys* were in sunflowers (97%) than in peppers (3%) ( $F = 42.45$ ;  $df = 1, 3$ ;  $P = 0.007$ ). Additionally, there was an interaction between year and crop ( $F = 15.21$ ;  $df = 1, 3$ ;  $P = 0.029$ ). When the data were partitioned to evaluate simple effects, a difference in the number of *H. halys* was observed between peppers and sunflowers in 2012 ( $T = -7.36$ ;  $df = 3$ ;  $P = 0.005$ ) while no difference was observed in 2013 ( $T = -1.85$ ;  $df = 3$ ;  $P = 0.161$ ). Additionally, *H. halys* were significantly higher in sunflowers in 2012 than 2013 ( $T = 5.72$ ;  $df = 3$ ;  $P = 0.011$ ) while no difference among years was observed in peppers ( $T = 0.82$ ;  $df = 3$ ;  $P = 0.471$ ). In 2012, ~11% of all *H. halys* were found in peppers, while in 2013 only 5% of the *H. halys* were found in peppers. A greater proportion of the *H. halys* were found in the sunflowers in 2013 when *H. halys* populations were lower.

When the number of *H. halys* found on the center eight rows of peppers in each of the two treatment groups was compared, no difference was observed between the peppers surrounded by peppers or the peppers surrounded by sunflowers ( $F = 0.77$ ;  $df = 1, 3$ ;  $P = 0.444$ ). However, a trend toward sunflowers acting as a trap crop was observed when the data were partitioned to evaluate simple effects between years, with more *H. halys* observed in the peppers not surrounded by sunflowers when the populations of *H. halys* were high.

**Table 1.** Presence of *H. halys* in crabapple, corn, and forest

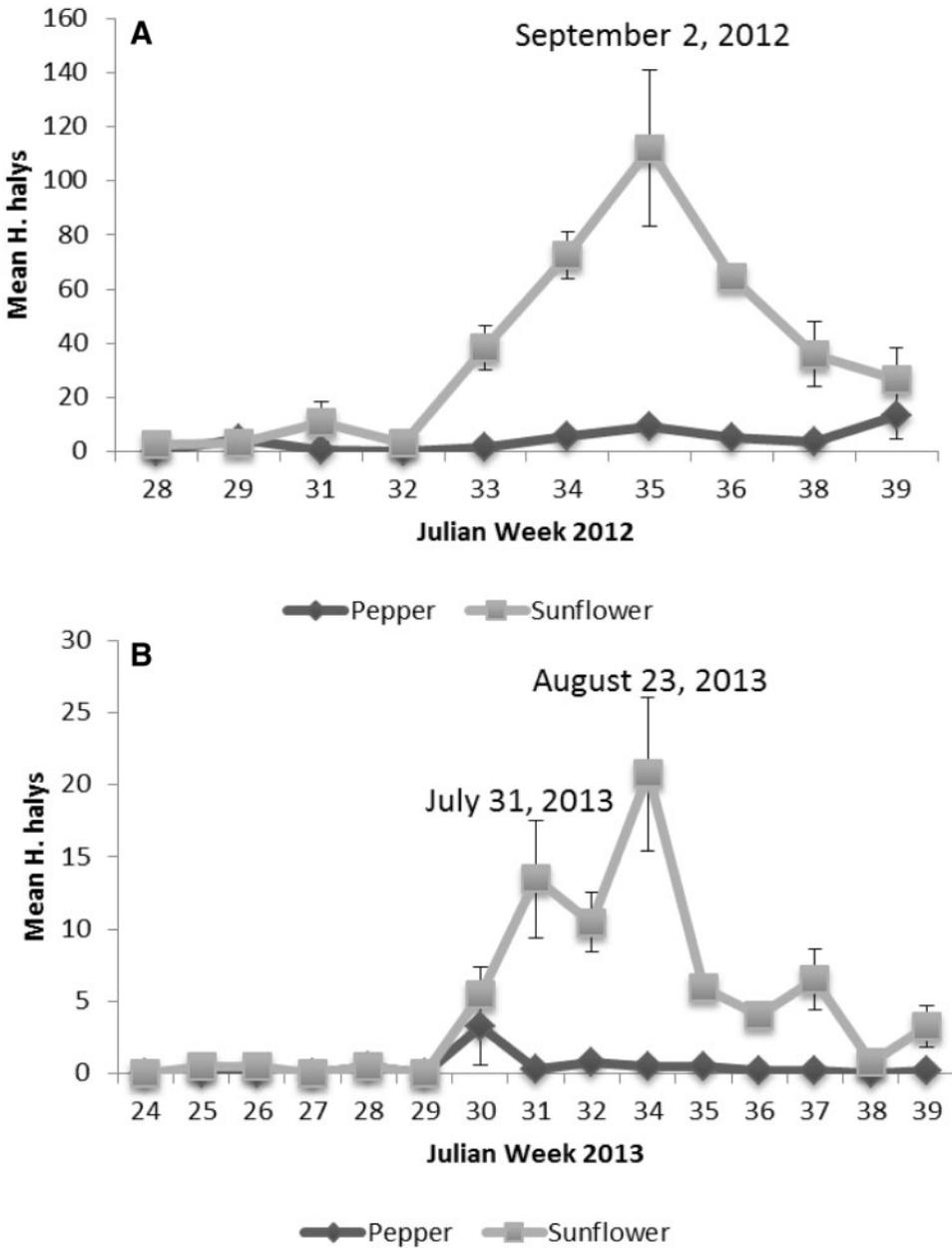
Crop	Frequency	Percent
Crabapple	293	91.25
Corn	8	2.49
Forest	20	6.23

*H. halys* were found most frequently in crabapples (Fisher Exact Test;  $P = 5.180 \times 10^{-106}$ ).

Crabapples, corn, and trees within a forested area were the primary hosts near the experimental fields in 2012 and 2013. *H. halys* were found in crabapples more frequently than on any other noncrop plant evaluated (Fisher Exact Test:  $2 \times 2$  contingency table—crabapple versus other;  $P = 4.396 \times 10^{-14}$ ). When comparing numbers of *H. halys* among crabapple, corn, and trees, more were observed in crabapples (91%) than corn (3%) or trees on forest edge (forest; 6%) (Fisher Exact Test:  $2 \times 3$  contingency table—crabapple versus corn versus trees;  $P = 5.180 \times 10^{-106}$ ; Table 1).

**Seasonal Observations of *H. halys*.** The crop and the month were important factors in determining *H. halys* abundance. Overall, the sunflower crop showed significantly higher numbers of *H. halys* ( $15.41 \pm 1.66$  *H. halys* per replicate) compared to the pepper crop ( $1.36 \pm 1.66$  *H. halys* per replicate;  $F = 36.45$ ;  $df = 1, 190$ ;  $P < 0.0001$ ). Additionally, an interaction was observed between crop and month ( $F = 12.32$ ;  $df = 3, 190$ ;  $P < 0.0001$ ). No differences were observed in peppers across months in the number of *H. halys*. In sunflowers, significantly more *H. halys* were observed through the season with September > August > July > June ( $P = 0.0478$ ,  $P < 0.0001$ ,  $P < 0.0001$ , respectively; Fig. 4). When month and crops are controlled, the overall number of *H. halys* did not differ by year (2012:  $8.0158 \pm 1.4208$ ; 2013:  $8.7598 \pm 1.2103$ ;  $F = 0.42$ ;  $df = 1, 190$ ;  $P = 0.5192$ ).

Adults and nymphs were found with equal frequency ( $F = 0.31$ ;  $df = 1, 357$ ;  $P = 0.581$ ). No interaction was observed between life stage (adult or nymph) and month ( $F = 1.8$ ;  $df = 2, 357$ ;  $P = 0.1667$ ; Table 2). However, when looking at nymphs only, more 2nd–3rd instars were observed than either 1st instars or 4th–5th instars ( $F = 17.81$ ;  $df = 2, 538$ ;  $P < 0.0001$ ) and all nymphal stages (1st instar, 2nd–3rd instar, and 4th–5th instar) were observed more often in sunflowers than peppers ( $F = 30.12$ ;  $df = 1, 538$ ;  $P < 0.0001$ ). There was an interaction between crop and month ( $F = 5.0$ ;  $df = 2, 538$ ;  $P = 0.0071$ ). No significant difference was observed in the number of nymphs observed in peppers among the months (July, August, and September) but in sunflowers significantly more nymphs were observed in September than July and August ( $T = -3.88$ ;  $df = 538$ ;  $P = 0.0001$  and  $T = -3.49$ ;  $df = 538$ ;  $P = 0.0005$ , respectively) and no differences were observed between August and September ( $T = 0.97$ ;  $df = 538$ ;  $P = 0.3303$ ). Additionally, there was an interaction between nymphal stage and month ( $F = 7.79$ ;  $df = 4, 538$ ;  $P \leq 0.0001$ ). No difference was observed in the frequency of first instars by month. More 2nd and 3rd instar nymphs were observed in



**Fig. 4.** *H. halys* populations peak in late summer. Mean number  $\pm$  SE of adult and nymphal *H. halys* found in pepper and sunflower crops in 2012 and 2013 season. (A) Peak number of *H. halys* in 2012 occurs during week 35, the first week of September, with sunflowers being a favored crop. (B) In 2013, the number of *H. halys* peak around week 34, the end of August. Overall numbers were lower in 2013 than during the 2012 season. *H. halys* were more commonly found in sunflowers than peppers.

August than July and September ( $T = -4.93$ ;  $df = 538$ ;  $P < 0.0001$  and  $T = 2.73$ ;  $df = 538$ ;  $P = 0.0066$ , respectively) and September than July ( $T = -2.23$ ;  $df = 538$ ;  $P = 0.0259$ ). Significantly more 4th and 5th instar nymphs were observed in September than July and August ( $T = -4.20$ ;  $df = 538$ ;  $P < 0.0001$ ,  $T = -2.49$ ;  $df = 538$ ;  $P = 0.0129$ , respectively) but no differences were observed between July and August ( $T = -0.41$ ;

$df = 538$ ;  $P = 0.6788$ ). In July no differences in the number of *H. halys* nymphs were found between peppers and sunflowers ( $T = -1.56$ ;  $df = 538$ ;  $P = 0.1203$ ). More nymphs were observed in August and September in sunflowers than peppers ( $T = -3.54$ ;  $df = 538$ ;  $P = 0.0004$  and  $T = -3.01$ ;  $df = 538$ ;  $P = 0.0027$ , respectively). Only one unhatched egg mass was observed in sunflowers.

**Table 2.** Analysis of life stage (adult vs. nymph) indicating the significance of crop ( $F = 61.81$ ;  $df = 1, 357$ ;  $P < 0.0001$ ), and the interaction of crop  $\times$  month ( $F = 20.88$ ;  $df = 2, 357$ ;  $P < 0.0001$ )

	F-value	Degrees of freedom	P-value
Crop (Pepper, Sunflower)	61.81	1, 357	<0.0001
Life stage (Adult, Nymph)	0.31	1, 357	0.5809
Year	3.41	1, 357	0.0656
Crop $\times$ month	20.88	2, 357	<0.0001
Life stage $\times$ month	1.8	2, 357	0.1667

**Table 3.** Analysis of *H. halys* showing the significance of the crop, year, month, and sex, and their interactions

	F-value	Degrees of freedom	P-value
Crop	53.99	1, 354	<0.0001
Year	18.05	1, 354	<0.0001
Month	30.03	2, 354	<0.0001
Sex	9.81	1, 354	0.0019
Crop $\times$ month	35.78	2, 354	<0.0001
Sex $\times$ month	4.04	2, 354	0.0183
Crop $\times$ sex	6.56	1, 354	0.0109
Crop $\times$ sex $\times$ month	3.62	2, 354	0.0278

A 2:1 ratio of females to males was observed for both years ( $F = 9.81$ ;  $df = 1, 354$ ;  $P < 0.0019$ ; Table 3). Additionally, interactions were observed between sex and month, crop and sex, and crop, sex, and month ( $F = 4.04$ ;  $df = 2, 354$ ;  $P = 0.0183$ ,  $F = 6.56$ ;  $df = 1, 354$ ;  $P = 0.0109$ ,  $F = 3.62$ ;  $df = 2, 354$ ;  $P = 0.0278$ , respectively). No differences were observed in the number of males and females in the pepper crop but significant differences were observed in sunflowers, with more females than males in September ( $T = 3.33$ ;  $df = 354$ ;  $P = 0.0010$ ) and nearly more females than males in August ( $T = 1.92$ ;  $df = 354$ ;  $P = 0.0559$ ). Significantly more females were observed in sunflowers than peppers in August and September but not July ( $T = -4.46$ ;  $df = 354$ ;  $P < 0.0001$ ,  $T = -5.64$ ;  $df = 354$ ;  $P < 0.0001$ ,  $T = 1.28$ ;  $df = 354$ ;  $P = 0.2025$ ). Significantly more males were observed in sunflowers than peppers in August and September but not July ( $T = -2.80$ ;  $df = 354$ ;  $P < 0.0055$ ,  $T = -2.55$ ;  $df = 354$ ;  $P < 0.0112$ ,  $T = 0.63$ ;  $df = 354$ ;  $P = 0.5269$ ).

**Feeding Damage by *H. halys*.** While more *H. halys* were observed in sunflowers than peppers, this did not result in reduced damage to peppers. Damage to the peppers fruit was compared between those inner rows of peppers surrounded by sunflowers and those inner rows surrounded by peppers (Fig. 5). No significant difference was observed in 2012 (Fisher Exact Test,  $P = 0.110$ ), 2013 (Fisher Exact Test,  $P = 0.790$ ), or when the two years were combined (Fisher Exact Test,  $P = 0.092$ ).

## Discussion

*H. halys* is an economically important pest because of its wide host range and direct damage to the

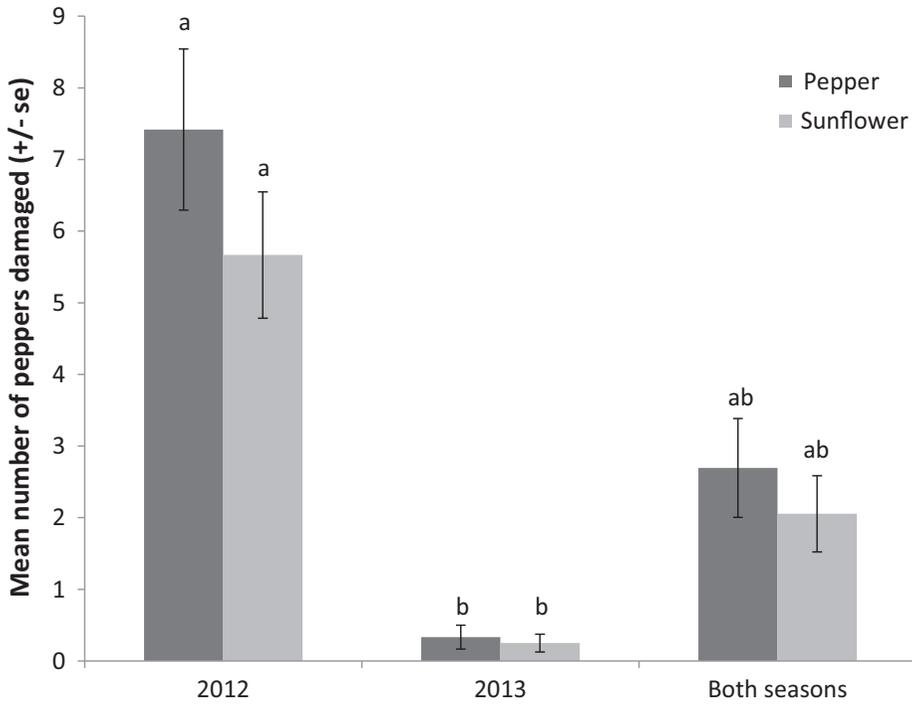
marketable portion of plants. Many vegetable crops, including peppers, corn, beans, and peas in the United States (Leskey et al. 2012) are threatened by *H. halys*. Understanding of *H. halys* host preference is useful in creating future farm-based management tools.

In both 2012 and 2013, *H. halys* were observed more frequently on sunflowers surrounding the pepper field. While more *H. halys* were observed in sunflowers than peppers, no difference in fruit damage was observed in peppers surrounded by sunflowers versus those peppers surrounded by peppers. This result leaves open the possibility of using sunflowers as a trap crop but a number of questions, including the proximity of the trap crop (sunflowers) to the cash crop (peppers), need to be addressed. In this study, the sunflowers width was only 1 m (2 rows) and immediately adjacent to peppers. Factors such as distance between sunflowers and cash crop, size of trap crop relative to cash crop, and other variables need to be determined prior to implementation of this technique for *H. halys* control. Future research should determine the optimal placement of a variety of trap crop mixtures relative to cash crops. If the mixture is attractive enough, there is potential to limit *H. halys* invasion of cash crops, promote pollinators, and minimize pollinator disruption through pesticide usage.

While this study demonstrated the attractiveness of sunflowers to *H. halys*, we did not show that sunflowers would be an effective solo trap crop. Mizell et al. (2008) recommended a variety of different flower and crop species (triticale, sorghum, millet, buckwheat, and sunflower) throughout the season to control native stink bug populations in the southern coastal plain. Although only sunflowers were tested, rather than in combination with other potential companion traps, results suggest they hold potential as an attractive component in a trapping crop blend. Future work should evaluate the inclusion of other trap crops combined with sunflowers. Herbert and Toews (2011, 2012) showed *E. servus*, *Chinavia hilaris* (Say), and *N. viridula* with no reproductive development (overwintering adults) to be in soybeans, cotton, peanuts, and corn after the autumnal equinox. Destruction of trap crops may be important to prevent overwintering of *H. halys*.

Higher numbers of *H. halys* were mostly found in the outer row of Giant/Mammoth Grey Stripe sunflowers. Height of plants may be a factor in *H. halys* host choice (G. K., unpublished data). Tillman found taller trap crops to be a barrier to *E. servus*, *C. hilaris*, and *N. viridula* in cotton (2014). The giant/mammoth grey stripe sunflower variety height is 2.4–3.6 m, while Zohar F1 is ~1.2 m tall. Surrounding the outside of the pepper plants with these tall sunflower varieties may have acted as a vertical barrier rather than as a more attractive host plant. Additional research should address the question of how critical trap crop height is to *H. halys*.

Our data suggest crabapples as a possible trap plant. In both 2012 and 2013, 91% of *H. halys* in the surrounding noncrop plants were observed in crabapples. Alternatively, this could place crabapples as a noncrop source into later-season crops. Differences in *H. halys*



**Fig. 5.** Surrounding crops had no impact on damage levels. Inner rows of mean pepper damage during 2012 season, 2013 season, and both seasons (2012 and 2013 combined). There was no significant difference between damage levels to inner peppers, regardless of surrounding pepper or sunflower rows (Fisher Exact Test,  $P=0.1102$ ; Fisher Exact Test,  $P=0.7905$ ; Fisher Exact Test,  $P=0.0922$ , respectively). Damage data were collected at ~2-wk intervals, with three evaluations in 2012 and six evaluations in 2013. Each evaluation examined 128 peppers for damage.

populations between 2012 and 2013 cannot be explained by the proximity of crabapples, as these trees were near both test plots. While the 3-min visual observations used to assess *H. halys* may not have been as robust early in the season as compared to later in the season when *H. halys* populations were higher, this bias is the same across all noncrops plants that were assessed. Converting to individual plant observations, as done within the research plot, was not practical for crabapples and other trees due to their height and dense foliage. Even though it is likely the *H. halys* counts later in the season underestimated actual population size, our observations suggest that *H. halys* are found in surrounding crops and noncrop plants, especially crabapples, and are not exclusively drawn to sunflowers (Table 1).

The stage of *H. halys* development did not differ by crop, nor were there more nymphs than adults observed. As expected, nymphal stages (1st instar, 2nd–3rd instar, and 4th–5th instar) did show variation throughout the season, with more 2nd and 3rd instars found in August and September and more 4th and 5th instars found in September. As only one unhatched egg mass was found during this study, we were not able to evaluate female fecundity and ovipositional preference throughout the season among crops and noncrops. However, the higher numbers of young instars in sunflowers is consistent with a hypothesis of ovipositional preference in sunflower. Critical information includes

egg viability, plant preferences for the deposition of egg masses, and potential interactions between location of egg mass and egg viability.

A clear trend of increasing *H. halys* population from June to late August/early September was observed, indicative of late migration into the pepper and sunflower crops. The total number of *H. halys* was significantly higher in 2012 than 2013; however, if the effect of crop and month (but not adult/nymph, nymphal stage, or sex) are used in a repeated measures analysis then this difference between years disappears. This may be due to the population of *H. halys* being more evenly distributed throughout the 2013 season while large peak abundance was observed in August and September in 2012.

While feeding damage did not differ significantly between the peppers surrounded by sunflowers or by peppers, a trend was observed. In 2012 when the *H. halys* population was high, nearly significantly less damage was observed in pepper fruit surrounded by sunflowers than in pepper fruit surrounded by peppers but no difference was observed in 2013. Additionally, when data from both years were combined, results were significant at the 10% level. Most likely other unmeasured factors inflated levels of variability between replicate plots, i.e., size of sunflowers, size of the plots and distance between trap and cash crops in adjacent treatment plots. Future work with larger plots and increased spatial separation may be able to

demonstrate significant differences in fruit damage from *H. halys*.

Fruit damage was only compared within the internal eight rows of peppers, while damage to the external two rows on each side was not assessed. Because *H. halys* and other stink bugs have been shown to cause damage in edge regions of other crops, such as soybean (Tillman et al. 2009, Leskey et al. 2012), an edge effect may exist, and will be addressed in future studies. The possibility of an edge effect should be evaluated, as it may be possible to use this to reduce damage to the interior crop.

While feeding damage was measured in this study, it cannot be directly attributed to *H. halys*, as several native stink bugs (i.e., the green stink bug [*Acrosternum hilare* (Say)], the dusky stink bug [*Euschistus tristigmus* (Say)], the brown stink bug [*E. servus* (Say)], the red-shouldered stink bug [*Thyanta custator accerra* (McAtee)], etc.) and tarnished plant bugs [*Lygus lineolaris* (Palisot de Beauvois)] were located in the pepper field throughout the season. It is likely, however, that *H. halys* causes the majority of damage, as the numbers of native stink bugs was low.

It is important to recognize that sunflowers are attractive to a variety of native pollinators, and so care must be taken if chemical control is used within the sunflower trap crop to reduce *H. halys* populations. Visual observations during 2013 included an informal midnight observation of sunflowers to determine if *H. halys* remain in the sunflower crop overnight. These anecdotal observations do suggest that *H. halys* remain in fields at night, rather than leaving for nearby wood lines. While the nighttime presence of *H. halys* may present an opportunity for the application of chemical controls, it is important to note that native pollinators, e.g., bumble bees, are observed on flowers early in the morning or at dusk (Kapustjanskij et al. 2007) and have been observed on flowers at night (personal observation). Direct and residual effects on pollinators need to be taken into consideration before chemical controls are used.

Many consumers are aware of *H. halys* as a pest both within their homes, and local agricultural communities. Sunflowers planted as a trap crop has potential on small farms as cut flowers, or in agrotourism. Small farms participating in agro tourism could raise awareness of sustainable management practices by including control of *H. halys* through trap cropping. This would minimize pesticide usage and reduce farm costs, while potentially improving community support. To achieve these goals, more research on *H. halys* trap cropping is needed.

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